

Neuroanatomical Evidence for Distinct Cognitive and Affective Components of Self

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Abstract

■ This study examines whether the cognitive and affective components of self-reflection can be dissociated using functional magnetic resonance imaging. Using a simple paradigm in which subjects judged the personal relevance of personality characteristics that were either favorable (e.g., “honest”) or unfavorable (e.g., “lazy”), we found that distinct neural circuits in adjacent regions of the prefrontal cortex subserve cognitive and emotional aspects of self-reflection. The medial prefrontal

cortex responded only to material that was self-descriptive, and this did not differ as a function of the valence of the trait. When material was judged to be self-relevant, the valence of the material was resolved in an adjacent region of ventral anterior cingulate. The nature of self is one of the most enduring questions in science, and researchers are now beginning to be able to decompose the neural operations that give rise to a unitary sense of self. ■

INTRODUCTION

A central feature of human experience is the possession of a sense of self that persists across space and time. Understanding the essence of this experience—what self is, how it emerges and what it does—has challenged scholars for many centuries. The advent of brain imaging has allowed for empirical examination of previously intractable aspects of mental processing, such as the nature of self-reflection. Of particular theoretical importance is the issue of how cognitive and affective elements of self are realized in the neural operations that support social cognition. In this study, we used event-related functional magnetic resonance imaging (fMRI) to dissociate these essential components of self-reflection.

Previous work has noted the involvement of the medial prefrontal cortex (MPFC, Brodmann’s area [BA] 10) during tasks that require self-reflection (Macrae, Moran, Heatherton, Banfield, & Kelley, 2004; Fossati et al., 2003; Johnson et al., 2002; Kelley et al., 2002; Gusnard, Akbudak, Shulman, & Raichle, 2001; Craik et al., 1999). For example, Craik et al. (1999), using positron emission tomography (PET), and Kelley et al. (2002), using fMRI, demonstrated greater MPFC activity when subjects judged trait adjectives to be self-descriptive than when they made comparable judgments about other people. Similar effects were reported by Johnson et al. (2002) when self-judgments were contrasted with general semantic judgments (e.g., “Is 10 minutes longer than an

hour?”). However, the precise functional significance of MPFC activity during self-referencing tasks remains unspecified. One possibility is that MPFC activity is process specific and reflects evaluative operations required to compare incoming information against a self-concept. Alternatively, MPFC activity may be further modulated dependent on the outcome of self-referential processing; that is, information that is deemed to be self-relevant may produce greater activity than information that is considered irrelevant to the self. A third possibility is that MPFC activity is sensitive to the emotional valence of information that is often considered during self-reflection.

Thus far, neuroimaging studies have focused on explicit evaluations of self and have linked MPFC activity to the “task” of self-reflection. Within the task of self-reflection, however, there have been reports suggesting that MPFC activity might be additionally modulated by self-relevance (Macrae et al., 2004; Fossati et al., 2003). That is, MPFC appears to be more responsive when the outcome of a self-referencing judgment is affirmative (e.g., “Yes, that trait describes me”) than when the outcome is negative (e.g., “No, that does not describe me”).

A particular challenge, however, in linking MPFC activity to self-relevance is that self-relevance is often confounded with emotional valence. Said differently, we have emotional reactions to information that is self-relevant. Indeed, when considering the personal relevance of information, individuals are more likely to endorse positive information as self-descriptive (Taylor & Brown, 1988). Thus, cortical activity during self-reflection

may index the self-relevance of the material, the valence of the material, or an interaction of the two.

Here we provide evidence for discrete regions of prefrontal cortex that subserve dissociable components of self-referential processing, specifically the cognitive and emotional elements of self-reflection.

Subjects ($n = 42$) were imaged by using event-related fMRI while judging the extent to which a series of favorable (e.g., happy, talented) and unfavorable (e.g., hostile, angry) personality characteristics were self-descriptive. Responses were collected on a 4-point rating scale that indexed the self-relevance of each item (1 = *not at all like me*, 4 = *very much like me*). On the basis of these ratings, it was possible to create sets of relevant and irrelevant personality characteristics that were positive and negative for each subject. To investigate the cognitive and emotional components of self-referential processing, fMRI data were analyzed by using a voxelwise analysis of variance (ANOVA) that examined the effects of self-relevance (“high” vs. “low”) and trait valence (“favorable traits” vs. “unfavorable traits”) on the neural activity that accompanies self-reflection.

METHODS

Subjects

Forty-two subjects between the ages of 18 and 33 years (17 men, mean age = 20.6 years) were recruited from the local Dartmouth community. Subjects reported no significant abnormal neurological history, had normal or corrected-to-normal visual acuity, and were strongly right-handed as measured by the Edinburgh Handedness Inventory (Raczkowski, Kalat, & Nebes, 1974). Subjects received course credit or were paid for their participation and gave informed consent in accordance with the guidelines set by the Committee for the Protection of Human Subjects at Dartmouth College.

Functional Imaging

Anatomical and functional whole-brain imaging was performed on a 1.5-T GE Signa Scanner (General Electric Medical Systems, Milwaukee, WI). An Apple Powerbook G3 computer running PSYSCOPE V.1.2.5 (Cohen, Macwhinney, Flatt, & Provost, 1993) was used for stimulus display. Anatomical images were acquired by using a high-resolution 3-D spoiled gradient sequence (SPGR; 124 sagittal slices, TE = 6 msec, TR = 25 msec, flip angle = 25°, 1 × 1 × 1.2-mm voxels). Functional images were collected in six functional runs of 135 time points each, using a gradient spin-echo, echo-planar sequence sensitive to blood oxygen level dependent (BOLD) contrast (T2*) (20 axial slices per whole-brain volume, 3.75-mm in-plane resolution, 5.5-mm thickness, 1-mm skip, TR = 2000 msec, TE = 35 msec, flip angle = 90°).

Behavioral Task

During scanning, subjects judged the self-descriptiveness of 540 trait words previously normed for valence (Anderson, 1968). Words (48-point Geneva font) were presented for 1250 msec in white print on a black background, followed by a fixation cross for 750 msec. Null events consisting of a fixation cross for 2000 msec were pseudorandomly interspersed to introduce jitter into the fMRI time series. Subjects responded by key-press, using the scale 1 (*not at all like me*) through 4 (*most like me*). For purposes of our second analysis, items attracting a response of 1 or 2 were considered low in self-relevance, whereas items attracting a response of 3 or 4 were considered high in self-relevance.

Data Analysis

fMRI data were analyzed by using the general linear model for event-related designs in SPM99 (Wellcome Department of Cognitive Neurology, London, UK). For each functional run, data were preprocessed to remove sources of noise and artifact. Functional data were corrected for differences in acquisition time between slices for each whole-brain volume, realigned within and across runs to correct for head movement, and coregistered with each participant’s anatomical data. Functional data were then transformed into a standard anatomical space (3-mm isotropic voxels) based on the ICBM 152 brain template (Montreal Neurological Institute) that approximates Talairach and Tournoux’s atlas space (Talairach & Tournoux, 1988). Normalized data were then spatially smoothed (6-mm full width at half maximum) using a Gaussian kernel. Analyses took place at two levels: formation of statistical images and regional analysis of hemodynamic responses.

In the first analysis, a general linear model incorporating a single task effect, a parametric regressor (indicating the subject’s response to each word), and covariates of no interest (a session mean, a linear trend, and six movement parameters derived from realignment corrections) was used to compute parameter estimates (β) and t -contrast images (containing weighted parameter estimates) for each comparison at each voxel and for each subject. In this way, the height of the expected hemodynamic response function was parametrically adjusted for all word events as a function of each subject’s own self-relevance ratings for each word.

In the second analysis, trials were sorted into four conditions based on the valence of each trait and the subjects’ responses to those traits. A median split was used to divide words into positive and negative valence categories (Anderson, 1968) (mean valence rating; positive words = 423.67, negative words = 162.24; range, 26 [most negative: liar]–577 [most positive: sincere]). Each valence category was then subdivided into low self-relevance (traits that received a 1 or 2 response from

the subject) and high self-relevance (traits that received a 3 or 4 response) categories. A general linear model incorporating these four task effects (comprising the four cells of the 2×2 ANOVA: positive and low in self-relevance, negative and low in self-relevance, positive and high in self-relevance, negative and high in self-relevance) and covariates of no interest (a session mean, a linear trend, and six movement parameters derived from realignment corrections) was used to compute parameter estimates (β) and contrast images (containing weighted parameter estimates) for each comparison at each voxel and for each subject. Contrast images comparing each condition to the baseline control (fixation) were then used to compute a whole-brain voxelwise ANOVA that yielded F -statistical maps for both main effects (self-relevance and valence) and the interaction. A log ratio image was created to index regions more sensitive to either valence or self-relevance (see Figure 3). Regions of interest were defined by using an automated peak-search algorithm. Parameter estimates from these regions (MPFC [-3 47 0], pCC [0 -43 21], and vACC [0 22 -9]) were extracted for each subject and each condition and submitted to a 2×2 ANOVA.

RESULTS

Behavioral Results

Due to equipment failure, response latencies during the self-reference task were not recorded from four subjects. The resulting behavioral analysis reflects data from the remaining 38 subjects. A repeated measures ANOVA revealed a main effect of self-relevance on the speed of subjects' responses, $F(3,37) = 10.77$, $p < .0001$. Responses at the tail ends of the self-descriptive scale (1 and 4 responses) were faster than the graded responses (2 and 3), $F(1,37) = 21.47$, $p < .0001$ (Figure 1A).

Judgments were then collapsed into high (3 and 4 responses) and low (1 and 2 responses) self-relevance categories and considered in a 2×2 ANOVA examining the main effects of self-relevance (high vs. low) and valence (positive vs. negative) on reaction time. Results revealed no main effect of self-relevance ($F < 1$), a trend toward a main effect of valence, $F(1,37) = 3.77$, $p = .06$ and a Self-relevance \times Valence interaction, $F(1,37) = 5.41$, $p < .05$ (Figure 1B, top).

Consistent with prior work (Taylor & Brown, 1988), subjects were more likely to endorse positive information as self-descriptive and negative information as low in self-relevance (Figure 1B, bottom). To test this, proportions of negative traits labeled as low in self-relevance and positive traits labeled as high in self-relevance were combined. A one-sample t test compared this proportion against 50%, $t(37) = 23.78$, $p < .0001$. This result revealed that subjects were more likely to label both positive and negative information as high and low in self-relevance, respectively, than vice versa, rep-

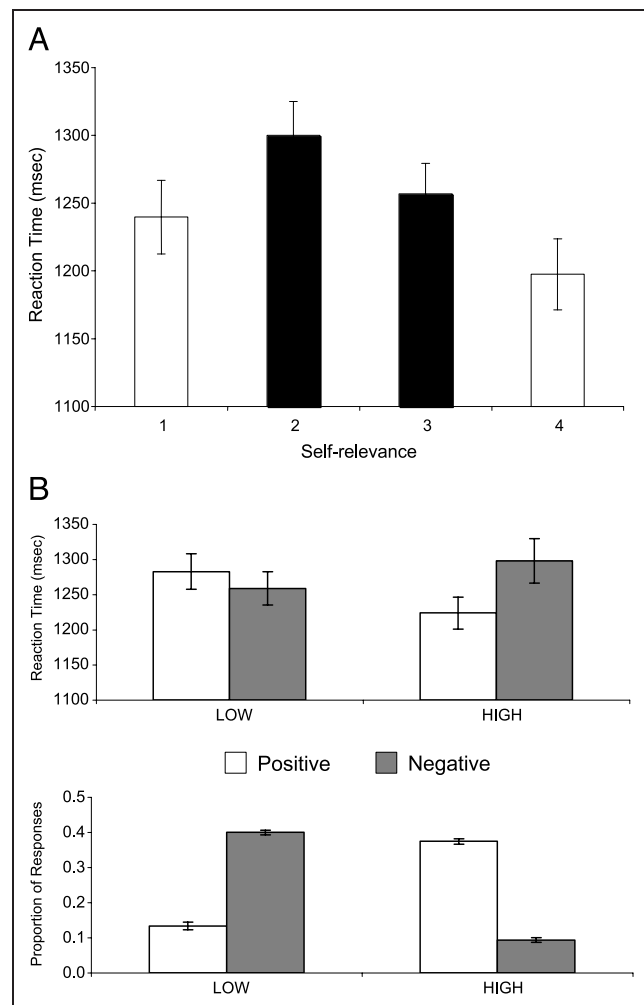


Figure 1. (A) Response latencies were shortest for responses at the tail ends of the self-descriptive scale. Dark bars represent significantly slower reaction times than light bars ($p < .0001$). Error bars indicate standard error of the mean. (B) Top: Subjects responded more slowly when judging negative traits to be high in self-relevance and when judging positive traits to be low in self-relevance. Bottom: Overall, subjects were more likely to rate positive traits as high in self-relevance and negative traits as low in self-relevance. Error bars indicate standard error of the mean.

licating Taylor and Brown (1988). We investigated these responses further and found that subjects made significantly more high than low responses to positive information, $t(37) = 13.48$, $p < .0001$, and that subjects made significantly more low than high responses to negative information, $t(37) = 25.37$, $p < .00001$.

fMRI Results

Two analyses were performed. To identify brain regions that showed a linear relationship with judgments of self-relevance, self-descriptiveness ratings for each trait word (1–4) were considered as a parametric regressor. Group analysis (see Methods) revealed four circumscribed mid-

line regions for which activity increased in a linear fashion with increasing self-descriptiveness judgments. These regions were located in the MPFC along the medial frontal gyrus (BA 10), the posterior cingulate cortex (pCC: BA 29/30), and bilateral regions of the caudate (Figure 2A). Figure 2B shows hemodynamic responses in MPFC as a function of both increasing self-relevance and time. As can be seen, there is a linear increase in MPFC activity as self-relevance increases.

A second analysis attempted to dissociate valence and self-relevance. Events were sorted into four categories based on valence (positive vs. negative) and self-relevance ratings (high [3 and 4 responses] vs. low [1 and 2 responses]) and were considered by using a voxelwise whole-brain ANOVA. Figure 3 and Table 1 summarize brain regions that revealed a main effect of self-relevance, a main effect of valence, and an interaction between self-relevance and valence. Closer inspection of these images revealed an apparent functional dissociation between the MPFC (BA 10), pCC (BA 29/30), and ventral anterior cingulate cortex (vACC: BA 25) that was examined further using a region-of-interest analysis.

MPFC and pCC responded preferentially to material that was self-relevant, regardless of valence. Both regions revealed a main effect of self-relevance, MPFC: $F(1,41) = 29.3, p < .0001$; pCC: $F(1,41) = 15.12, p < .00005$; no main effect of valence, MPFC: $F < 1$; pCC: $F < 1$; and no interaction, MPFC: $F < 1$; pCC: $F(1,41) = 1.29, p = .26$ (Figure 4). In contrast, vACC responded preferentially to favorable information, but only when this material was judged to be personally relevant. That is, there was a main effect of valence in this region, $F(1,41) = 13.11, p < .01$, but this main effect was qualified by the interaction between self-relevance and valence, $F(1,41) = 13.16, p < .01$ (Figure 4). The main effect of self-relevance was not significant ($F < 1$). Post hoc statistical analyses revealed that vACC differentiated items for their valence when items were high in self-relevance (positive > negative), $F(1,41) = 29.3, p < .0001$, but not when items were low in self-relevance (positive > negative), $F < 1$. It should be noted that the

hemodynamic responses observed in MPFC, pCC, and vACC reflect decreases relative to the baseline control condition. These findings are consistent with a broad literature showing task-independent BOLD deactivations in these regions when compared to resting baseline conditions (Greicius, Krasnow, Reiss, & Menon, 2003; Gusnard et al., 2001; Raichle et al., 2001; Shulman et al., 1997; Ingvar, 1979).

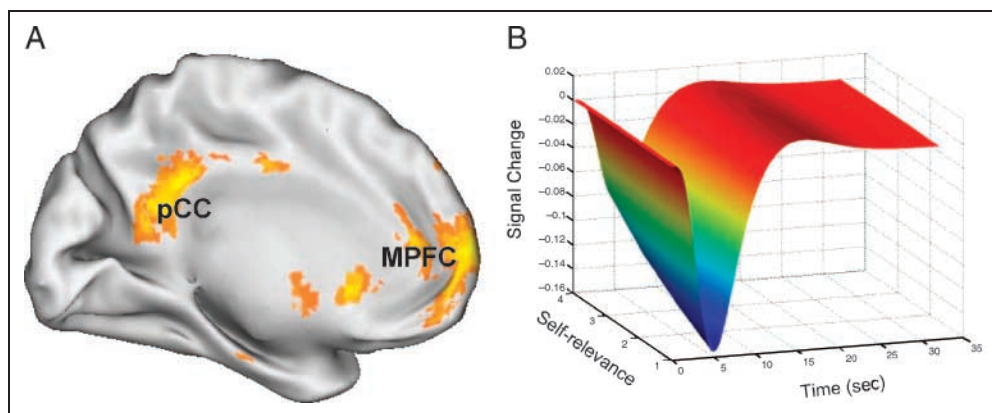
Although the vACC exhibited an interaction between self-relevance and valence, a number of additional brain regions revealed an interaction pattern that more closely matched the self-relevance by valence interaction observed in behavioral response latencies (i.e., slower reaction times when judging negative traits to be high in self-relevance and when judging positive traits to be low in self-relevance). Specifically, bilateral regions of the inferior prefrontal cortex, left BA 47: $F(1,41) = 79.5, p < .0001$; right BA 47: $F(1,41) = 29.6, p < .0001$; left BA 45: $F(1,41) = 35.8, p < .0001$; right BA 45: $F(1,41) = 27.5, p < .0001$; the dorsal anterior cingulate, BA 32: $F(1,41) = 53.0, p < .0001$; and the supplementary motor area, SMA: $F(1,41) = 53.1, p < .0001$, all demonstrated greater activity when judging positive traits to be low in self-relevance and when judging negative traits to be high in self-relevance (Figure 5).

DISCUSSION

These findings demonstrate that distinct neural circuits in adjacent regions of the prefrontal cortex subservise cognitive and emotional aspects of self-reflection. Whereas MPFC signifies the personal relevance of information, distinguishing emotional valence of this material is accomplished by adjacent vACC.

MPFC activity has been noted in many studies in which task demands encourage introspection or self-reflection (Macrae et al., 2004; Johnson et al., 2002; Kelley et al., 2002; Gusnard et al., 2001; Craik et al., 1999). In the current work, we extend these findings by demonstrating that MPFC activity during self-referencing

Figure 2. (A) An inflated cortical rendering of the left hemisphere (Van Essen et al., 2001) illustrates regions that increased their activity as a function of increasing item self-descriptiveness. The MPFC (BA 10: -9 59 5), pCC (BA 30: -3 -51 19), and bilateral caudate nuclei (left, -9 20 -1; right, 10 21 0) showed this pattern of activity. (B) Signal change (y axis) over time (x axis) in MPFC increases as a function of increasing self-relevance (z axis).



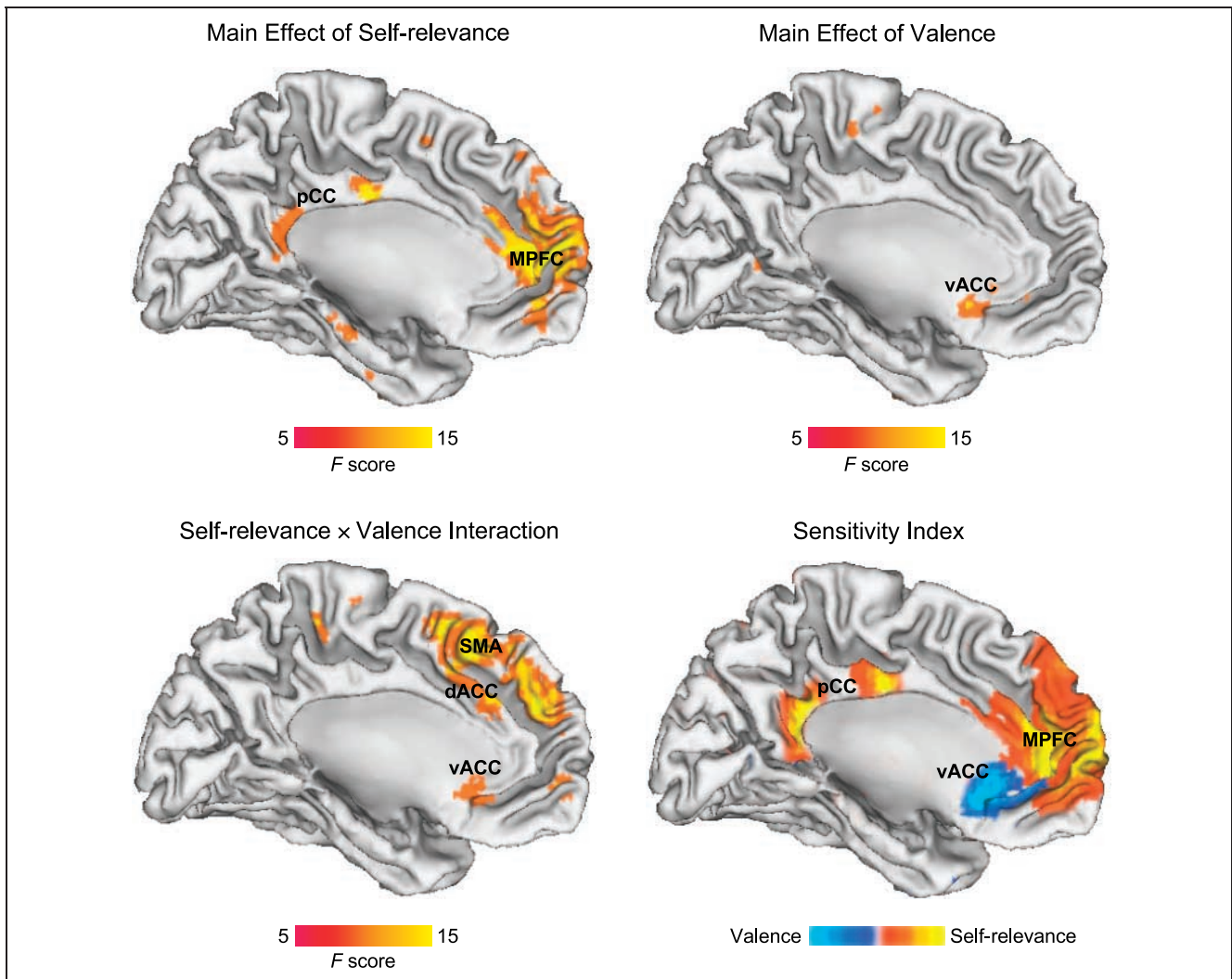


Figure 3. A voxel-by-voxel whole-brain ANOVA examining self-relevance and trait valence was used to compute F -statistical maps for each main effect and the self-relevance by valence interaction. Statistical images were superimposed on an inflated cortical rendering of the medial surface. The whole-brain ANOVA analysis revealed a main effect of self-relevance (top left) in the medial prefrontal cortex (MPFC) and posterior cingulate cortex (pCC), a main effect of valence (top right) in the ventral anterior cingulate cortex (vACC), and a self-relevance by valence interaction (bottom left) in the vACC, the dorsal anterior cingulate cortex (dACC), and the supplementary motor area (SMA). To qualitatively identify whether brain regions identified in the ANOVA analysis showed a strong bias toward one of the two main effects, a self-relevance/valence sensitivity measure (F ratio) was computed on a voxel-by-voxel basis by dividing the self-relevance F score for each voxel by the valence F score. Voxels that did not yield a significant main effect of either self-relevance or valence were excluded from further analysis to avoid spurious F ratio effects. To facilitate visualization of this sensitivity measure, F ratios were transformed to a logarithmic scale. Voxels that were more sensitive to trait valence yielded negative values (blue color scale), whereas voxels that were more sensitive to self-relevance yielded positive values (yellow color scale). Voxels at the tail end of the color scales were those voxels that exhibited the greatest bias toward trait valence and self-relevance, respectively. Voxels in the MPFC (BA 10) and two regions of the pCC (BA 29/30 and BA 23) demonstrated greater sensitivity to self-relevance, whereas voxels in the vACC (BA 25) demonstrated greater sensitivity to trait valence.

is further modulated by self-relevance. Personally relevant material engages MPFC to a greater extent than material that is judged less relevant. Inherent in such judgments, however, is an emotional evaluation. To truly isolate the effects of self-relevance, the valence of these judgments must be considered. Indeed, even when care is taken to consider valence by contrasting positive versus negative traits judged in reference to self, as was done previously by Fossati et al. (2003), such results

may still be confounded with self-relevance. As was demonstrated here and elsewhere (Taylor & Brown, 1988), subjects are more likely to endorse positive rather than negative information as self-relevant. Here, using a factorial design, we show that activity in MPFC differs solely as a function of increasing self-relevance, regardless of valence.

In the current study, pCC activity showed a similar linear relationship with increasing self-relevance that was in-

Table 1. Identification of BOLD Signal Changes Associated with the Main Effects of Self-relevance, Valence, and the Self-relevance by Valence Interaction

<i>Brain Region</i>		<i>F</i>	<i>Voxels</i>	<i>x</i>	<i>y</i>	<i>z</i>
<i>Main effect of self-relevance</i>						
BA 10	L medial frontal gyrus	22.31	373	-6	53	6
BA 23/24	Posterior cingulate gyrus	16.26	23	0	-13	31
BA 7	Superior parietal lobule	12.87	63	30	-59	50
BA 40	Superior parietal lobule	10.60	58	53	-27	46
BA 23/30	Posterior cingulate gyrus	7.51	116	-6	-49	16
<i>Main effect of valence</i>						
BA 24	Ventral anterior cingulate cortex	10.20	8	-15	35	1
BA 25	Ventral anterior cingulate cortex	8.95	4	0	17	-8
<i>Self-relevance × valence interaction</i>						
BA 47	L inferior frontal gyrus	40.53	684	-33	23	-11
BA 47	R inferior frontal gyrus	22.54	305	33	26	-14
BA 45	L inferior frontal gyrus	15.10	684	-56	15	10
BA 45	R inferior frontal gyrus	13.61	305	50	24	10
BA 9/10	Dorsal anterior cingulate cortex	12.73	480	-3	19	38
BA 6/8	Supplementary motor area	12.64	480	-3	14	49
BA 25	Ventral anterior cingulate cortex	9.40	21	9	23	-9

Activations determined to be significant are listed along with the best estimate of their location. BA = approximate Brodmann's area location. Coordinates are from the Talairach and Tournoux (1988) atlas. Locations of the activations are determined based on the functional responses superimposed on averaged anatomical MRI images and are referenced to the Talairach and Tournoux atlas.

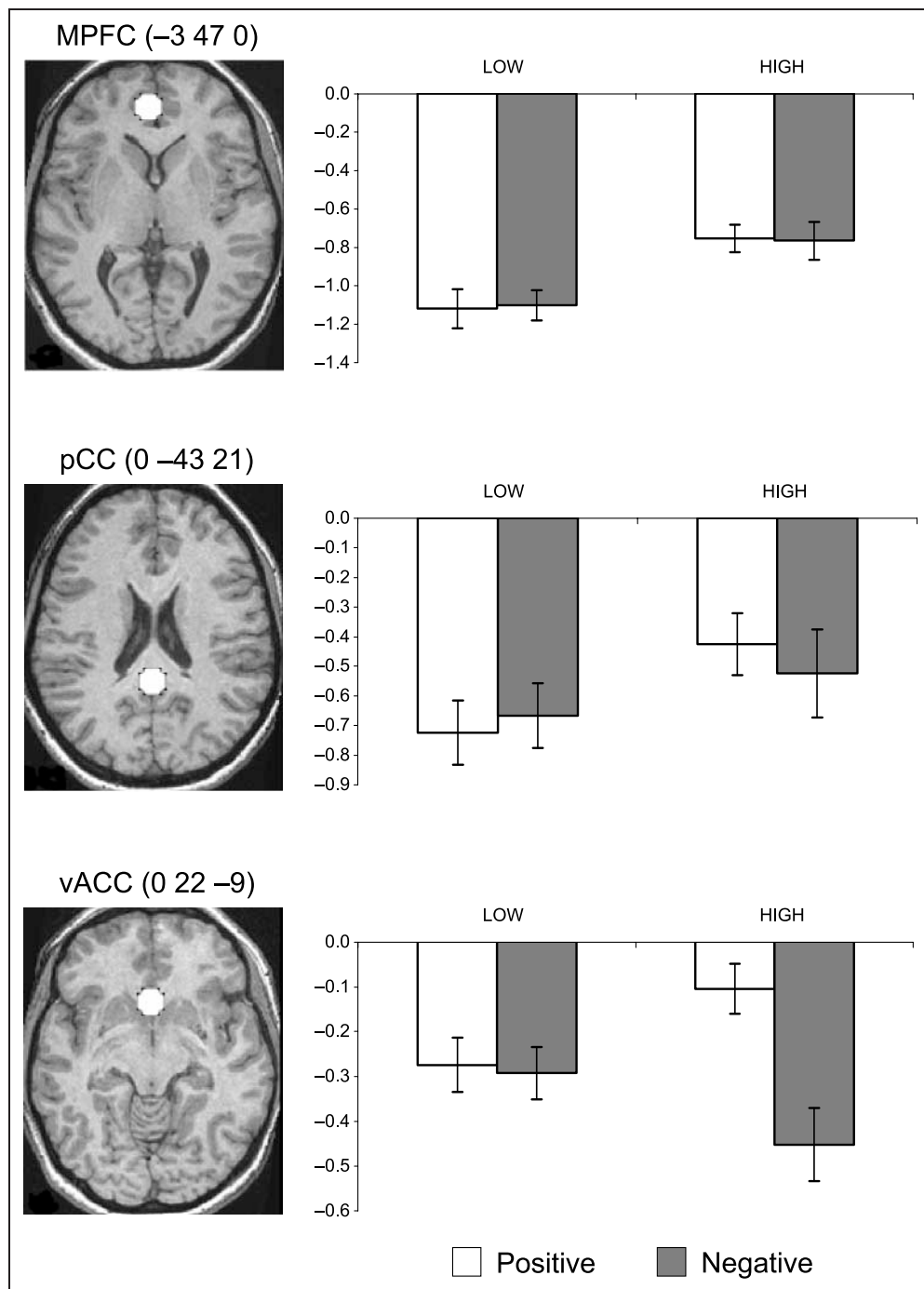
dependent of the valence of the material. Activity in pCC has been noted in a number of neuroimaging studies during tasks that permit self-referential processing (for a review, see Northoff & Bermpohl, 2004). The functional role of the pCC has been a topic of considerable interest and debate recently. Like the MPFC, the pCC appears to be part a default network of brain regions whose metabolic activity is attenuated during a variety of goal-directed external tasks (Gusnard & Raichle, 2001; Gusnard et al., 2001). Perhaps the most consistent finding with regard to pCC functioning is that activation is often observed during memory tasks that encourage episodic or autobiographical retrieval. Although a review by Maddock (1999) has suggested a specific role for a sub-region of the pCC (retrosplenial cortex) in relating episodic memories and emotions, a number of studies have argued for a more general PCC role in episodic memory (for a review, see Wagner, Shannon, Kahn, & Buckner, 2005). Specifically, Wagner et al. (2005) suggest that activity in the pCC may index differences in memory strength independent of emotional significance (e.g., remembering vs. knowing) and may function to shift attention

toward the internally generated representations that typically characterize episodic memories. The present study is not well suited to reconcile these competing hypotheses, as the valence effects reported here contrast emotionally positive to emotionally negative traits (and not to a neutral valence condition).

The caudate nucleus has not traditionally been associated with self-referential processing. However, Fossati et al. (2004) found that activity in this region was associated with successful retrieval of trait adjectives encoded with reference to the self, and behavioral studies of the self-reference effect in memory show also that subjects tend to remember self-relevant information more than irrelevant information (Rogers, Kuiper, & Kirker, 1977).

The vACC appears to play a complementary role to that of MPFC during self-referential processing. The present results indicate that when information is judged to be self-relevant, activity in the vACC will convey the valence of that information. Specifically, activity in the vACC is attenuated when unfavorable information is considered self-descriptive. Given the functional pattern

Figure 4. Axial sections display MPFC (top), pCC (middle), and vACC (bottom) spherical regions of interest superimposed on a normalized anatomic image. Graphs to the right of each image display signal change (parameter estimates) across high and low self-relevance conditions relative to the baseline fixation. Error bars indicate standard error of the mean. Activity in both MPFC and pCC was greater for traits judged to be high in self-relevance, regardless of the valence of the trait. Activity in the vACC exhibited an interaction between self-relevance and valence such that activity was greater in response to positive than to negative traits, but only when traits were judged to be self-descriptive.



of results and anatomical proximity of the MPFC and vACC, it is tempting to suggest a processing hierarchy. As information is encountered, the MPFC functions to signal its personal relevance. Information that is considered to be self-relevant is then tagged for valence via the participation of the vACC. Such a possibility awaits further investigation, but fits nicely with prior research linking hypometabolism in the vACC to unipolar depression (Buchsbaum et al., 1997; Drevets et al., 1997; George et al., 1997). Decreased metabolism in this

region can be accompanied by a corresponding loss in cortical volume (Drevets et al., 1997), suggesting that some of the deficits associated with major depression may be attributable to a loss of functioning and volume in the vACC. Indeed, depression is often characterized by a loss of interest in activities that were previously considered pleasurable (American Psychiatric Association, 1994), a symptom that may find its origin in reduced vACC functioning. Here we show that activity in this region plays a key role in denoting the valence of

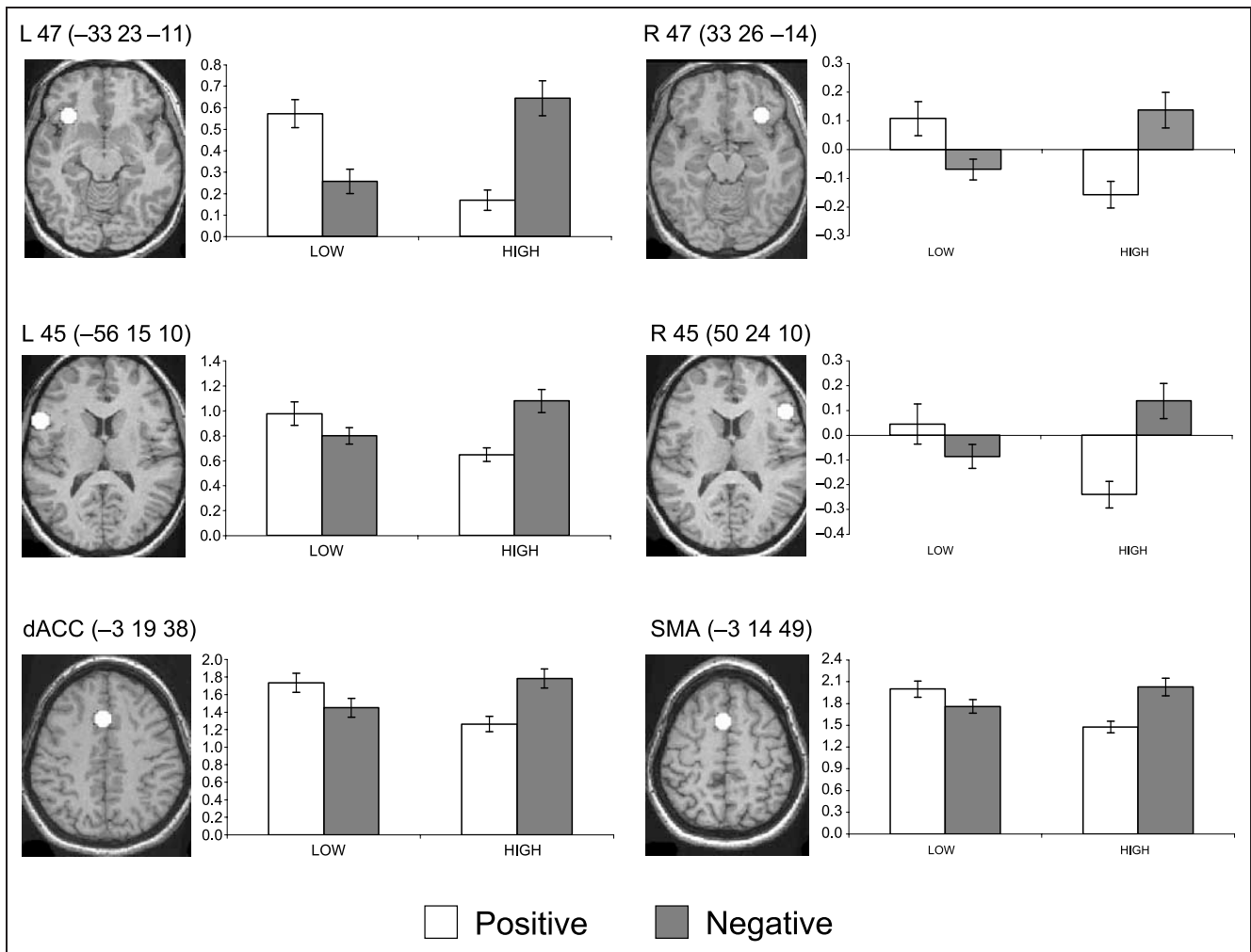


Figure 5. A number of brain regions (identified from the ANOVA interaction image) revealed a pattern of activation that mirrored behavioral response latencies. Axial sections display left and right inferior frontal cortex (L47, top left; R47, top right; L45, middle left; R45, middle right), dorsal anterior cingulate (dACC, bottom left), and supplementary motor area (SMA, bottom right) spherical regions of interest superimposed on a normalized anatomic image. Graphs to the right of each image display signal change (parameter estimates) across conditions relative to the baseline fixation. Error bars indicate standard error of the mean. Activity in each of these regions was greater when negative traits were judged to be high in self-relevance (high) and positive traits were judged to be low in self-relevance (low).

self-relevant material. A potential by-product of reduced vACC activity in depressed individuals may include a recasting of self-relevant information in an unfavorable light.

Possession of a sense of self and the ability to reflect on the contents of inner mental life are arguably uniquely human capacities (Frith & Frith, 1999). These data provide an important first step in decomposing the cognitive and emotional aspects of higher level, self-referential mental processes and offer a potential mechanism by which cognitive and affective mental operations are integrated into seamless streams of conscious thought.

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