The neural correlates of implicit and explicit self-relevant processing

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ABSTRACT

Neuroimaging investigations of self-processing have generally focused on the neural correlates of explicit self-reflection. However, very little is known about the neural basis of implicit self-related processes. We utilized the concept of self-schemas to construct a two-task fMRI study that elicited both implicit and explicit self-relevant processes. The sample consisted of 18 participants who were schematic for either athletics or science. In the implicit self-relevance task, individuals made non-self-relevant judgments about affectively neutral scientific and athletic images. In the explicit self-reference task, participants judged the self-descriptiveness of adjectives related to athletics or science. Implicit and explicit processing of self-relevant (schematic) material elicited activity in many of the same regions, including medial prefrontal cortex, posterior cingulate/precuneus, ventromedial prefrontal cortex, subgenual anterior cingulate, amygdala, and ventral striatum. We suggest that processing self-related material recruits similar neural networks regardless of whether the self-relevance is made explicit or not.

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Within the past decade, investigations of the neural basis of self-knowledge have yielded a remarkably consistent body of evidence. In particular, an assortment of neuroimaging studies has convincingly demonstrated that cortical midline structures are implicated in self-referential thought and self-reflection (Lieberman, in press; Northoff et al., 2006). The medial surface of the prefrontal cortex and precuneus/posterior cingulate cortex (precuneus$_{PCC}$) have been shown to be engaged during tasks which involve relatively unstructured self-reflection (D'Argembeau et al., 2005; Kjaer, Nowak, and Lou, 2002), as well as tasks which require making specific judgments about one's own traits compared to judgments of others or semantic judgments (Craik et al., 1999; Gusnard et al., 2001; Heatherton et al., 2006; Johnson et al., 2002; Kelley et al., 2002; Moran et al., 2006; Zysset et al., 2002). A recent review (Lieberman, in press) identified the medial prefrontal cortex (MPFC, Brodmann's area [BA] 10) as a particularly significant region for processing self-related information, as 94% of the self-processing studies reviewed evinced activation in this area. Precuneus$_{PCC}$ and dorsomedial prefrontal cortex (dMPFC) were the next most frequently observed regions at 63% and 53%, respectively.

These investigations all utilized paradigms that involved explicit forms of self-reflection, and commonly asked participants to judge whether a broad variety of adjectives were self-descriptive. However, the extent to which such paradigms capture the kinds of self-related processing that occurs in everyday life remains unclear, because it is relatively unusual that one is directly asked about one's personality or abilities. Rather, self-reflection of the variety that these experiments instantiate probably takes place relatively infrequently — for example, in therapy, writing a resume, or becoming acquainted with a new individual. As noted by Devos and Banaji (2003), it has been commonly assumed that studying the self primarily involves measuring reflective self-consciousness, with knowable and accessible goals, motivations, and cognitions. However, studies of "unconscious modes of thinking and feeling, when applied to self and identity processes, question these assumptions, and they do so based on the discovery of mental acts that are fully meaningful and lawful but that appear to arise without introspective access or deliberative thought" (p. 153).

Much of the contemporary research on the self has relied less on explicit evaluations of the self and instead examined aspects of the implicit self-concept, which has been found to have profound effects on life decisions, such as career choice (Pelham et al., 2005). In keeping with this behavioral literature, we broadly define implicit self-processing as associations about the self that are relatively automatic and occur below the level of conscious awareness. These forms of implicit self-knowledge and self-evaluation may better reflect the operation of self-processes in everyday life (Bargh and Barndollar, 1996; Fitzsimons and Bargh, 2004). For example, when flipping through television channels, one usually does not explicitly ask oneself: "Am I a funny person who likes comedies or a serious person who prefers documentaries?" Instead, one's implicit self-knowledge guides one's behavior to make an appropriate selection in a way that is adaptive, automatic and below the level of awareness.

To our knowledge, only one neuroimaging study has attempted to examine implicit self-processing (Moran et al., 2009). In this study,

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participants completed a color oddball task in which the experimenters manipulated whether text stimuli were self-related or not. The cover story informed participants that self-related stimuli (hometown, initials, parent's name, etc.) were included to make the task more interesting. Compared to control stimuli, self-related information activated MPFC, dMPFC and posterior cingulate, areas previously associated with explicit self-processing. However, although this task was intended to solely elicit implicit processing, it is possible that the nature of the stimuli employed in the study may have also unintentionally instigated explicit self-processes. Most prominently, the fact that the stimulus materials were directly and obviously related to the self may have encouraged spontaneous explicit self-reference regardless of instructions. For example, seeing the name of one's pet might cause an explicitly self-referential reaction such as, "Hey — that's my dog!" which might also lead to further explicit self-related processes ("I wonder when I will be done with this so I can take Fido for a walk"). While this study represents a commendable first step towards isolating the neural regions associated with implicit self-processing, it seems clear that additional research utilizing novel methodologies is needed to confirm and expand these initial findings.

The current study attempts to identify the neural regions involved in implicit self-processing while avoiding some of the limitations of previous work. To construct such a task, we drew upon the behavioral literature examining self-schemas (Markus and Wurf, 1987). Possessing a self-schema for a particular domain is effectively equivalent to being highly identified with the domain (Markus, 1977). Previous neuroimaging research has already identified regions associated with explicit self-schematic processing (e.g., actors responding to acting words), including ventromedial prefrontal cortex (vMPFC, BA 11), ventral striatum, amygdala, and precuneus$_{PCC}$ (Lieberman et al., 2004). However, employing self-schematic materials also provides an ideal means of inducing implicit self-processing by exposing participants to pictorial stimuli that are inherently self-relevant while avoiding explicit forms of self-reference. Thus, the current study seeks to expand upon the previous investigation through the inclusion of an additional task that specifically targets implicit self-schematic processes through such presentations.

For this study, we recruited individuals who were self-schematic for either athletics or science, but not both. We chose two domains in order to increase generalizability of the results and to provide a neutral control condition. The study consisted of two tasks. The *implicit self-relevance task* was designed to instantiate implicit self-processing through exposure to self-relevant (schematic) material. In this task, participants viewed a series of affectively neutral images related to science and athletics and made a non self-referential judgment about each ('is there a person in the image?'). The *explicit self-reference task* was designed to isolate the neural correlates of explicit self-reflection associated with schematic processing. In this task, participants judged the self-descriptiveness of a series of positive and negative adjectives related to science and athletics.

We were specifically interested in testing whether the same neural structures that were involved in the explicit processing of schematic content would be recruited during implicit processing of schematic material. In other words, does the implicit processing of self-schematic material activate the network previously shown to be associated with self-schematic processing, more traditional self-reflection regions, or neither?

Method

Participants

We recruited 18 healthy, right-handed, non-claustrophobic UCLA undergraduate students from the Psychology participant pool, classroom announcements, and campus fliers. Individuals are considered self-schematic for a particular domain if they believe themselves to be extreme on a dimension that is important to their self-concept (Markus, 1977). Therefore, to assess schematicity, potential participants rated the adjectives "scientific" and "athletic" on their descriptiveness and importance to self-concept on a scale from 1 (*not at all*) to 11 (*very much*). The two ratings for each adjective were averaged to create independent indices of athletic and scientific schematicity and individuals who scored above 8 on one domain and below 4 on the other were eligible to participate. Participants were given either course credit or $25 as compensation. This study was approved by and conducted in compliance with UCLA's institutional review board.

1 participant was excluded due to excessive head motion during scanning which resulted in a final fMRI dataset of 17 (4 male, 9 athletes, mean age = 19.5). Equipment failure resulted in the loss of behavioral data for another participant, therefore behavioral analyses were conducted on 16 individuals (4 male, 9 athletes, mean age = 19.4).

Implicit self-relevance task

Procedure

In this event-related task, participants viewed a series of 88 affectively neutral athletic and scientific images for 3 s each and judged whether each image contained people or not. This instruction was intended to prevent explicit self-reference and ensure equal attendance to all images. Null events of the same duration were included in order to obtain a measure of baseline neural activity as well as enable estimation of the hemodynamic response. The stimuli were presented in two runs of 198 s and presentation order was determined using OptimizeDesign (Wager and Nichols, 2003). The implicit task was run first in order to avoid any potential self-related priming from the explicit schematic self-reflection task.

Materials

Images were chosen that were representative of their respective categories, low in arousal, and of neutral valence. Half of the images from each category depicted people and half depicted inanimate objects. A wide range of exemplars was included in order to make sustained explicit self-reference implausible, because participants were unlikely to have a range of experience equal to the breadth of the material. For example, athletic images included depictions of basketball, football, lacrosse, tennis, track and field, swimming, baseball, hockey, water polo, and weight lifting. Scientific images encompassed the fields of biological science, chemistry, mathematics, physical science, earth science, computer science, and social science. See the Methodological details portion of the online Supplementary materials for further information.

Explicit self-reflection task

Procedure

In this mixed-design task, participants viewed 40 scientific and 40 athletic adjectives and judged whether each adjective was self-descriptive by responding "me" or "not me" as quickly as possible. Half of the adjectives within each domain were positively related to the domain (e.g., "sporty" for athletics), and half were negatively related (e.g., "flabby"). Adjectives were presented for 3 s each within alternating domain-specific blocks of 30 s in length. Each block was separated by 18 s of rest. Forty null events of 3 s in duration were inserted within blocks to allow for separate estimation of the hemodynamic response to the four conditions (positive athletic, negative athletic, positive scientific, negative scientific). Stimuli were presented in two runs of 288 s each, comprised of 6 blocks of trials and 6 rest periods. Trial order was determined using OptimizeDesign

(Wager and Nichols, 2003) in order to optimize the estimation of the hemodynamic response.

Materials

Positive and negative athletic and scientific words were rated as representative of their respective categories and matched on valence, number of syllables, familiarity, and approximately equated on word length (http://www.psy.uwa.edu.au/mrcdatabase/uwa_mrc.htm). For additional detail, see Methodological details in the online Supplementary materials.

Image acquisition

Functional magnetic resonance imaging (fMRI) was performed on an Allegra 3 T head-only scanner. Both tasks employed identical fMRI protocols with the exception of the number of image acquisitions, which was determined pursuant to each run's duration. Functional images were acquired using an EPI gradient-echo sequence (TR = 2000 ms, TE = 25 ms, 3 mm slice thickness/1 mm gap, FOV = 20 cm, matrix = 64×64, flip angle = 90°, 36 slices). A T2-weighted structural image was acquired coplanar with the functional images (TR = 5000 ms, TE = 33 ms, 3 mm slice thickness/1 mm gap, FOV = 20 cm, matrix = 128×128, flip angle = 90°, 36 slices).

Data analysis

Functional images were realigned to correct for head motion, normalized into standard stereotactic space as defined by the Montreal Neurological Institute, resliced into voxels of 2 mm^3 and smoothed with an 8 mm (full width half maximum) Gaussian kernel to increase signal-to-noise ratio. First level effects were estimated using the general linear model and employing a canonical hemodynamic response function convolved with the experimental designs. Low-frequency noise was removed using a high-pass filter of 128 s. Group analyses were conducted using random-effects models in order to enable population inferences (Friston et al., 1999). Image preprocessing and data analysis was performed using Statistical Parametric Mapping 5 (SPM5; Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK; http://www.fil.ion.ucl.ac.uk/spm). Whole-brain group-level analyses were performed using an uncorrected *p*-value of <.005 with a cluster size threshold (*k*) of 15 voxels (Forman et al., 1995; Lieberman et al., 2009).

Results

Explicit self-reflection task

Behavioral results

Consistent with previous research (Markus, 1977), a 2×2 repeated-measures ANOVA using within-subjects factors of word type (schema and nonschema) and valence (positive and negative) revealed that participants responded faster to schematic words than nonschematic (*M* = 1249 ms v. 1307 ms), *F*(15) = 6.18, *p*<.05 (see Fig. 1). There was no effect of valence on reaction time *F*(15) = .64, *p* = *ns*. A trend was observed in the interaction of word type and valence *F*(15) = 3.97, *p* = .07. Investigating this trend, we found that participants responded faster to positive words in their schematic domain than their nonschematic (*M* = 1243 ms v. 1334 ms), *t*(15) = 2.68, *p*<.05, but there was no difference between the two domains for negative words (*M* = 1254 ms v. 1276 ms), *t*(15) = .95, *p* = *ns*.

A second repeated-measures ANOVA using percentage of adjectives endorsed as the dependent variable confirmed two main effects. Participants endorsed more positive than negative words (*M* = 61% v. 21%), *F*(15) = 45.32, *p*<.001, and more schematic than nonschematic words (*M* = 46% v. 36%), *F*(15) = 8.06, *p*<.05 (see Fig. 2). As expected, these effects were qualified by an interaction between valence and
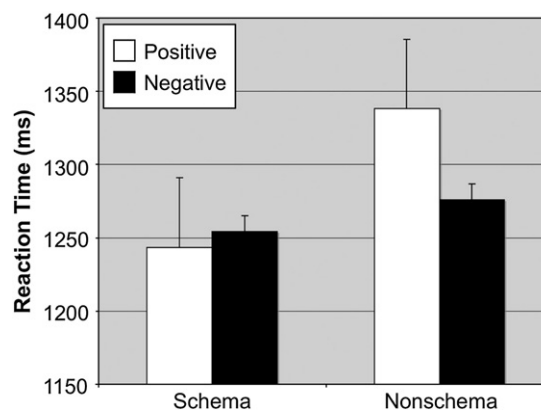

Fig. 1. Reaction times for schematic and nonschematic words. A main effect of word type was observed such that participants responded faster to words in their schematic domain compared to their nonschematic (*p*<.05). Participants were faster to respond to positive words in their schematic domain compared to their nonschematic (*p*<.05), but this was not true for negative words (*p* = *ns*).

word type *F*(15) = 33.06, *p*<.001, such that participants were more likely to endorse positive words in their schematic domain than their nonschematic (*M* = 75% v. 46%), *t*(15) = 5.00, *p*<.001, and less likely to endorse negative words in their schematic domain than their nonschematic (*M* = 16% v. 25%), *t*(15) = 2.40, *p*<.001.

fMRI results

Trials were sorted by both domain and valence because positive and negative words likely differ in their cognitive, affective, and neural consequences (Ochsner et al., 2005). We focus here on contrasts utilizing positive words, because prior research (Lieberman et al., 2004) used positive adjectives and because their interpretation is the most straightforward. The Additional analyses portion of the online Supplementary materials details analyses involving negative stimuli.

For this task, we were primarily interested in how neural responses to processing information in one's schematic domain differ from processing information in one's nonschematic domain. We therefore performed a whole-brain regression analysis that contrasted positive scientific word trials with positive athletic trials and included as a regressor the difference between participants' scientific and athletic schematicity scores (described under 'Participants'). This is comparable to a main-effects analysis (i.e., schematic–nonschematic) but is both more appropriate and yields greater power because
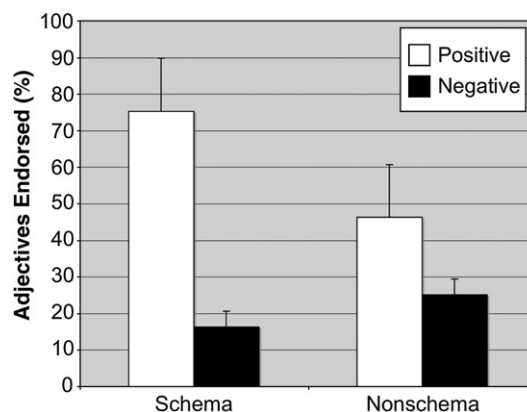

Fig. 2. Endorsement rates for schematic and nonschematic words. Participants endorsed more positive than negative words regardless of schematic domain (*p*<.001). However, an interaction was evident such that participants endorsed more positive words in their schematic domain than their nonschematic, and fewer negative words in their schematic domain compared to their nonschematic (*p*<.001).
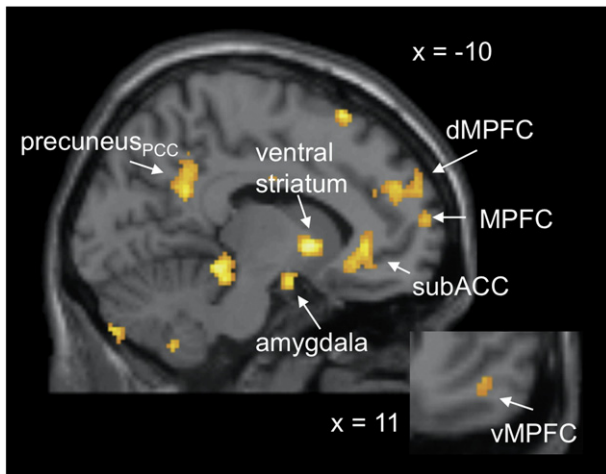
Fig. 3. Neural correlates of explicit self-relevant processing. Regressing the difference between scientific and athletic schematicity onto the contrast of positive scientific word trials − positive athletic word trials revealed activity in dMPFC, MPFC, vMPFC, precuneus$_{PCC}$, amygdala, ventral striatum, and subACC.

it utilizes the observed variance in self-reported identification (MacCallum et al., 2002). Consistent with previous research (Lieberman et al., 2004), this analysis revealed activity in vMPFC, precuneus$_{PCC}$, amygdala, and ventral striatum. Additionally, activity was observed in MPFC, dMPFC, and subgenual anterior cingulate (subACC; see Fig. 3 and Table 1).

Implicit self-relevance task

Behavioral results

As intended, participants were highly accurate in judging whether images contained people ($M = 96.6\%$, $SD = 4.1\%$). Accuracy of

Table 1
Regions associated with explicit processing of self-relevant information. The difference between scientific and athletic schematicity was regressed onto the contrast of positive scientific word trials compared to positive athletic word trials. Note: where the number of voxels is not specified, the activation is a subcluster of the preceding cluster.

| Region	Hemisphere	Coordinates			No. of voxels	t
		x	y	z		
Precuneus$_{PCC}$	Left	−2	−44	34	802	6.55
	Right	8	−48	30		4.79
Ventral striatum	Left	−10	8	0	449	5.86
	Right	4	8	0		5.45
Amygdala	Left	−16	−4	−24		4.37
Parahippocampal gyrus	Left	−16	−28	−18		4.32
Dorsal striatum	Left	−18	12	8	24	3.87
MPFC (BA 10)	Right	18	54	8	48	3.58
	Left	−14	64	14	38	3.84
	Right	8	56	−2	48	3.91
vMPFC (11)	Right	12	52	−10		3.37
dMPFC (BA 8)	Right	4	40	54	27	3.78
dMPFC (BA 9)	Left	−24	50	28	497	4.58
	Right	12	56	44	17	3.61
SubACC (BA 32)	Left	−8	34	−2	305	5.26
Superior frontal gyrus	Left	−18	18	64	191	5.26
Inferior frontal gyrus	Right	50	28	−10	81	4.82
	Left	−44	30	2	47	4.68
Superior occipital gyrus	Right	28	−84	46	111	4.08
Middle occipital gyrus	Left	−36	−80	34	383	4.06
Middle frontal gyrus	Left	−36	22	32	244	5.00
Mid-cingulate	Left	−6	−6	34	24	3.85
Inferior temporal gyrus	Left	−40	−50	−10	218	6.76
Middle temporal gyrus	Right	60	−46	−4	26	3.79
	Left	−62	−10	−12	31	3.74
Caudate	Right	16	20	2	19	3.56
Cerebellum	Left	−14	−88	−40	127	5.40
	Right	18	−74	−32	21	4.43
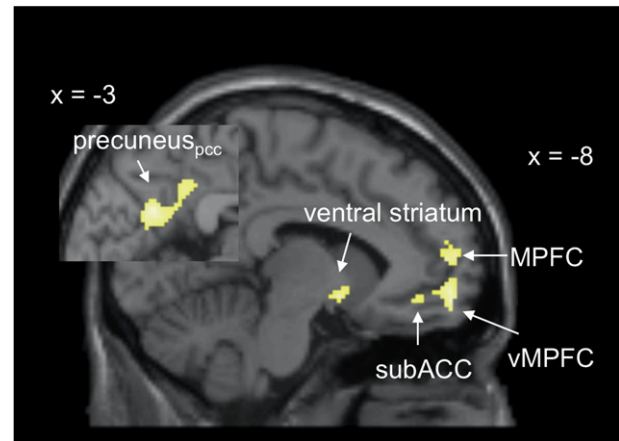
Fig. 4. Neural correlates of implicit self-relevant processing. Regressing the difference between scientific and athletic schematicity onto the contrast of scientific image trials − athletic image trials resulted in activity in MPFC, vMPFC, precuneus$_{PCC}$, ventral striatum, and subACC.

responses did not differ for athletic and scientific images ($M = 96.2\%$ v. 96.7%), $t(15) = .78$, $p = ns$, nor did reaction time ($M = 769$ ms v. 765 ms), $t(15) = .3$, $p = ns$. Participants were no more accurate in their schematic domain than their nonschematic ($M = 96.3\%$ v. 96.6%), $t(15) = .38$, $p = ns$, nor were they faster ($M = 759$ ms v. 775 ms), $t(15) = 1.28$, $p = ns$. Accuracy did not vary between images with people and those without ($M = 96.6\%$ v. 94.6%), $t(15) = 1.61$, $p = ns$), although participants were faster to respond to images with people ($M = 727$ ms v. 807 ms), $t(15) = 4.55$, $p < .001$.

fMRI results

We were principally interested in identifying regions that responded more when participants were processing information in their schematic compared to their nonschematic domain. Thus, as with the explicit self-reflection analysis, we performed a regression that contrasted scientific and athletic image trials and included as a regressor each participant's scientific and athletic schematicity difference score. This analysis revealed activity in many of the same regions observed in the explicit task, including precuneus$_{PCC}$, vMPFC, MPFC, ventral striatum, and subACC, (see Fig. 4 and Table 2). Because activity in the left amygdala was observed during the explicit task and it was an a priori region of interest (ROI), we used Marsbar to conduct an ROI analysis of this area (Brett et al., 2002). Using a functional amygdala mask derived from the activity during the explicit self-reflection task (thresholded at $p < .001$), this ROI analysis revealed significant activity ($t = 2.78$, $p < .01$). For the results of other analyses,

Table 2
Regions associated with the implicit processing of self-relevant information. The difference between scientific and athletic schematicity was regressed onto the contrast comparing scientific image trials to athletic image trials. Note: where the number of voxels is not specified, the activation is a subcluster of the preceding cluster.

| Region	Hemisphere	Coordinates			No. of voxels	t
		X	y	Z		
Precuneus$_{PCC}$	Left	−2	−60	24	373	3.79
	Right	10	−50	30		3.64
vMPFC (BA 11)	Left	−14	54	−14	219	4.14
MPFC (BA 10)	Right	4	58	−8		3.98
MPFC (BA 10)	Left	−8	58	−6		3.69
	Left	−12	58	14	62	4.15
Ventral striatum	Left	−10	6	−8	36	3.74
SubACC (BA 32)	Left	−12	42	−8	29	3.64
	Left	−6	20	−12	18	3.62
Parahippocampal gyrus	Left	−20	−20	−24	35	3.84
Inferior temporal gyrus	Right	48	−56	−20	63	4.06
Inferior occipital gyrus	Right	40	−80	−2	35	3.85
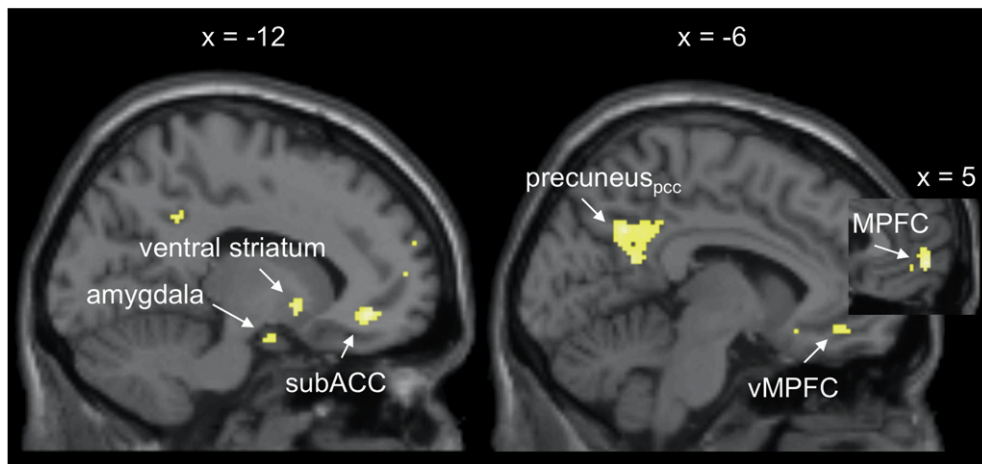
Fig. 5. Neural overlap during implicit and explicit self-relevant processing. Implicit and explicit processing of self-relevant information show overlapping areas of neural activity, including MPFC, vMPFC/subACC, precuneus_PCC, amygdala, and ventral striatum.

please see the Additional analyses portion of the online Supplementary materials.

Joint implicit/explicit analyses

In order to identify regions that were commonly activated by implicit and explicit processing, we recomputed the results of the implicit analysis, using a threshold of $p < .01$ and employing a mask of the activity during the explicit task, also thresholded at $p < .01$. This analysis results in a map of regions commonly activated in both tasks, with a joint probability of $p < .001$ that a given region would be activated in both (Kampe et al., 2003; Ochsner et al., 2009). Common activity was observed in MPFC, precuneus_PCC, ventral striatum, amygdala, and a cluster that encompassed both vMPFC and subACC (see Fig. 5 and Table 3). Additionally, a whole-brain mask composed of all neural activity during explicit self-reference was created. Using Marsbar, we examined the average activity across all of the voxels in this multi-region mask during the implicit self-reference task and found greater average activity in response to pictures from the schematic, relative to the nonschematic, domain ($t = 2.31$, $p < .05$).

We were also interested in whether the regions that showed joint activity between the explicit and implicit tasks might also evince within-region correlations across the tasks. To this end, we created separate masks derived from the joint activity observed in the previous analysis for MPFC, precuneus_PCC, vMPFC/subACC, amygdala, and ventral striatum. We then re-ran the implicit and explicit self-processing analyses separately with these masks, in order to restrict the results to commonly activated regions. We extracted the mask-averaged parameter estimates for each of these regions individually and then computed within-region correlations across the two tasks. It is worth noting that while we expect all the parameter estimates to be

relatively large and positive (because voxels were taken from the results of group-level analyses), it does not necessarily follow that the magnitude of the response would be correlated across participants for a given region. In other words, this analysis is designed to show whether that the extent to which a participant activates a given region in the implicit task is correlated with the extent to which the same participant activates the same region in the explicit task. Correlations were significant for all regions, namely MPFC $r(15) = .56$, $p < .05$, precuneus_PCC $r(15) = .60$, $p < .05$, vMPFC/subACC $r(15) = .52$, $p < .05$, amygdala $r(15) = .50$, $p < .05$, and ventral striatum $r(15) = .75$, $p < .01$, see Fig. 6. This suggests that participants who activate one of these regions more when doing explicit self-reflection also tend to activate the same region more when exposed to self-relevant stimuli without explicit reference to the self.

Discussion

One of the major goals of the present research was to investigate whether explicit and implicit forms of self-processing result in the recruitment of similar neural networks. This research question is rooted within a larger tradition of social cognition research, which has often found that implicit and explicit measurement of self-related concepts (e.g., self-esteem, personality traits, attitudes) tend to show weak or inconsistent correlations with each other (Hofmann et al., 2005). Furthermore, some research has shown that implicit and explicit measures dissociatively predict unique behaviors (Spalding and Hardin, 1999). For example, an implicit measure of shyness uniquely predicted spontaneous shy behavior (such as nonverbal body language), while an explicit measure of shyness uniquely predicted controlled shy behavior like speech (Asendorpf et al., 2002).

The mechanisms that underlie these divergences remain unclear. Some researchers have argued that implicit measures tap into 'true' beliefs or attitudes, while explicit measures include contaminates such as social desirability and self-presentation (Fazio et al., 1995; Greenwald et al., 1998). In contrast, others have argued that these divergences reflect the presence of two relatively independent evaluative systems that serve complementary but discrete roles, similar to the distinction between implicit and explicit motor learning (e.g., Wilson and Dunn, 2004; Wilson et al., 2000). If it is the case that implicit and explicit self-processing constitute two independent systems, one might expect to observe a dissociation in the brain such that different neural networks are recruited during the two kinds of processing (Lieberman, in press).

Perhaps surprisingly, our results suggest that processing self-relevant information engages roughly the same neural structures regardless of whether it is done in an implicit or explicit manner. We

Table 3
Regions commonly activated by implicit and explicit self-relevant processing. This joint map reflects the implicit regression analysis thresholded at $p < .01$ and masked by the results of the explicit regression analysis thresholded at $p < .01$. Note: where the number of voxels is not specified, the activation is a subcluster of the preceding cluster.

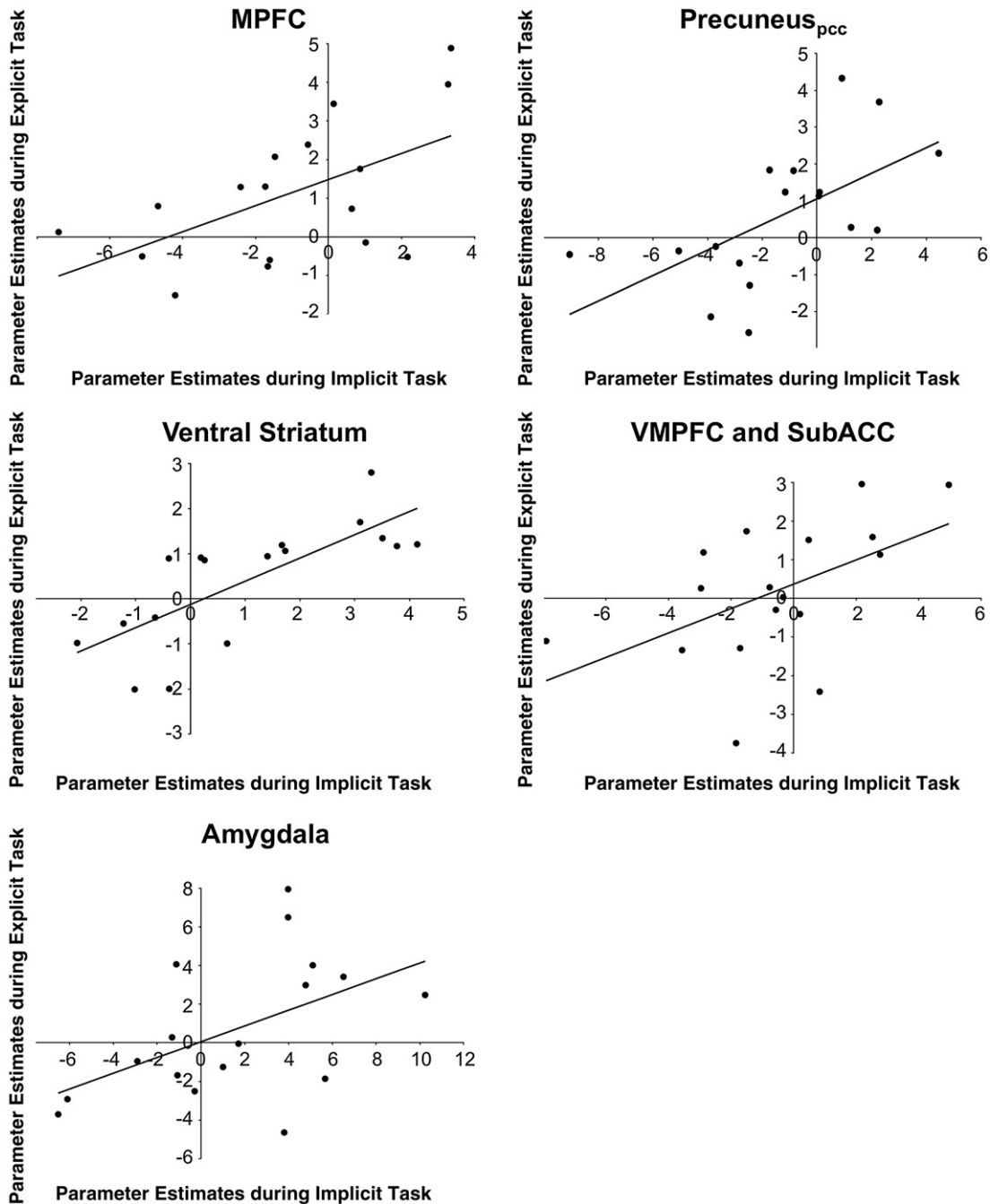| Region	Hemisphere	Coordinates			No. of voxels	t
		x	y	Z		
Precuneus_PCC	Right	10	−50	30	380	3.64
	Left	−6	−58	34		3.58
vMPFC/subACC	Left	−12	42	−8	70	3.64
MPFC	Right	4	58	−8	50	3.98
	Left	−10	60	12	13	3.90
Ventral striatum	Left	−12	8	−4	24	3.33
Amygdala	Left	−14	−6	−20	17	3.18

Fig. 6. Within-region correlations across implicit and explicit processing. Neural activity during explicit processing of self-relevant information was positively associated with activity during implicit processing of self-relevant information in MPFC $r(15) = .56$, $p<.05$, precuneus$_{PCC}$ $r(15) = .60$, $p<.05$, ventral striatum $r(15) = .75$, $p<.01$, vMPFC/subACC $r(15) = .52$, $p<.05$, and amygdala $r(15) = .50$, $p<.05$.

found that both modes commonly recruited precuneus$_{PCC}$, MPFC, vMPFC, ventral striatum, subACC, and the amygdala. Furthermore, implicit and explicit self-processing not only recruited the same general regions, but actually demonstrated considerable specific neural overlap across the two tasks. In addition, all of these regions also demonstrated a strong correlation across the two tasks. These results suggest that implicit and explicit self-processing both rely on many of the same neural structures and utilize them in similar ways.

While these results may seem discordant with a social psycholog- ical literature that has largely emphasized the independence of implicit and explicit processes, more recent evidence suggests that they may be more strongly associated than previously suspected (Hofmann et al., 2005). This meta-analysis investigated correlations

between explicit self-report measures and the implicit association test and found a small but significant positive association between the two (mean effect size of .24). In addition, almost half of the variability across correlations was due to the effect of moderator variables, such as the conceptual correspondence of the two measures. It is therefore perhaps not surprising that our implicit and explicit tasks, which were conceptually quite similar, instantiated activity in common neural networks.

Our results are also consistent with the theoretical position advanced by Northoff and Bermpohl (2004), in which they argue that vMPFC (defined by the authors as the ventromedial portion of BA 10 as well as BA 11 and 12) is responsible for tagging incoming information as self-relevant while dMPFC (defined as the dorsomedial

portion of BA 10 and medial BA 9) functions to cognitively evaluate self-relevant information. According to this model, one would expect vMPFC to be engaged during both the implicit and explicit tasks because both require the tagging of information as self-relevant, which is indeed what we found. In contrast, only the explicit task calls for effortful evaluation of the material, and so one would expect that this task would uniquely engage dMPFC (Satpute and Lieberman, 2006), which is also consistent with our results.

Our findings also share points of convergence and divergence with the only other study attempting to compare implicit and explicit self-processing modes (Moran et al., 2009). Although that study also found that implicit self-processing was associated with activity in precuneus$_{PCC}$ and MPFC (BA 10), they also observed dMPFC (BA 9) during implicit processing but not during explicit. The current study found precisely the opposite pattern, such that dMPFC was active during explicit, but not implicit, processing. We also observed activity in vMPFC (BA 11) during both explicit and implicit self-relevant processing, which had not been previously reported.

There are some potential limitations of the current study that bear mention. Because reaction times were faster for the schematic words than the nonschematic during the explicit self-reflection task, the possibility exists that some activity in this contrast might be partly the result of greater time spent in default mode processing during the schematic trials. However, this possibility seems remote due to the small magnitude of the reaction time difference. On average, participants responded to positive schematic words only 91 ms faster than positive nonschematic words. Over 20 trials, the schematic condition accrued only 1.82 more seconds of default processing time compared to the nonschematic (out of a total of 60 s). It therefore seems extremely unlikely that this negligible time difference is responsible for the majority of the observed effects.

Another limitation of the current study concerns the difficulty inherent in ensuring that participants did not engage in explicit self-reflection during the implicit task. We attempted to preclude explicit self-reflection through multiple features of the study's design. First, we directed participants to engage in a non self-referential task (judging whether each image had people in it or not). Additionally, the fact that the images depict such a large breadth of material makes it likely that the majority of images, even in one's schematic domain, would be only loosely relevant to the self for each participant. For example, a psychologist (who identifies as a scientist) would be unlikely to view an image of a test tube and explicitly think, "that's a 'me' object." Rather, the images in the schematic domain link to the self in a more automatic and implicit manner through one's association with the schematic domain. Nonetheless, future studies (such as a replication of the current study but with the addition of cognitive load) would be helpful in eliminating this possibility.

It is worth noting that the use of self-schemas as a conceptual framework for comparing implicit and explicit self-processing resulted in the activation of several regions that are not generally associated with self-reflection, namely the amygdala, ventral striatum, vMPFC, and subACC. Instead, these regions are typically associated with affective processing. The activation of these regions during both implicit and explicit processing of self-relevant material (compared to non self-relevant material) suggests that participants processed what would otherwise be neutral information in an affective manner due to the nature of its self-relevance. Domains about which we feel strongly and with which we identify are likely to play particularly important roles in our lives, and as of yet have remained a relatively unexplored topic in the literature of the neural basis of self-knowledge.

These results also underscore the highly subjective manner in which we experience and make sense of the world. In this study, the way in which a participant processed a particular stimulus depended largely upon his or her own personal characteristics (i.e., schema), rather than upon any objective property of the stimulus per se. The observation that neutral self-relevant stimuli were processed in an affective manner highlights the fact that many stimuli do not inherently possess the properties we perceive, but rather are imbued with value and meaning that are unwittingly determined by their perceiver. As Asch (1952) observed, "Although phenomenally we see objects directly, with no process intervening, objectively the process is mediated…. the object in the environment and our experience of it are two distinct, though related, events" (p. 47). Psychology has a long history of examining how we each construe the world differently from one another based on our existing associations and expectations, and this investigation provides an illustration of the way in which this subjective construal can be observed at the neural level.

Acknowledgments

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.neuroimage.2009.12.098.

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