

The role of the fusiform face area in social cognition: implications for the pathobiology of autism

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A region in the lateral aspect of the fusiform gyrus (FG) is more engaged by human faces than any other category of image. It has come to be known as the ‘fusiform face area’ (FFA). The origin and extent of this specialization is currently a topic of great interest and debate. This is of special relevance to autism, because recent studies have shown that the FFA is hypoactive to faces in this disorder. In two linked functional magnetic resonance imaging (fMRI) studies of healthy young adults, we show here that the FFA is engaged by a social attribution task (SAT) involving perception of human-like interactions among three simple geometric shapes. The amygdala, temporal pole, medial prefrontal cortex, inferolateral frontal cortex and superior temporal sulci were also significantly engaged. Activation of the FFA to a task without faces challenges the received view that the FFA is restricted in its activities to the perception of faces. We speculate that abstract semantic information associated with faces is encoded in the FG region and retrieved for social computations. From this perspective, the literature on hypoactivation of the FFA in autism may be interpreted as a reflection of a core social cognitive mechanism underlying the disorder.

Keywords: amygdala; autism; fusiform face area; medial prefrontal cortex; social cognition; superior temporal sulcus

1. INTRODUCTION

For the first time, the field of autism has a replicated neurofunctional marker of the disorder—hypoactivation of the FFA. The FFA is that region of the middle aspect of the right FG that is selectively engaged by faces (when contrasted with object perception tasks) (Puce *et al.* 1995; Kanwisher *et al.* 1997; Kanwisher 2000). Anatomically, the middle portion of the FG is split along its rostral–caudal extent by a shallow MFS. In fMRI, the centre of activation in face perception tasks is typically offset towards the lateral aspect of the FG, in the right hemisphere (Haxby *et al.* 1999). Whereas individual subjects may or may not also show left FG activation during face perception, group composites always show right-side activations to be larger. At least five fMRI studies have shown that older children, adolescents and adults with autism spectrum disorders have reduced levels of activity to images of the human face in this specialized face region of the right hemisphere (Crichtley *et al.* 2000; Dierks *et al.* 2001; Pierce *et al.* 2001; Schultz *et al.* 2000a, 2001). These data are consistent with an older, and more extensive, psychology literature documenting performance deficits in face perception (Langdell 1978; Klin *et al.* 1999),

and facial expression recognition in autism (e.g. Hobson *et al.* 1988a,b; MacDonald *et al.* 1989; Yirmiya *et al.* 1992). They seem to provide an important clue as to the neural ontogeny and pathobiology of autism.

Whereas the consistency of these findings is encouraging, what it means to have an under-responsive FFA remains unclear. Our initial interpretation of this finding focused on the role of experience for shaping the visual cortices (Schultz *et al.* 2000a,b; Grelotti *et al.* 2001). It is known that the ventral temporal visual areas are quite plastic and can be moulded by early experiences (Gaffan *et al.* 1988; Webster *et al.* 1991; Fujita *et al.* 1992; Löwel & Singer 1992). Persons with autism pay much less attention to the face (Osterling & Dawson 1994; Klin *et al.* 2002) and this may be why they fail to acquire normal perceptual skill in this domain. Inadequate attention to faces during critical periods of cortical development should affect the maturation of these areas, and presumably lead to under-activation of the FFA during face perception.

This interpretation fits nicely into the perceptual expertise model of the FFA, first championed by Gauthier and colleagues (Gauthier *et al.* 1999, 2000). Gauthier has shown, in two elegant fMRI studies, that the FFA responds preferentially to any class of object for which a person is perceptually ‘expert’. For example, she found that bird experts engage the FFA more strongly when viewing birds than cars, but the reverse is true for car experts (Gauthier *et al.* 2000). Moreover, normal young

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adults can enhance their FFA activity to a class of novel objects through extensive perceptual training (Gauthier *et al.* 1999). Interpreting the hypoactivation of the FFA in autism from an expertise model, however, argues that this finding is an outcome of having autism rather than part of the cause. In other words, the hypoactivation of the FFA is merely a reflection of the social disability, the culmination of a set of developmental experiences across many years whereby the person has reduced interest in other people and pays inadequate attention to their faces. In this regard, the under-responsiveness of the FFA is a biological marker. Identifying an endophenotype such as this is extremely important and takes the field one significant step closer to understanding the underlying biological mechanisms, but it falls short of providing a snapshot of the brain mechanisms that actually cause autism.

An alternative view would be that the FFA is a core component of the 'social brain'. Data emerging over recent years from neuroimaging studies, human lesion studies and animal studies suggest a working model of the social brain that comprises a diverse set of frontal, limbic and temporal lobe circuitry. Select aspects of the orbital and medial prefrontal cortices, the amygdala and lateral aspects of the temporal cortex involving the STS have each been implicated in social functioning (Brothers 1990; Fletcher *et al.* 1995; Baron-Cohen *et al.* 1999; Frith & Frith 1999; Allison *et al.* 2000; Castelli *et al.* 2000, 2002; Schultz *et al.* 2000*b*). The frontal and temporal cortices have dense, and often reciprocal, connections to the amygdala (Carmichael & Price 1995; Price *et al.* 1996). The amygdala is centrally positioned, and capable of modulating and interpreting the emotional significance of data processed in the perceptual cortices, as well as assisting with the integration of emotion and cognition for decision making and action in the frontal cortices (Amaral *et al.* 1992; Schultz *et al.* 2000*b*). Collectively, this system defines a heuristic model of the social brain, with the precise functions of each node only understood in an, as yet, superficial manner.

But is there a role for the FFA in this social circuitry? Whereas the role of the FG in face perception is undisputed, only one prior study has implicated the FFA in social cognition. Castelli *et al.* (2000) used social animations involving interacting geometric shapes to probe the social brain. These animations were based on the classic study of Heider & Simmel (1944) that showed how certain movements by inanimate objects could strongly and automatically suggest personal agency, and that a group of interacting geometric forms will naturally suggest social interactions. All but one of the 34 female college students in Heider and Simmel's study described the animations through a social lens and in human terms (e.g. shapes chase one another, fight, entrap, play, get frightened, elated, etc.). It seems that the contingent nature of the shape movements and the fact that their movements violate the rules of simple physics (i.e. the shapes seem to have 'agency' or will) naturally invoke social cognitive and social perceptual ideation. Using PET in six healthy young adults, Castelli *et al.* showed that interpreting this type of animation engaged the medial prefrontal cortices, the TP, the STS and the right FG. Although the localization of the fusiform activations in their study is in the area generally reported to be the FFA, it is not clear whether this region

of activation would have overlapped with the FFA in these subjects, as location of the FFA can vary from person to person. Nevertheless, engagement of the right FG by a social cognitive task that does not involve images of the face suggests that this FG region may have a broader, more important set of functions, extending beyond simple face perception. As such, it provides a basis to argue that the hypoactivation of the FFA to faces in autism might be illuminating part of a causal mechanism, as opposed to a developmental consequence of having autism.

The current study also used an adaptation of the procedure of Heider & Simmel (1944), involving what Klin (2000) called the SAT. Klin (2000) used the SAT to show how persons with autism fail to spontaneously impose social meaning on these types of movements. Other investigators have also reported a paucity of theory of mind ideation among persons with autism to other renditions of the Heider-Simmel procedure (Abell *et al.* 2000; Bowler & Thommen 2000). Use of simple shapes to display human social interactions without perceptual representations of real people strips the social event down to the essential elements needed to convey social meanings. In this regard, the SAT is an ideal neuroimaging probe for assessing social cognitive and social perceptual processes in a way that is not confounded by perceptual processes that would be provoked if actual images of faces or people were used. The original SAT from Klin (2000) is a 50 s silent film in which three moving geometric shapes (a circle, a small triangle and a larger triangle) interact with each other in a social manner. Interestingly, in Klin's study, some attributions by those with an autism spectrum disorder were given in terms of physical meaning (e.g. magnetic forces), not social meaning. We took note of this observation in developing the following fMRI experiments, and created a control task for the SAT that involves judgements of object mass.

In two fMRI studies of the same group of normal control subjects, we show that the FG is robustly engaged by an adaptation of the SAT suitable for a block design fMRI study. Engagement of the right FG by non-face stimuli suggests that this region has functions beyond static face perception. To test the exact location of the fusiform activations during the SAT, nine of the 12 participants consented to return for a fMRI study of face perception. Results from this second study found the location of the FFA to be highly overlapping with the FG activations to the SAT. Thus, making social judgements on non-face geometric figures, and making identity judgements on grey-scale pictures of human faces, draws upon a similar neural substrate in the FG. This result challenges the specificity of the middle portion of the FG for faces, and raises the possibility that the FFA is part of the primary circuitry for social cognition. As such, it has important implications for the hypoactivation of the FFA in autism, and more generally, for specifying a distributed social network whose dysfunction might cause autism.

2. METHODS

(a) *Participants*

Twelve participants were recruited for this study from the staff and student populations at Yale University. The sample included six men (three left-handed) and six women (one left-

handed), ranging in age from 20 to 31 years (mean \pm s.d. = 24.2 ± 3.1). Participants were screened for neurological and DSM IV Axis I psychiatric disorders. Estimated full-scale IQ, as measured by four subtests of the Wechsler Adult Intelligence Scale, 3rd edition (Wechsler 1997) averaged 128.8 (± 10.4) (Information, Vocabulary, Picture Completion and Block Design). All subjects scored in the normal range on the Benton Test of Facial Recognition (Benton 1994) (raw score range: 41–50; mean \pm s.d. = 46.8 ± 2.6). There were no significant differences between the sexes on any of these variables.

Nine of the twelve agreed to participate in a follow-up fMRI study of face perception conducted so that localization of the FFA could be compared with SAT activations in the middle FG area in the right hemisphere. Five were male (one left-handed) and four were female (one left-handed); mean age was 23.6 ± 2.6 years. All subjects gave written informed consent for both studies in accordance with procedures and protocols approved by the Institutional Review Board of the Yale University School of Medicine.

(b) *Experimental tasks*

We adapted the SAT for use in a fMRI block-design study by programming 16 new SAT QuickTime film skits using Director published by Macromedia (600 Townsend Ave, San Francisco, CA; www.macromedia.com). From these, a final set of eight were chosen for use in the fMRI study on the basis of ratings by project staff of the film's realism and ability to capture one's social attention (these films can be downloaded from http://info.med.yale.edu/chldstudy/neuroimg/sat_movies.htm). Each film lasted 15.1 s and was designed like the original SAT with movements intended to suggest a sense of personal agency, and reciprocal and contingent interactions that were meant to be easily interpreted as social. Each film contained three types of white geometric figures (a triangle, diamond and circle) that moved against a black background. In common with the original SAT, there was a box in the centre of the field, with one wall that opened as if on a hinge, allowing the shapes to open and shut the door, and to enter, chase or drag other shapes inside. Each film was scripted to follow a social story, for example, hide-and-seek, a fight, a love triangle, etc. The participants were asked to decide, by pushing a button, if all three of the shapes were 'friends' or not. Half of the films were intended to have 'all friends' as the correct answer (correct answer was determined by a consensus-rating process among the developers of the tasks, with each final film version judged to have a clear answer). The films were scripted such that any adversarial interactions occurred in the final few seconds of the film, to force the participant to attend throughout to derive the correct answer. In creating our control task for contrast to the SAT, we reasoned that each SAT film requires three important processes:

- (i) monitoring the movements and physical interactions between the shapes;
- (ii) pretending that the shapes represent something else, i.e. people; and
- (iii) an inferential, social reasoning process based on the nature of the interactions (judging whether the movements represent friendly or non-friendly interactions).

A 'bumper car' control task was created that contained all of the elements of the SAT films, with the exception of the social reasoning process. This task also entailed eight 15.1 s films depicting the same geometric shapes moving about a black field

with the same centrally positioned white box. The participant's task was to pretend that these figures were 'bumper cars'—small racing cars found at amusement parks that are encapsulated by rubber bumpers to allow safe, playful collisions. Participants monitored the car's movements and interactions, and decided on the basis of the car's trajectories and speed after each collision if the three shapes were all equally 'heavy' or not, for example, upon collision, if one car shot off more rapidly than another, then the two were not equally heavy. Key collisions that gave away the correct answer always occurred in the final seconds of the film. Collisions early in the 15.1 s skit were often mere grazes that failed to provide definitive information about relative mass. Thus, the control task contained the first two elements, but instead of a social decision, participants were required to make a decision about a physical property. The bumper car and SAT films were designed to be equivalent with respect to movement quantity and location, so that the comparison between the two tasks would reveal the location of brain processes that are distinctly involved in social perceptual and social cognitive processes. It is interesting to note that we piloted a version of the control task that involved physical judgements on the SAT films (as opposed to the bumper car films), but participants reported that they were not able to consciously stop seeing the films as social stories. Thus, it did not seem possible to use the exact same stimuli in both tasks as might otherwise be desirable, because social perceptual and cognitive processes would probably be engaged to a greater or lesser extent in both the experimental and control tasks. Two other lower level control conditions were also included in each experimental run in the block design, and were intended to further pull apart the three distinct processes outlined above. However, the results of these contrasts were generally uninformative and thus are not reported here. Between each film was a 12 s rest period with a black screen. All participants underwent practice, using films that did not make the final group of eight, in order to become completely familiar with the tasks before fMRI scanning. During the fMRI experiment, each film was preceded by a 3 s cue: 'BUMPER CARS, SAME WEIGHT?' or 'PEOPLE, ALL FRIENDS?' Subjects responded by pressing a button upon completion of each film, both as a measure of reaction time and accuracy, and to ensure that the subjects watched the entire film.

In the follow-up study (hereafter, 'Study 2') side-by-side grey-scale faces, objects or patterns were presented in a same/different task, in a block-design experiment to localize the FFA. We have previously used this task to localize the FFA in a large group of normal controls (Schultz *et al.* 2000b, 2001). Image pairs were presented for 2.8 s, with a 0.5 s inter-stimulus interval. The person identity task employed same-gender pairs of neutral (non expressive) faces on a black background. Pictures were taken from standard sources and were edited to remove hair, ears and shirt collars, so as to force subjects to focus on features of the face with central relevance to non-verbal social communication, i.e. the eyes, nose, mouth and face geometry. Objects were pictures of spectacles taken from an online retail catalogue that were contrast inverted to make the background black and the spectacles shades of grey, to match the faces. Patterns were distorted versions of the faces or spectacles. Results from contrasts with patterns were not used to localize the FFA, and thus are not reported here. As is conventional, the face versus subordinate-level object-discrimination contrast defined the FFA. Each task block lasted 16.5 s, and was separated by a 10.5 s rest period during which cross hairs (+ +)

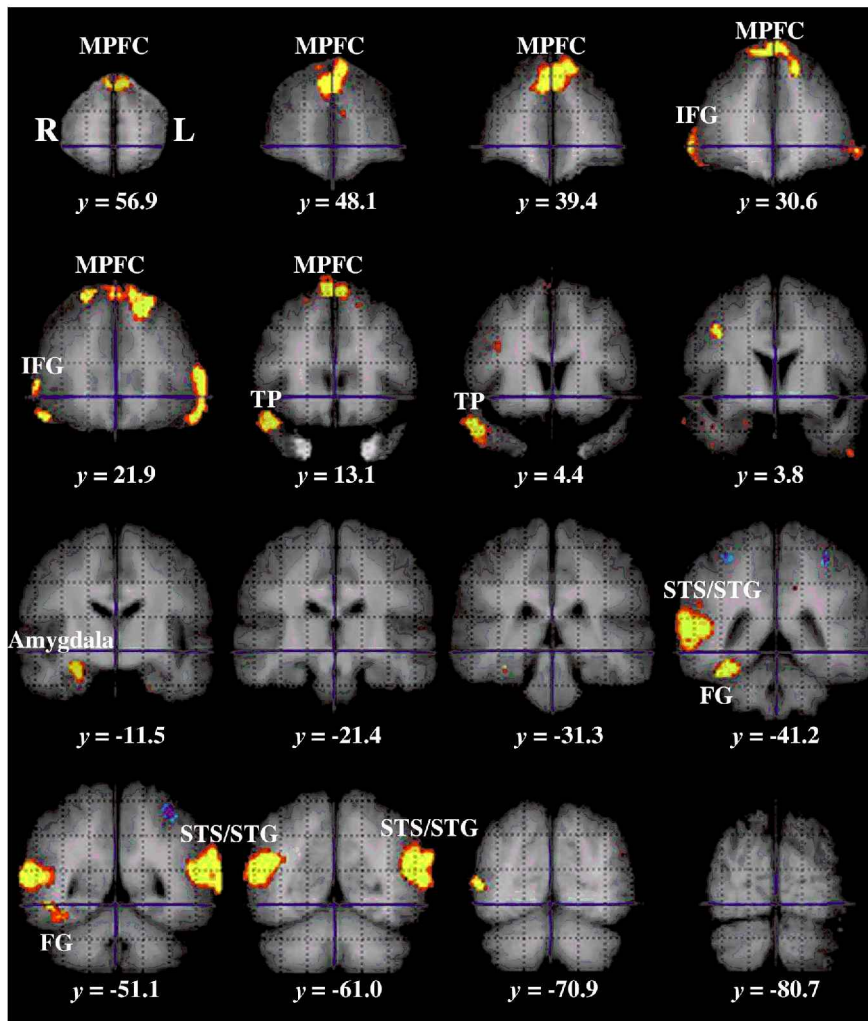


Figure 1. Composite t -map for 12 healthy controls, contrasting the social attribution (yellow/red) and the bumper car (blue/purple) tasks ($p < 0.0005$). Right and left are reversed by convention. Abbreviations: BA, Brodman area; FG, fusiform gyrus; IFG, inferior frontal gyrus; MPFC, medial prefrontal cortex; STG, superior temporal gyrus; Y-coordinates are from the system of Talairach & Tournoux (1988).

centred in the same position as the image pairs flashed with the same presentation rate.

(c) *Data acquisition*

SAT and face perception fMRI data were collected on different occasions, averaging approximately 2.5 months apart (range: 3 weeks to 6 months). Only after the original 12 subjects completed the SAT fMRI study was the decision made to rescan subjects with the face-localization protocol. Changes in BOLD contrast were measured as subjects performed the SAT, bumper car, face-discrimination and object-discrimination tasks. The stimuli were run as QuickTime films in Study 1, and as PICT image files in Study 2. Studies were programmed in PsyScope 1.2.5 PPC (Carnegie Mellon University, Pittsburgh, PA, USA) and run on a MacIntosh G3 computer. Images were back-projected onto a translucent screen mounted near the end of the MRI gantry, and were viewed through a periscopic prism system on the head coil. Behavioural response data were collected with a fibre-optic button box, with two response alternatives (Yes or No for 'all friends?', 'same weight?', 'same person?' and 'same object?'). The participant's head was immobilized using foam wedges, and tape across the forehead.

T2* weighted images sensitive to BOLD contrast were acquired on a GE Signa 1.5 Tesla scanner with a standard quad-

ature head coil, using a gradient echo, single-shot echo planar sequence and a coronal orientation perpendicular to the plane through the AC-PC. The pulse sequence for both studies was TR = 1500 ms, TE = 60, flip angle = 60, NEX = 1, in-plane voxel size = 3.125 mm \times 3.125 mm. In the SAT study, we collected 14 coronal slices, 10 mm thick (skip 1 mm) starting at the anterior-most aspect of the frontal lobe, and covering all of the brain except the caudal-most aspect of the occipital lobe. Data were collected in four runs of an ABCD block design (block = one 15.1 s film), with blocks of each type presented twice per run in a pseudo-random order. Across runs, a total of 80 echo planar images were collected per slice, per task condition. In the face-perception study, we also collected 14 coronal slices perpendicular to the AC-PC, starting from the posterior aspect of the occipital cortex up through the rostral-most aspect of the cingulate gyrus. Slice thickness was 9 mm (skip 1 mm) to be compatible with a separate face-perception study ongoing at that time. Data were collected in a block design with a pseudo-random order across six separate runs, with three blocks of each task per run, for 180 echo planar images per slice, per task condition. Functional data in both studies were co-registered to T1-weighted structural images of the same thickness collected in the same session (TR = 500, TE = 14, field of view = 200 mm, 256 mm \times 192 mm matrix, 2 NEX).

(d) Data analysis

Data were corrected for motion using SPM99 for three translation directions and for the three possible rotations (Wellcome Department of Cognitive Neurology, London, UK). Image volumes with centre of mass (x , y or z) movement of more than 1.5 mm within a run were discarded. Image analyses and tests of statistical significance were done using locally developed software (Skudlarski; http://mri.med.yale.edu/members_framed.html). Motion corrected images were spatially smoothed with a Gaussian filter with a full-width half-maximum value of 6.25 mm. The specific effects of each task were evaluated by creating t -maps for each imaging series, incorporating a correction for linear drift (Skudlarski *et al.* 1999), of specific task contrasts: social versus bumper car in Study 1, and face versus object in Study 2; t -maps were averaged across imaging series and co-registered with the higher resolution anatomical images for display and localization. These maps were then transformed, by in-plane registration and slice interpolation, into a proportional three-dimensional grid defined by Talairach & Tournoux (1988), and averaged across all subjects to create composite t -maps, with the acquired data in 14 slices interpolated to 18 slices (N.B. 16 slices are shown in figure 1, as fMRI activations on the first and last slice are corrupted by motion correction). The SAT versus bumper car maps are displayed in the figures using a significance level of $p < 0.0005$ (uncorrected). Face versus object t -maps were created and displayed at $p < 0.05$ (uncorrected) with the *a priori* hypothesis that the right lateral FG would define the FFA. No other brain areas are examined in the second study, thus avoiding any multiple comparison problem.

ROI analyses were conducted in the SAT study by tracing significant pixels on the group composite activation map (figure 1) in the following regions: the right FG, the right and left STS and STG, the right TP, the right amygdala, and right and left dorsal MPFC. To more thoroughly assess activity in the FG, medial and lateral FG ROIs (and the combined whole FG) were defined anatomically and traced across the two coronal slices where there was significant SAT activation. The activated SAT ROI for the FG is 33% of the size of the entire anatomically defined FG at those two slices. Individual subject data were interrogated using the ROIs to obtain the mean per cent signal change for each person for each region, and Talairach centre of mass coordinates (the centre of ROI activation, weighted by the amplitude of activation across the region). Mean per cent signal-change data were used in correlational analyses to estimate the consistency of conjoint activity between ROIs, across subjects.

3. RESULTS**(a) Behavioural performance**

There were no significant differences between the social and bumper car tasks in performance accuracy ($t_{1,22} = 1.63$, $p > 0.10$; social = $86 \pm 16\%$ correct; bumper = $74 \pm 16\%$ correct) or reaction time ($t_{1,22} = 0.62$, $p > 0.60$). There were no significant differences in task accuracy between males and females or left-handers and right-handers. In addition, there were no significant correlations between task performance and age, Full Scale Intelligence Quotient or Benton Face Recognition performance.

(b) Brain activity associated with the social attribution task

As shown in figure 1, comparison of the SAT with the bumper car control condition resulted in a widely distributed set of significant activations. There was very little significant activation for the bumper car task, with the one region shown clearly in figure 1 being bilateral activation of the dorsal bank of the intra-parietal sulcus. The SAT network included a region within the right and left dorsal MPFC, the right and left inferior frontal gyrus, pars orbitalis and the lateral orbital gyrus, the right TP, the right amygdala, the right and left STS and STG, and the right FG. It is important to note that at lower thresholds (e.g. $p < 0.01$) there was also left amygdala activation, and a ROI analysis of the per cent signal change failed to find significantly more right than left amygdala activation. It is also worth noting that the FG activations seem quite specific to the SAT task, in the sense that reducing the threshold down to $p < 0.05$ failed to show additional ventral pathway activation. More widespread activations might have indicated a general SAT effect on arousal or attention that was manifested throughout the ventral stream, but this was not the case.

The largest areas of activation were the STG (especially on the right) and MPFC. Direct comparison of the right versus left MPFC mean per cent signal change failed to find significant differences (paired $t_{11} = 0.45$, $p > 0.50$). However, the right STG was significantly more activated than the left STG (paired $t_{11} = 2.64$, $p = 0.02$). Table 1 presents the Talairach coordinates for the centre of activation mass for each ROI. Table 2 presents a correlational matrix showing the consistency of conjoint activity between regions. The strongest correlation is between the right amygdala and the ROI that defines the significantly activated region of the right FG ($r = 0.71$, $p = 0.01$). Interestingly, this correlation is nominally larger than that of the entire FG and the smaller, subcomponent FG ROI defined by the SAT activated pixels ($r = 0.69$, $p = 0.013$). Since some correlation would be expected between these overlapping ROIs, especially since the data were spatially smoothed, the robust correlation to the amygdala is even more impressive. Other notable results from the correlation matrix include the lack of correlation between the MPFC and either the amygdala or temporal lobe ROIs. Within the temporal lobes, however, the right STG is significantly correlated with the left STG and with both definitions of the right FG.

Accuracy of performance on the SAT correlates with the amount of activity in the anatomically defined right FG ($r = 0.65$, $p = 0.02$) but not with any other node in the SAT network. Females showed significantly more right STG activation than males ($t_{10} = 2.34$, $p = 0.04$). Males, however, showed significantly more right TP activation ($t_{10} = 2.53$, $p = 0.03$). There were no other significant sex differences, and no significant associations with handedness or age.

(c) Comparison of activity in the right fusiform gyrus during social attribution task and face perception

At the time Study 1 data were collected, finding significant right FG activation to the SAT was unexpected. To clarify whether the FG activation was in the precise

Table 1. ROI centres of mass coordinates.

ROI	mean Talairach coordinates (X, Y, Z)			Brodmann areas
	right hemisphere	left hemisphere		
MPFC	4.9, 34.9, 43.6	-7.4, 36.1, 43.4		6, 8, 9
TP	46.3, 13.8, -12.8	—		38
amygdala	22.8, -10.9, -12.4	—		—
FG (SAT)	34.4, -46.8, -9.0	—		37
FG (face)	37.4, -48.0, -12.6	—		37
STG	50.7, -57.1, 15.2	-56.5, -60.8, 19.4		22, 39

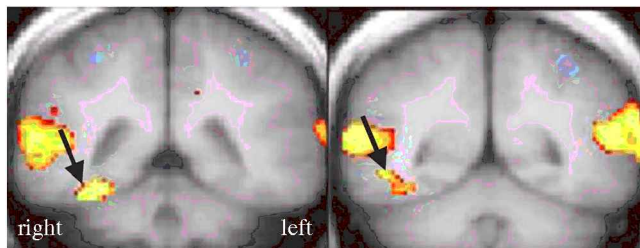
Table 2. ROI correlation matrix.

(Correlations are based on mean per cent signal change from each ROI (see § 2 for ROI procedures). SAT accuracy data represent the percentage of films that each participant correctly.)

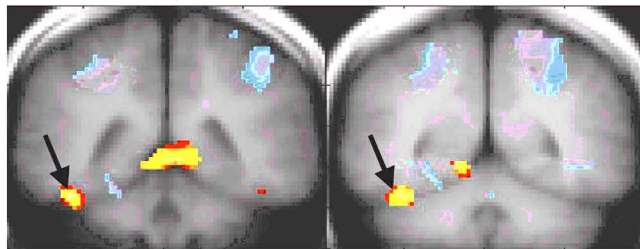
	activated right FG	whole right FG	right amygdala	left amygdala	left MPFC	right MPFC	left STG	right STG	right TP
whole right FG	0.69***								
right amygdala	0.71***	0.32							
left amygdala	0.56*	0.19	0.70***						
left MPFC	0.21	0.13	0.32	0.11					
right MPFC	-0.18	-0.08	0.21	0.19	0.48				
left STG	0.21	0.29	0.19	0.05	0.56*	0.18			
right STG	0.54*	0.69***	0.22	0.25	0.09	-0.16	0.60**		
right TP	-0.07	-0.11	0.40	0.33	0.48	0.34	0.38	-0.10	
SAT % accuracy	0.45	0.65**	-0.12	0.09	0.13	-0.17	-0.1	0.22	-0.34

*** $p \leq 0.01$ ($r \geq 0.69$); ** $p \leq 0.05$ ($r \geq 0.57$); * $p \leq 0.10$.

(a) SAT versus bumper car: FFA activation



(b) face versus object discrimination: FFA activation



(c) enlargement and alignment of FFA

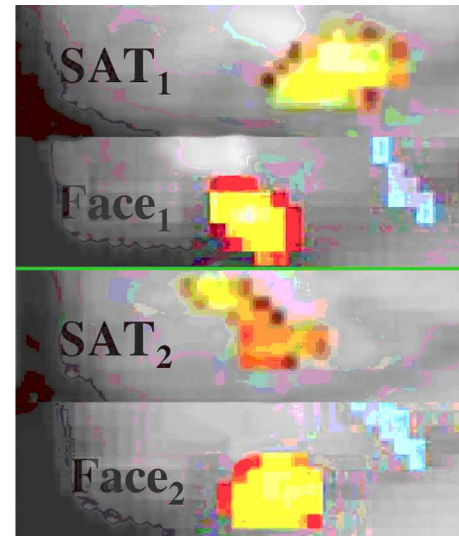


Figure 2. (a) Composite ($n = 12$) t -map at two slices showing significant ($p < 0.0005$) activation for the SAT contrast (yellow/red) with the bumper car control task (blue/purple). (b) Composite ($n = 9$) t -map at two slices showing significant ($p < 0.05$) activation for the face (yellow/red) versus object discrimination (blue/purple). This contrast defines the FFA. (c) Subregions of composite t -maps shown in (a) and (b) are enlarged and aligned to demonstrate the overlap of activation in the FG for the SAT and face discrimination activations. Subscripts 1 and 2 refer to the first (more anterior) and second coronal slices with significant activation.

location of the FFA, we compared it with the result of the face versus object discrimination contrast (the standard means of identifying the FFA in the literature). Both the FFA and the SAT activations of the FG were confined to two coronal slices, in highly overlapping locations. These two sets of group composite maps are shown in figure 2.

The FG activations were stronger in the SAT versus bumper contrast than the face versus object contrast, but this may have had as much to do with the baseline as the experimental tasks. The Talairach coordinates for the SAT and FFA activations show that their centre of mass differs by less than one voxel. The SAT activation is 3 mm

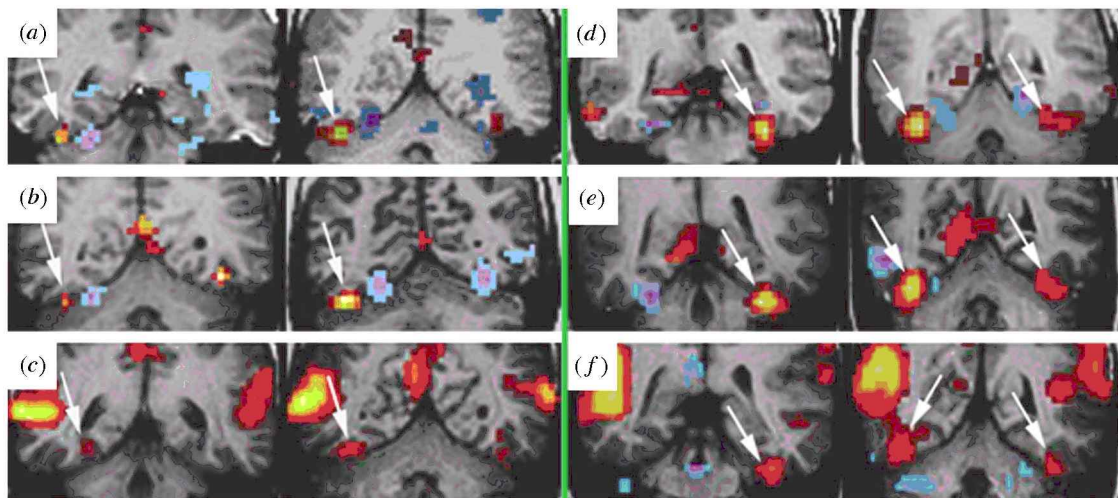


Figure 3. Scans of two individuals across three different occasions showing the reproducibility of FFA activations at two time-points, and relationship to SAT activations. (a–c) are from a 23-year-old male; (d–f) are from a 24-year-old female. Panels are arranged chronologically. (a,d) The first face versus object experiment. (b,e) The second face versus object scan. (c,f) SAT versus bumper car contrast. Both coronal slices are shown where there was FFA ($t \geq 1.5$ in yellow/red) or SAT activation ($t \geq 3.0$ in yellow/red). Arrows point to FG activity (right and left are reversed by convention). As in the group results (figure 2), the SAT activation is centred slightly more medially along the MFS. Left FG activation shown in these two subjects does not survive thresholding in the group composite (figure 2). Control tasks (object discrimination, bumper car) are shown in purple/blue.

more medial than that of the FFA, straddling the MFS that delineates the lateral and medial aspects of the FG. The FFA, on the other hand, is clearly positioned in the lateral FG, as expected (Haxby *et al.* 1999). The SAT activation is also centred 3.6 mm more superior and about 1 mm more anteriorly than the FFA. A count of the overlapping significant pixels showed that 50% of the SAT activation falls within the FFA. This provides a good approximation of how these regions overlap. However, there is no definitive way to measure the percent overlap in this study, because it would change with the use of different control tasks in either condition or different significance levels for thresholding the t -maps.

Two of the participants (one male, one female) were also part of a reproducibility study of the FFA, and had both undergone the face discrimination protocol on two occasions. Figure 3 presents t -maps of their FG for each face perception study and the SAT. The female participant shows reversed asymmetry, as sometimes happens, with the left FG showing greater face activation than the right. Nevertheless, her SAT activations track her FFA and are more left-sided than typical. These results show that the FFA activation is reproducible, so that the less than perfect overlap between the FFA and the SAT FG activation is probably not a measurement or reliability issue.

4. DISCUSSION

(a) *The social brain network*

The current study required participants to observe the movements of geometric figures, and to interpret these with regard to a conceptual template about what constitutes a friendly or unfriendly social interaction. It required close attention to the contingent nature of a sequence of movements, and inferences about mental states of each character to explain their actions. Perception of the move-

ments of these simple shapes as wilful seems to be automatic and effortless for healthy controls, but not for persons with autism (Klin 2000). As shown in figure 1, the network engaged by the social attribution process (in contrast to the physical attribution control task) included nearly all of the brain areas implicated by past research on the social brain (Brothers 1990), including cognitive aspects, such as theory of mind (Castelli *et al.* 2000), as well as perceptual aspects, such as the perception of social displays and biological movement (Allison *et al.* 2000). We found significant activation of the bilateral MPFC, superior STG and STS, and inferior FG, pars orbitalis extending into the lateral orbital gyri. In addition, there were significant activations on the right side only for the amygdala, TP and the FG. The predominance of right-side activations is consistent with the notion that the right hemisphere is more concerned than the left with social processes (Siegal *et al.* 1996; Winner *et al.* 2002). Our results differ from some past research by finding significant right FG activation, and by failing to find orbito-MPFC activation.

Several earlier neuroimaging studies have shown that the dorsal MPFC (i.e. that cortex anterior and superior to the anterior cingulate gyrus) is a critical substrate for social judgements, including empathizing and thinking about other's thoughts and intentions (Fletcher *et al.* 1995; Goel *et al.* 1995; Happé *et al.* 1996; Castelli *et al.* 2000, 2002; Gallagher *et al.* 2000). Our findings are consistent with these imaging studies and with non-human primate studies that have documented social failures and loss of social position within the group following lesions to orbital prefrontal cortices and MPFC (Butter *et al.* 1969; Myers *et al.* 1973; Bachevalier & Mishkin 1986). The important role for the MPFC in social cognition is further suggested by studies of autism spectrum disorders that find functional abnormalities in this area (Happé *et al.* 1996; Ernst *et al.* 1997; Haznedar *et al.* 1997; Castelli *et al.* 2002).

Gusnard *et al.* (2001) suggest that the dorsal MPFC is involved in any kind of thought that uses the self as a referent. Thus, the SAT activations in this area may have been driven by theorizing about others' minds, but with explicit reference to the participant's own frame of reference as to how they would feel in a similar situation.

The orbital prefrontal cortex and to a lesser extent the dorsal MPFC have dense reciprocal connections with medial temporal areas (Price *et al.* 1996; Carmichael & Price 1995), providing the anatomical bases for a system that regulates emotional processes. Damasio and colleagues (Damasio *et al.* 1990; Bechara *et al.* 1996) have argued that the orbito-MPFC have a primary function of integrating information about rewards and punishments to bias future behaviour (Rolls 1995; Dias *et al.* 1996; Hornak *et al.* 1996; Lane *et al.* 1997; Reiman *et al.* 1997). A functional circuitry such as this would seem especially important in the development and acquisition of social behaviour. However, even acquired lesions to these regions in adulthood can result in abnormalities of social conduct (Damasio *et al.* 1990). Brothers (1990) highlighted the orbital prefrontal cortex as one of the three principal brain regions involved in social cognition. We observed poor signal in this region (these areas are notoriously prone to fMRI signal drop-out and distortion), and thus we cannot know if the orbital prefrontal region was engaged by the SAT or not. However, using a similar psychological task but with PET, where signal acquisition in this region is not degraded, Castelli *et al.* (2000, 2002) failed to find activation of the orbital prefrontal cortex. Collectively, these results call into question the importance of the orbital prefrontal cortex in social cognition, and instead shift the focus on anterior cortices toward the dorsal MPFC.

The SAT also generated robust activations of the right amygdala, and nearby cortex of the right TP. The amygdala is often given a central role in theories of social perception and cognition (Brothers 1990; Bachevalier 1994; Adolphs *et al.* 1998; Baron-Cohen *et al.* 2000; Schultz *et al.* 2000*b*). The amygdala has a critical role in emotional arousal, assigning significance to environmental stimuli and mediating the formation of visual-reward associations, that is, 'emotional' learning (Gaffan *et al.* 1988; LeDoux 1996; Anderson & Phelps 2001). It is reliably engaged during judgements of personality characteristics from pictures of the face or part of the face (Adolphs *et al.* 1998; Baron-Cohen *et al.* 1999; Winston *et al.* 2002). Activation of the amygdala appears to be automatic and stimulus driven, as it can be engaged by images of facial expressions in conscious awareness, as well as by subliminal presentations of faces displaying affect (Morris *et al.* 1998; Whalen *et al.* 1998; Critchley *et al.* 2000). Thus, the amygdala's engagement by the SAT could stem from the general emotional arousal evoked by the animations, or it could represent its computational role in some more specific social perceptual process.

The amygdala has dense reciprocal connections with the ventral visual processing stream (Amaral & Price 1984). The strong correlation observed in this study between the right amygdala and the right FG could indicate that emotional inputs from the amygdala to the FG are necessary for engaging the social computational processes of the FG. Brothers (1995) has speculated that the

amygdala generates 'social feelings' that are of importance in cutting through the complexities of social situations and guiding behaviour by simpler, learned contingencies. Social events are complex because their meaning often comes from specific combinations of features that do not add up in a linear manner, making it more difficult to decompose the events by cognitive analysis. Effective social engagement requires *integration* of context, historical relationships and current social-emotional communications expressed through prosodic tone as well as facial expressions, posture and gesture. They are made more complex by the rapid pace of social transactions. This would necessitate some fast response system based on general principles from past social-emotional experiences, a role for which the amygdala would seem ideally suited. In other words, the amygdala might drive intuition or 'gut feelings' to guide rapid non-verbal social interactions involving facial expressions, gesture, etc. Thus, the strong amygdala-FG correlation observed here could be interpreted as the amygdala informing the FG of the relevance of a social event, and also of the outcome of its quick and dirty social perceptual analyses, thereby guiding the FG (and other social nodes) in their finer grained computations.

Perhaps the largest and strongest activations to the SAT were those of the posterior aspects of the STS, spreading into the adjacent STG. This area has been implicated as a specific site for perception of biological motion (Bonda *et al.* 1996; Allison *et al.* 2000; Grezes *et al.* 2001; Vaina *et al.* 2001). Biological motion is a broad construct that seems to encompass the perception of static images of events that could move, or did move, such as facial expressions, as well as actual movement by animate objects. This region of the STS-STG is also critical for the decoding visual displays of social action or intention (e.g. gaze direction, gesture and facial displays of emotion) (Critchley *et al.* 2000; Hoffman & Haxby 2000). In this regard, the SAT activations here are completely expected, and a testament to the effectiveness of these animations in inducing the desired illusion of anthropomorphic action. The majority of the STS-STG activations were anterior to location of the V5/MT, as defined in other recent fMRI studies (Culham *et al.* 2001), but they also extended posteriorly into these more general movement sensitive cortices. Unlike the amygdala, some evidence suggests that activity of the STS is mediated by explicit attention to social characteristics of the face, and that STS engagement it is not automatic or stimulus driven (Winston *et al.* 2002). We surmise, therefore, that activation of the STS by the SAT was due to explicit task instructions to judge the social interactions.

(b) *Role of the fusiform face area in social cognition*

We also found significant SAT activation of the right FG. When compared directly in a subset of participants to their FFA gleaned from a separate scanning session with a perceptual discrimination task of person versus object identity, we found that both ROIs were confined to the right side, on the same two coronal slices. There was about 50% overlap between the SAT, FG and FFA activations, and the centre of the two activations differed by less than 1 voxel. The FFA activation was offset to the

lateral prominence of the FG, whereas the SAT activated a region of the FG that was closer to the centre of the FG, but still largely in the lateral aspect. Because the SAT does not contain any face representations, the FFA engagement was unexpected, as this region is thought of as selective for faces (Kanwisher *et al.* 1997) or to other classes of complex objects for which one is perceptually expert (Gauthier *et al.* 2000).

These results have important implications for the possible role of the fusiform in social brain circuitry and autism. Interestingly, the magnitude of the FG activation predicted SAT task accuracy; no other ROI correlated significantly with task accuracy. This would seem to argue against any interpretation that the FFA activation is inconsequential to the SAT; that it is activated simply because it is well connected to other areas that are directly involved in the social attribution process. Using a task that is similar to the SAT, Castelli *et al.* (2000) also reported significant right FG activation using PET. However, in their follow-up PET study comparing autism and normal controls (Castelli *et al.* 2002), they failed to find significant FG activation in either group. The failure of their second study to find right FG activations may be due to the more stringent random effects model used in the data analyses. However, because we find right FG activation with fMRI, which is more sensitive than PET and because Castelli *et al.* (2000) found it with what amounts to a lower threshold, it seems quite probable that the effect is real. In fact, we have preliminary evidence from an ongoing fMRI study that reproduces the SAT FG activations in healthy controls (Schultz *et al.* 2001). In addition, there may be some task attributes that differ between our studies and Castelli *et al.*'s that might impact into the strength with which FG computational processes are evoked.

The key question, then, is why is the FG engaged by the SAT and what role does the right FG have in social cognition and perception? Currently, there are three competing theories of the functional organization of the FG and related ventral visual perceptual areas. One model, put forth by Haxby, Chao, Martin and colleagues, specifies that objects are encoded in a distributed fashion across a wide expanse of the ventral temporal-occipital cortex (Haxby *et al.* 2001). They call this the 'object form typology' model (Ishai *et al.* 1999). Their data indicate that object category specificity is achieved by unique spatial patterns of activation across this extrastriate visual cortex. They show that the pattern of activations across this cortex is diagnostic of object category membership, more so than any localized activation maxima (Haxby *et al.* 2001). They also argue that object category perception involves retrieval of category-related information about specific features and attributes of the object category (Chao *et al.* 2002). They admit that the 'nature of the information about objects that is represented in the ventral temporal cortex is a great puzzle' (Haxby *et al.* 2000, p. 4), but open the possibility that semantic information may be important.

A second view championed by Kanwisher *et al.* holds that several select perceptual categories, including faces, bodies and spatial layout of places are encoded in highly specific locations, in a modular fashion (Kanwisher *et al.* 1997; Epstein & Kanwisher 1998; Downing *et al.* 2001; Spiridon & Kanwisher 2002). The FFA is thought to be

most concerned with discriminating among individual identities, and not with discriminating images at the categorical level. In fact, lesions to the FFA cause a specific deficit in recognizing individual identities, but not in recognizing the general category of face versus non-face (Wada & Yamamoto 2001). Spiridon & Kanwisher (2002) provide a partial replication of Haxby *et al.*'s (2001) object form typology model. They show that patterns of ventral visual cortical activation can distinguish object categories. Nevertheless, their data show category specificity for select areas, such as the FFA, and they argue the ventral visual cortex is not equipotential.

Gauthier *et al.*, however, have argued that the ventral occipital temporal pathway is organized by the nature of the perceptual computations, and that these processing biases are acquired through experience (Gauthier *et al.* 2000; Tarr & Gauthier 2000). For example, the parahippocampal place area is a function of a bias towards processing landscapes in terms of their spatial layout, because we have learned through repeated experiences that this is very useful information to extract when perceiving landscapes and related visual images. Similarly, we learn quite early in life that it is important to discriminate faces on an individual level, for example, discriminating mother from others. This bias towards individual identification, according to Gauthier, accounts for the FFA's apparent modularity (Gauthier *et al.* 1997, 2000; Tarr & Gauthier 2000). According to this third model, the type of information needed and our cumulative experience in processing that information organizes the ventral occipital-temporal pathway into regional centres with preferred modes of processing.

All three models seem to agree that the functional organization of the ventral visual cortices is driven by the need to categorize perceptions into object classes. We believe that our findings showing FFA activation by non-face objects are consistent with aspects of both the processing map model of Gauthier and the object form typology model of Haxby *et al.* First, consistent with Haxby *et al.*, we suggest that semantic information is important to the ventral visual pathway for object categorization. Second, consistent with Gauthier *et al.*, we believe that repeated perceptual experience with faces biases the type of information that FG finds important. We propose that the middle FG area encodes semantic attributes of people because of repeated perceptual experiences with faces that occur during social interactions. In fact, we would guess that most perceptual experiences with faces occur during social situations, and these social situations often involve repeated social judgements. Thus, information about the social nature of people might be stored in the FG (though not exclusively).

The nature of the semantic information stored in the FG might be restricted to anything that would be helpful in defining faces as a distinct category of object, because making such distinctions appears to be the primary charge of the ventral visual pathway. This would include knowledge of people as having personal agency and of having the capability to disturb each other's emotional homeostasis (e.g. to act friendly or unfriendly). By pretending that the three shapes in the SAT are people, stored knowledge about people in social interactions might be retrieved, causing the observed activations in the FG.

There would be a measure of efficiency from this arrangement, that is, having representations and computations of more abstract attributes of people inter-digitated with front-end perceptual processes about physical attributes. Gauthier's claim is that the same group of neurons can be engaged by perceptually different categories of objects; it is the type of processing, rather than the visual details, that are important. Extrapolating from this, we would argue that the SAT engages a region of the FG, overlapping with the FFA, because it demands computational processes to classify the SAT geometric figures as people or person-like. Chao *et al.* (1999) reach a similar conclusion. They argued that activity in the ventral pathway reflects stored information about an object category, not just physical features. They point out that this arrangement could explain why lesion patients with category specific perceptual deficits also have trouble retrieving general information about that visual category. Thus, we would add that the FFA must store general information about people, or some meta-representation of 'peopleness'.

(c) *Implications for the pathobiology of autism*

The SAT used in this current study appears to be an effective neurobehavioural probe for engaging a distributed network of brain regions involved in different aspects of social perception and cognition. It will be important to use this and similar procedures in persons with autism to better define the nature of brain functions in this disorder. Castelli *et al.* (2002) have already taken the first step in this process, and they describe a pattern of hypoactivation in the MPFC, STS and TPs in autism. In an ongoing study of autism spectrum disorders, we have presented preliminary data using the SAT showing that we too find hypoactivation of these regions, and in the amygdala and FG (Schultz *et al.* 2001). Thus, we predict that future work in this area will show that the entire social brain network is underactive in autism during tasks requiring social perceptual and social cognitive processing.

There are already sufficient data to argue strongly for a role of the FG in the pathobiology of autism. No less than five previous fMRI studies have shown the FFA region to be significantly less engaged among persons with autism compared with controls during face perception tasks (Critchley *et al.* 2000; Dierks *et al.* 2001; Pierce *et al.* 2001; Schultz *et al.* 2000a, 2001). Activation of the FG by the social judgements in the current study adds an important piece of evidence in favour of a causal role for the FG in the pathobiology of autism. This conclusion, however, must remain tentative, until additional studies more precisely define the factors leading to FG activation during social attribution and gather better data to prove its computational role in social cognition. In addition, the effect of FG lesions for social functioning must be clarified. If the FG is involved in social computations, one would expect to find social cognitive deficits in persons with lesions to this area. However, social deficits in prosopagnosics have not been widely reported. It might be that prosopagnosic patients have not been carefully tested on this dimension. In this regard, using our behavioural version of the SAT (Klin 2000) to test social perception among prosopagnosics would be quite interesting. The parallels, however, between autism and prosopagnosia are

incomplete, because autism is clearly a developmental disorder, whereas the research literature on prosopagnosia is mostly confined to lesions acquired in adolescence or adulthood. Among the few cases of developmental prosopagnosia reported in the literature, there is indeed one that highlights severe social impairments (Kracke 1994). It may be that the role of the FG in the development of autistic symptoms is different from the role of the FG in the maintenance of social cognitive functions after brain maturity.

It is also possible that the role of the FG in social processes is dependent on its functional relationships with other nodes in the social brain, and that it is the collective action and interaction of the network that is of primary importance for social behaviours. For example, we found a strong correlation across participants in the amount of FG and amygdala activation. A strictly modular view of these areas may be inappropriate, as the functions of each node could be quite dependent on one another, and when only considered in isolation, quite insufficient to support social processes. Thus, whereas a lesion to the FG may impair visual perception, it might not have a large impact on social functioning if this depends on an extended network that is dynamic and capable of compensatory adjustments. Dysfunction of the FG may be necessary but not sufficient to produce social deficits. Indeed our reliance on modular models of brain functioning may be leading us astray in our search for causal mechanisms in autism. Instead, it may be the collective action of a distributed system that is critical to the pathobiology of autism. The FG region may be a key partner in this distributed system, but nevertheless just one node, and insufficient by itself to support in any substantive manner social cognitive processes, or to explain social cognitive deficits seen in autism.

5. CONCLUSION AND FUTURE DIRECTIONS

Using the SAT, we isolated a distributed network of activations that conform to the emerging model of the social brain. Most important, we found significant activation of the central aspect of the FG, thus adding this region to the expanding list of structures involved in social processes. The FG region activated by the SAT overlaps in its spatial extent with the FFA, with centres of mass differing by less than 1 voxel. We speculate that these SAT activations represent computational processes associated with more abstract attributes of people.

It is an open question as to whether the substantial overlap between the FFA and SAT FG activation is due to an overlapping or shared set of neuronal assemblies. This will need to be clarified by future work. Electrophysiological studies show that there are small face-specific patches in the FG cortex (Allison *et al.* 1999). In the current study, small patches of face cells and SAT cells could be intermingled, but distinct and not drawing on any of the same neuronal assemblies. The spatial resolution of fMRI has limitations that may preclude any definitive answer to this question, but there are strategies that can be used to address the issue. For example, the current study design did not contain SAT and face discriminations in the same experimental fMRI series. Doing so would enable direct comparisons of the computational demands placed on the

common area of the FFA. It also would be informative if follow-up studies superimposed faces within the geometric figures of the SAT without changing the film scripts in any way. We could then determine if the computations of the common area of the FFA increase in a predictable fashion—would the activation be a linear summation of the original SAT plus face discrimination? Any significant deviation from an additive model would suggest that there is some sharing of neuronal assemblies with the SAT and face discrimination tasks when presented alone.

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GLOSSARY

- AC-PC: anterior commissure–posterior commissure
 BOLD: blood oxygen level dependent
 FFA: fusiform face area
 FG: fusiform gyrus
 fMRI: functional magnetic resonance imaging
 IQ: intelligence quotient
 MFS: mid-fusiform sulcus
 MPFC: medial prefrontal cortex
 NEX: number of excitations
 PET: positron emission tomography
 ROI: region of interest
 SAT: social attribution task
 STG: superior temporal gyrus
 STS: superior temporal sulcus
 TE: echo time
 TP: temporal pole
 TR: repetition time