Brain (2002), **125,** 1808–1814

Neural correlates of self-reflection

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Summary

The capacity to reflect on one's sense of self is an important component of self-awareness. In this paper, we investigate some of the neurocognitive processes underlying reflection on the self using functional MRI. Eleven healthy volunteers were scanned with echo-planar imaging using the blood oxygen level-dependent contrast method. The task consisted of aurally delivered statements requiring a yes–no decision. In the experimental condition, participants responded to a variety of statements requiring knowledge of and reflection on their own abilities, traits and attitudes (e.g. 'I forget important things', 'I'm a good friend', 'I have a quick temper'). In the control condition, participants responded to statements requiring a basic level of semantic knowledge (e.g. 'Ten seconds is more than a minute', 'You need water to live'). The latter condition was intended to control for auditory comprehension, attentional demands, decision-making, the motoric response, and any common retrieval processes. Individual analyses revealed consistent anterior medial prefrontal and posterior cingulate activation for all participants. The overall activity for the group, using a random-effects model, occurred in anterior medial prefrontal cortex (t = 13.0, corrected P = 0.05; x, y, z, 0, 54, 8, respectively) and the posterior cingulate (t = 14.7, P = 0.02; x, y, z, –2, –62, 32, respectively; 967 voxel extent). These data are consistent with lesion studies of impaired awareness, and suggest that the medial prefrontal and posterior cingulate cortex are part of a neural system subserving self-reflective thought.

Keywords: fMRI; medial prefrontal cortex; posterior cingulate; self-awareness; self-reflection

Abbreviation: AMPFC = anterior medial prefrontal cortex

Introduction

The capacity to consciously reflect on one's sense of self is an important aspect of self-awareness. A sense of self is a collection of schemata regarding one's abilities, traits and attitudes that guides our behaviours, choices and social interactions. The accuracy of one's sense of self will impact ability to function effectively in the world. A patient for whom self-awareness is compromised may have a sense of self regarding abilities and traits that is not congruent with what others observe (Stuss, 1991; Prigatano, 1999). For example, a brain-injured patient may feel he/she can competently return to the same level of employment when observations by others indicate otherwise. When asked, brain-injured patients often underestimate their own emotional dyscontrol, cognitive difficulties and interpersonal deficits relative to a family member's rating of their abilities (Prigatano, 1996). Inaccurate self-knowledge can significantly impede efforts to rehabilitate brain-injured patients, since they may not appreciate the need for such treatment (Sherer *et al.*, 1998*a*, *b*).

Hughlings Jackson postulated that a sense of self is dependent on the evolutionary development of the prefrontal cortex (Meares, 1999). Lesion studies have generally supported this hypothesis. Damage to the anterior prefrontal regions has been associated with impaired self-awareness for the appropriateness of social interactions, judgement and planning difficulties (Prigatano and Schacter, 1991; Stuss, 1991), as well as impaired awareness of the mental states of others ('theory of mind'; Stone *et al.*, 1998; Stuss *et al.*, 2001). Impaired self-awareness appears to occur more frequently following medial prefrontal damage (Damasio *et al.*, 1990), but may not be limited to this region.

Although much has been learned from lesion studies, to date there is little functional imaging data on this topic. A recent study found that patients with frontal dementia and a change in personality functioning also exhibited greater right prefrontal hypoperfusion (Miller *et al*., 2001) using SPECT (single-photon emission computed tomography) scanning. Studies using cognitive activation paradigms report activations to self-monitoring of current emotional or somatic states (McGuire *et al*., 1996; Lane *et al*., 1997; Blakemore *et al*., 2000; Gusnard *et al*., 2001). Activations in these studies were within the anterior cingulate and paracingulate region, Brodmann area (BA) 32 (Frith and Frith, 1999). To date, no studies have addressed the process of conscious reflection on one's own traits, abilities and attitudes that comprise a sense of self.

For the paradigm reported in this paper, we used stimuli that were similar to what one might find on a self-report personality or mood survey. We asked participants to answer questions regarding stable traits, attitudes and abilities. The control condition involved retrieval of general factual knowledge (semantic knowledge retrieval). In light of previous lesion and imaging studies, we hypothesized that the medial prefrontal cortex would be involved in this task.

Methods

Subjects

Eleven right-handed, healthy volunteer participants (four females, seven males; mean age 35 years, SD = 12; mean education 17 years, SD = 2.3) were recruited from employees within the medical centre. The volunteers provided written informed consent to participate in this institutional review board-approved study.

Paradigm

In the functional MRI (fMRI) paradigm, the participants were asked to make decisions about themselves on specific statements requiring self-evaluation in the domains of mood, social interactions, cognitive and physical abilities. A standard set of statements was administered via headphones to each participant during scanning. The set included items such as 'I get angry easily', 'I often forget things', 'My future is bright', 'I'd rather be alone', 'I catch on quickly', 'I can be trusted' and 'I'm good at my job'. In the control condition (used to control for auditory processing, attention, language comprehension, decision making, the motor response and retrieval), participants made decisions about statements of factual knowledge. Statements included items such as 'Ten seconds is more than a minute' and 'You need water to live'. Participants responded to each statement with a 'yes' (right hand) or 'no' (left hand) button press. A constant visual reminder of which button to press for each response was displayed through the goggle projection system throughout the entire scan.

Statements were digitized and delivered aurally at 44.1 kHz. They were presented every 4 s in blocks of six for each condition. The statements were, on average, 2 s in duration, leaving 2 s to respond. The experimental and control conditions alternated over five cycles. The task was presented twice using equivalent forms (order of form administration was counterbalanced across subjects).

Scanning technique

Participants were positioned in a GE 1.5 Tesla NVi scanner with foam padding around the head to minimize participant motion. Stimuli were delivered into the scanner via a laptop computer connected to an MR-compatible goggle and headphone system from Resonance Technology (Northridge, CA, USA). The software Presentation (http://www.neurobehaviouralsystems.com) was used for delivering the auditory stimuli and recording responses. Input from the scanner via a low amplitude electrical pulse allowed the stimulus delivery software to monitor the scanner at every slice acquisition and deliver the auditory stimuli with accurate timing. A single-button MRI-compatible response device was placed in each hand for making yes–no responses.

Imaging parameters

T_2* weighted images were acquired with a gradient echo, echo-planar pulse sequence to elicit blood oxygen level-dependent (BOLD) contrast. The scanning parameters were as follows: TE (echo time) = 40 ms; TR (repetition time) = 3000 ms; flip angle = 90°; acquisition matrix = 64×64 voxels; field of view (FOV) = 240 mm. Thirty-two slices of the brain were acquired axially within the TR at each time point, with near isotropic voxel resolution of $3.75 \times 3.75 \times 4.2$ mm. Eighty-two time points were collected over a 4 min scanning run (images from the first 6 s were discarded).

High-resolution structural images were acquired for overlay of the statistical results. The images were collected using a SPGR (spoiled gradient) T_1-weighted, 3D acquisition with the following parameters: TR = 24 ms, TE = 6 ms, flip angle = 40°, NEX = 1, slice thickness = 1.9 mm, 0 skip between slices, FOV = 24 cm, in-plane resolution = 0.9375 mm^2 voxels. The T_1 and T_2* weighted images were co-registered using a least squares minimization routine.

Analysis

Images were analysed using Statistical Parametric Mapping software (SPM99, University College London, UK; http://www.fil.ion.ucl.ac.uk). Prior to statistical analysis, the time-series of images were corrected for motion, normalized into a standard atlas space (using the International Consortium for Brain Mapping template as implemented in SPM99), and then spatially smoothed using an 8-mm full-width at half-maximum Gaussian kernel.

Individual time-series analysis was performed on each participant. The boxcar model included bandpass filtering to remove high and low frequency signal, and convolution with a haemodynamic response function on a voxel by voxel basis

Table 1 *Coordinates (MNI space) and peak activation statistics for prefrontal and cingulate cortex for each participant*

		Talairach coordinates				
Participant	Region	*x*	*y*	*z*	*t*-value	*P*-value (corrected)
S1	AMPFC	0	66	10	5.72	0.001
	PC	–4	–48	36	9.90	0.000
S2	AMPFC	4	52	–4	5.77	0.012
	PC	–4	–74	38	5.49	0.032
S3	AMPFC	0	54	18	8.68	0.000
	PC	–4	–46	–6	5.38	0.005
S4	AMPFC	–10	64	26	7.61	0.000
	PC	0	–58	36	8.04	0.000
S5	AMPFC	2	60	18	7.62	0.000
	PC	–4	–54	32	8.40	0.000
S6	AMPFC	6	56	38	7.94	0.000
	PC	–8	–55	24	5.45	0.004
S7	AMPFC	–6	60	32	7.72	0.000
	PC	–4	–52	30	5.55	0.002
S8	AMPFC	2	62	20	9.76	0.000
	PC	10	–58	32	7.97	0.000
S9	AMPFC	0	76	8	13.63	0.000
	PC	–4	–44	24	12.65	0.000
S10	AMPFC	8	64	34	8.98	0.000
	PC	14	–54	20	5.98	0.006
S11	AMPFC	–8	60	30	6.24	0.000
	PC	–4	–56	10	8.31	0.000

AMPFC = anterior medial prefrontal cortex; PC = posterior cingulate cortex; MNI = Montreal Neurological Institute.

using the general linear model (Friston *et al*., 1995). The individual results were of most interest to us. However, we also characterized the average group response using a random-effects approach (Holmes and Friston, 1998).

Results

Inspection of performance data indicated an equivalent proportion of ‘yes’ (right button) responses between conditions across participants (mean of 50% ‘yes’ responses in the self-reflection condition, mean of 51% ‘yes’ responses in the semantic condition). These proportions did not differ significantly. The reaction time for the ‘self’ condition was 659 ms, and for the semantic condition it was 602 ms. The difference between the two conditions was not significant ($P = 0.61$).

All 11 participants individually activated the anterior medial prefrontal cortex and posterior cingulate above a *P*-value threshold (corrected for multiple comparisons) of 0.05, as shown in Table 1. Figure 1 depicts the individual activations for the 11 subjects prior to any spatial standardization. Activation maps are overlayed on their own co-registered T_1-weighted MRI scans. Peak activations in the anterior medial prefrontal cortex (AMPFC) occurred just to the right of midline in five of the participants, three were just left of midline, and the remaining three were at midline (see Table 1 for spatially normalized activation coordinates).

A summary of the group activity is shown in Fig. 2. The main effects of activation in the group analysis were highly consistent with the individual analyses, as expected. Activations included the AMPFC ($t = 13.0$, corrected $P = 0.05$; *x*, *y*, *z*, 0, 54, 8) and posterior cingulate ($t = 14.7$, corrected $P = 0.02$; *x*, *y*, *z*, –2, –62, 32). No other regions survived the correction for multiple comparisons.

Discussion

Consistent and robust anterior medial prefrontal and posterior cingulate activation during self-reflection was observed in all 11 participants. While the peak of the activation varied somewhat between individuals, the preponderance of activity was always within AMPFC, BA 9 and 10, and posterior cingulate, in the area of BA 23, 30 and 31. Activation of the anterior medial prefrontal region was consistent with our hypothesis and with lesion studies of patients with impaired self-awareness (Stuss, 1991). The consistency and magnitude of the activation was, however, somewhat greater than expected.

Previous functional imaging studies involving self-evaluation have focused on appraising current internal states rather than more stable traits (Frith and Frith, 1999). These prior studies have collectively demonstrated anterior medial prefrontal activation. Together, the current results and previous studies suggest that mentalizing about the self,

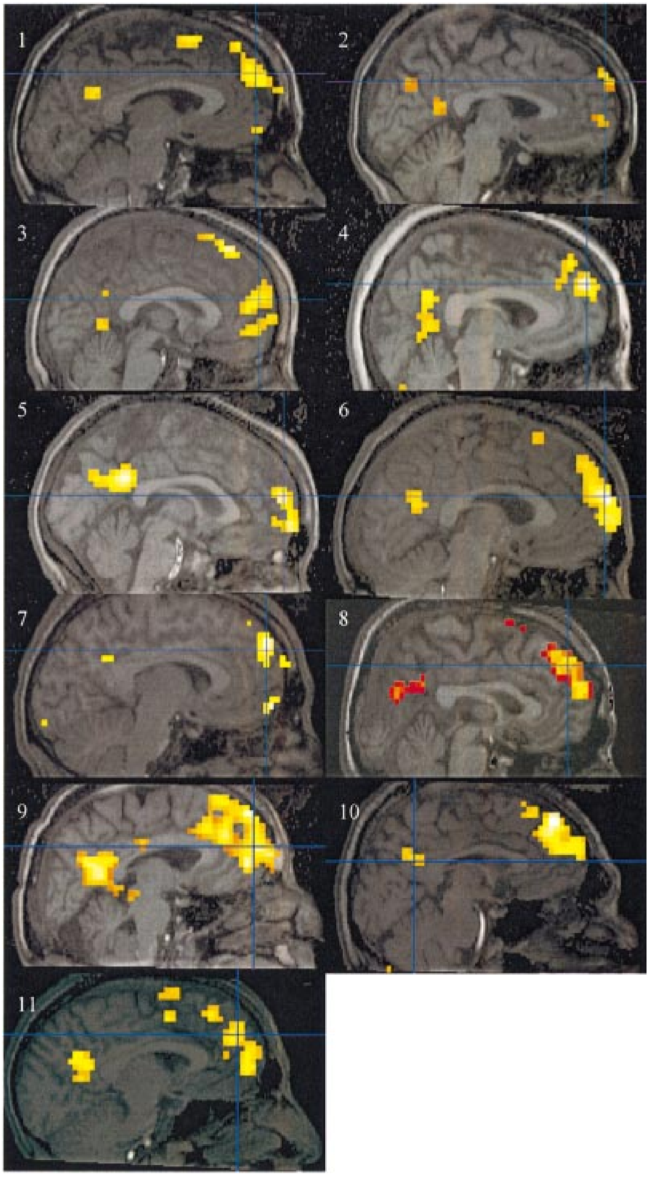

Fig. 1 Midsagittal view of each participant showing prefrontal activation during self-reflective thought. The activations are superimposed on top of each participant's anatomical scan. Note the consistent activation of the prefrontal cortex across subjects. For the purposes of this display, the statistical threshold was set to an uncorrected *P*-value of 0.0005. These results are prior to any spatial standardization. The coordinates for the spatially standardized results for each individual are shown in Table 1.

whether it be traits or current states, may activate the same or similar medial frontal network.

Developmental theorists have written that a sense of self begins in early childhood as a multidimensional set of schemata, is defined further through accommodation of experiences and perceptions in childhood and adolescence, and gains permanence in early adulthood (Rychlak, 1981; Kagan, 1982; Miller *et al*., 2001; Zeman, 2001). Piaget defined schema as the potential to act or to be a certain way (Rychlak, 1981). Over time, schemata may become unlinked to specific autobiographical events, and become part of a non-episodic knowledge base, analogous to semantic knowledge.

Functional imaging studies of episodic autobiographical memory retrieval have consistently reported posterior cingulate activation (Maddock, 1999; Maddock *et al*., 2001; Maguire *et al*., 2001). The posterior cingulate has reciprocal connections with other memory areas, including the dorsolateral prefrontal cortex, the posterior parahippocampal cortex, presubiculum and the entorhinal cortex, and with several nuclei of the thalamus (Duvernoy, 1998; Morris *et al*., 1999; Mesulam, 2000). The posterior cingulate has also been shown to respond to a familiar face or voice (Shah *et al*., 2001), retrieval of episodic information (Andreasen *et al*., 1995; Wiggs *et al*., 1999) as well as retrieval of semantic information (Pihlajamaki *et al*., 2000). Further, resting hypometabolism in this region has been observed consistently in very early-stage Alzheimer's disease, when difficulty with memory is the most prominent symptom (Minoshima *et al*., 1997). Persons who are at genetic risk for Alzheimer's disease also exhibit posterior cingulate hypometabolism (Reiman *et al*., 1996).

Although this study reports activations in the posterior cingulate, the paradigm differs from tasks of autobiographical episodic memory in many respects. Autobiographical memory paradigms used in functional imaging experiments generally entail recollection of vivid, personally relevant episodes from the past. These experiments generally allow for a relatively longer period of time, 4–20 s, for the participant to retrieve the event as well as its context (Maguire *et al*., 2001; Ryan *et al*., 2001) In the current study, participants were allowed only 2 s to reflect and decide. There was little time for participants to retrieve prior episodes and contexts on which to base their subjective decisions. Furthermore, they were specifically instructed to use their first impressions rather than ruminating on the question or justifying their responses with facts.

The posterior cingulate appears not only to be important for memory, but also for the perception and evaluation of emotional stimuli. A recent review paper (Maddock, 1999) observed that the posterior cingulate is the most frequently activated region during evaluation of emotional salience of a stimulus. Since this region is also activated in autobiographical retrieval, Maddock (1999) further argued that the posterior cingulate may mediate an 'interaction' between memory retrieval and emotion. This notion is relevant to our task, during which participants were required to retrieve and reflect on self schemata that may have had an emotional component. Measuring the emotional salience was beyond the scope of this study, but would have been helpful in interpreting the activations observed.

We note a consistent observation in research on emotion and memory, that stimuli with greater emotional salience tend to be better recalled (Cahill, 1997, 2000; Maddock and Buonocore, 1997; Maddock *et al*., 2001). Lasting personal memories typically have a salient affective tone, and it may be difficult to separate the retrieval of content from the

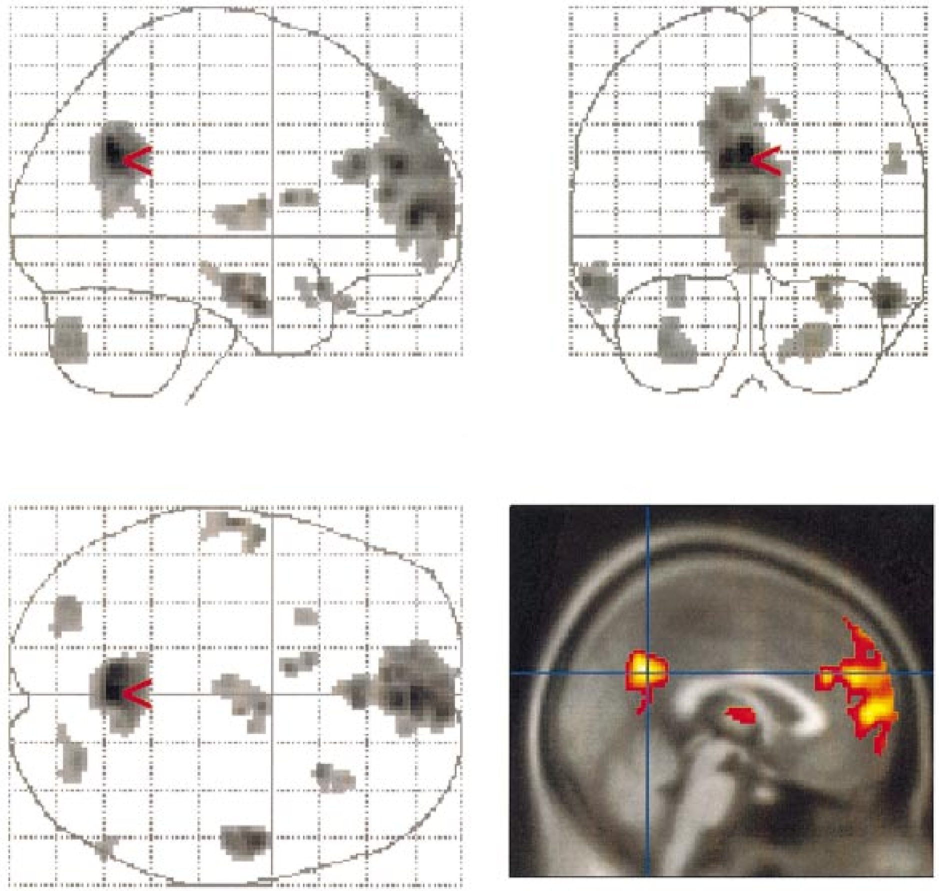

Fig. 2 Group activations for the self-reflection versus general knowledge conditions. This maximum intensity projection represents a random-effects group analysis. Lower right: a midsagittal anatomical view is shown with the group activation superimposed. The results are thresholded at an uncorrected *P*-value of 0.001, corresponding to a *t*-statistic of 4.14. The main effect of activation occurred in anterior medial prefrontal cortex (maxima $t = 13.0$, corrected $P = 0.05$; *x*, *y*, *z* = 0, 54, 8, respectively; cluster size 2326 voxels) and the posterior cingulate (maxima $t = 14.7$, corrected $P = 0.02$; *x*, *y*, *z* = –2, –62, 32; cluster size 976 voxels). Other activated regions at this threshold included the thalamus ($t = 7.53$; *x*, *y*, *z* = 4, –4, 12), bilateral posterolateral orbital cortex (right orbital: $t = 7.67$; *x*, *y*, *z* = 28, 18, –18; left orbital: $t = 7.51$; *x*, *y*, *z* = –10, 6, 14), bilateral inferior temporal gyrus (right: $t = 10.38$; *x*, *y*, *z* = 52, –6, –24; left: $t = 8.46$; *x*, *y*, *z* = –62, –14, –16) and bilateral cerebellum (right: $t = 6.13$; *x*, *y*, *z* = 24, –74, –38; left: $t = 6.12$; *x*, *y*, *z* = –32, –78, –38).

accompanying emotional tone. Nevertheless, future studies should attempt to control for the affective processes during autobiographical memory retrieval in order to define better the role of the posterior cingulate.

There are other limitations to these data. Although we instructed participants to respond with their first impressions, and not to rely on specific instances to answer each question, we are unable to rule out episodic autobiographical retrieval as a possible response strategy and source of activity in the posterior cingulate. Also, although the reaction times for the experimental and control conditions were equivalent, the self condition may have been more psychologically uncomfortable and revealing than the control task, and therefore more difficult.

Self-reflection, as we have described it here, can be considered a metacognitive function (Stuss *et al*., 2001), and our results may not be specific to self-reflection *per se*. Two previous PET studies examining ‘theory of mind’ tasks reported anterior medial prefrontal and posterior cingulate activity (Fletcher *et al*., 1995; Goel *et al*., 1995). The tasks used in these studies required the participant to ‘mentalize’ about the beliefs and desires of others so as to predict their behaviour. Fletcher *et al*. and Goel *et al*. found maximal medial prefrontal activity at Talairach (*x*, *y*, *z*) locations –12, 42, 40 and–6, 46, 28, respectively, slightly posterior and superior to the activation reported in the present study (2, 54, 8). To address the issue of whether the activations seen here represent generically metacognitive functions, or are in fact specific to the self-reflective thought process, future research should directly compare metacognitive tasks requiring mentalizing about the self with tasks requiring mentalizing about others.

We assumed that the healthy individuals in our study would rate themselves accurately. While this assumption may be reasonable for healthy, cognitively normal volunteers, it would probably not hold for patients with altered self-awareness. In such cases, other methods may be helpful to differentiate between self-reflection and self-awareness, such as incorporating patient and caregiver ratings of the patient's abilities into the statistical analysis. This work is underway in our laboratory.

Conclusion

The medial prefrontal cortex and posterior cingulate are important brain regions for accessing a sense of self. The frontal activation results are consistent with lesion studies in patients with impaired self-awareness, as well as other functional imaging tasks involving mentalizing about the self or others. The current results suggest that studying aspects of self-awareness is quite feasible, with functional imaging using this type of paradigm.

Acknowledgements

We wish to thank Sarah Hahn, PhD, and Patty Puppe, RT, for their efforts on this project. We also wish to thank Richard Lane, MD, PhD, for review and critical discussion of an earlier version of the manuscript. This study was supported in part by the National Institute on Aging (AG18540), the National Institute of Mental Health (MH65723), the Arizona Alzheimer's Research Center, and the Barrow Neurological Foundation.

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Received May 14, 2001. Revised January 21, 2002.
Accepted February 28, 2002