

basis for the concrete self-construct developed in early childhood (Dyl & Wapner, 1996; Montemayor & Eisen, 1977). Loss of material possessions through theft or damage or the need sell sentimental objects when moving into a nursing home can be devastating and experienced as a loss of self (Cram & Paton, 1993; Pierce et al., 2003). Given the significance of material objects to the development and maintenance of our sense of self, it is important to understand how these associations are formed and the resultant impact they exert on cognition and behavior.

As a result of their association with self, owned objects are believed to enjoy a special psychological status (Beggan, 1992). Indeed, owned objects are viewed as extensions of self, as Sartre states, “I am what I have...What is mine is myself” (Sartre, 1943/1969, pp. 591–592; see also James, 1890). This is further illustrated by the “mere ownership” effect, a tendency for objects arbitrarily assigned to self (i.e., owned but not chosen by self) to be imbued with more positive characteristics (Beggan, 1992; Belk, 1988, 1991) and to be perceived as more valuable (i.e., the endowment effect; Kahneman, Knetsch, & Thaler, 1991; Knetsch & Sinden, 1984) and subsequently more memorable than identical items not assigned to self (Van den Bos, Cunningham, Conway, & Turk, 2010; Cunningham, Turk, & Macrae, 2008). This skewing of value and valence reflects the operation of positivity biases that distort the evaluation of material possessions that comprise an important element of self (Beggan, 1992; Belk, 1988, 1991; Kahneman et al., 1991; Knetsch & Sinden, 1984).

Notwithstanding the observation that we are what we own, recent neuroimaging investigations have focused on the effect of explicit, evaluative self-referential encoding on memory. In the most widely used paradigm (Turk, Cunningham, & Macrae, 2008; Heatherton et al., 2006; Macrae, Moran, Heatherton, Banfield, & Kelley, 2004; Kelley et al., 2002; Rogers, Kuiper, & Kirker, 1977; see Symons & Johnson, 1997, for a review), participants are required to evaluate personality traits on the degree to which they describe either self or a familiar other person (e.g., *George W. Bush*, *Angelina Jolie*). When memory for the trait words is subsequently assessed, those encoded in relation to self are better remembered than those processed in the context of a familiar other. This so-called self-reference effect is a reliable phenomenon that has been reported in a range of experimental settings (see Symons & Johnson, 1997).

Psychological ownership, therefore, offers an alternative route to study self through its association with objects. Cunningham et al. (2008) tested subjects in pairs and told them to imagine that they each owned one of two colored shopping baskets that were placed in front of them. Participants were asked to place pictures of items found in any supermarket (e.g., *apple*, *socks*, *pencil*) into the baskets on the basis of a color-sorting task, at the end of which they each “owned” the items in one of the baskets. The task was operationalized, such that action (i.e., moving the item) was equally shared between self-owned and other-owned items. At the end of this sorting task, a recog-

nition memory task revealed a significant memorial advantage for items owned by self, regardless of who acted upon the object.

What Cunningham et al.’s (2008) findings reveal is that self-item associations forged through psychological ownership yield a similar mnemonic advantage to that generated through the explicit, evaluative encoding of trait adjectives (Turk et al., 2008; Symons & Johnson, 1997). This then raises an interesting question: To what extent are ownership effects supported by activation of the neural systems associated with self-referential processing?

The Neural Basis of Self-referential Encoding

A recent meta-analysis of functional neuroimaging studies suggests that self-referential processing is supported by activity in a network of cortical midline structures (CMS), in addition to task-related lateral brain areas (Northoff et al., 2006). The CMS areas engaged in core aspects of self-referential cognition include ventromedial pFC (vmPFC), dorsomedial pFC (dMPFC), posterior cingulate, and parietal cortices (Amodio & Frith, 2006; Heatherton et al., 2006; Macrae et al., 2004; Kelley et al., 2002). Northoff et al. (2006) argue that these commonly activated regions have specific functional roles in the instantiation of a core mental self. Specifically, the vmPFC functions as a polymodal convergence zone between exteroceptive sensory areas (e.g., amygdala, BG including the striatum and nucleus accumbens) and interoceptive areas in the midbrain and brainstem. In addition, the dorsal part of the medial pFC (including the anterior cingulate) is densely connected to lateral pFC (including the insula). These regions are believed to play an important role in affective processing and the reappraisal and evaluation of stimuli with regard to self (and “mind reading”; Frith & Frith, 2003). Finally, the posterior regions (composed of cingulate, retrosplenial, and parietal cortices) are densely connected to the hippocampus and may, therefore, reflect activity associated with autobiographical aspects of the self.

In the case of the trait–adjective paradigm (Kelley et al., 2002), the coactivation of ventromedial and posterior CMS areas reflects a need to evaluate external cues against internal representations of self in memory (e.g., “am I happy?”). But what of object ownership, how may it be supported in the brain? In addition to the aforementioned regions, it may be expected that ownership would also activate areas associated with affective processing, as acquiring an object is a potentially rewarding experience. In humans, the neural basis of reward has been studied in the context of taking addictive substances (David et al., 2005; Stein et al., 1998; Breiter et al., 1997), monetary gains and losses (Chiu, Holmes, & Pizzagalli, 2008; Liu et al., 2007; Elliott, Friston, & Dolan, 2000; Koeppe et al., 1998; Thut et al., 1997), risk-taking behavior (Dreher, 2007; Bechara, Damasio, Damasio, & Anderson, 1994; Damasio, 1994), listening to music (Menon & Levitin, 2005), and sexual intercourse (Ortigue, Grafton, & Bianchi-Demicheli, 2007). Brain areas associated

with reward and hedonic experience include the striatum, midbrain, thalamus, orbito-frontal cortices, limbic areas (including the amygdala and insula), and medial pFC (Liu et al., 2007; Kringelbach & Rolls, 2004; Damasio, 1996). We could, therefore, expect that in addition to CMS activation associated with self, psychological ownership may recruit a subset these affective brain regions reflecting the hedonic importance of self-object associations.

The Current Study

To determine the neural correlates of psychological ownership, we used fMRI to measure brain activity while participants performed a simple sorting task similar to that employed by Cunningham et al. (2008). Participants were required to allocate shopping items to one of two baskets (one of which was owned by self) by means of a button press. Following this sorting phase, participants undertook a surprise recognition test to assess the impact of ownership on memory. Because object possession reflects a combination of self-referential and affective processing (Pierce et al., 2003; Beggan, 1992; Belk, 1991), we expected cortical midline areas as well as regions associated with positive reward to underpin psychological ownership.

METHODS

Participants

Nineteen participants (12 women) recruited from the University of Aberdeen undergraduate community took part in the study. All participants were right-handed, native English speakers with no history of neurological problems. All gave informed consent according to the procedures approved by the Grampian Region Ethics Committee.

Design and Stimulus Materials

The experiment included an encoding (i.e., sorting) phase and a recognition test phase. Both were carried out while participants were lying in the magnet bore, but only brain activity at encoding was recorded. Before scanning commenced, participants were informed that the experiment was designed to measure the neural activity associated with sorting shopping items according to a color cue. During the encoding phase, images were presented in two functional runs. Each run contained 72 trials of interest and 38 rest trials. During the encoding phase images of two colored shopping baskets were presented in the top left (blue basket) and top right quadrants (red basket) of the visual field. Participants were informed that one basket belonged to them, whereas the other belonged to the experimenter in the control room. The color of the basket associated with self or experimenter was counterbalanced across participants. The task was to place items into the correct basket by matching a color patch presented directly above the item with the color of the basket.

The stimulus set comprised 216 full color photographic images of items available for purchase in a large supermarket (e.g., food, clothing, electrical items) sized to 400 × 400 pixels at a resolution of 72 dpi. They were divided into three equal sets (matched for item type, word length and number of syllables, and broadly on purchase price). One of the sets was paired with a red color patch, one was paired with a blue color patch, and the third was used as foils in a surprise recognition memory test that followed the encoding phase. In this phase, all 216 items were presented individually, and participants made an old/new recognition judgment.

During the encoding phase, a single item was presented for 2 sec. Following a 500-msec delay interval, a circular color patch (50 pixels in diameter) was presented to denote the location into which the item should be placed. Participants were then required to make a response with either the left or right index finger to place the item into the appropriate colored basket. There was then a 500-msec intertrial interval in which only the two colored baskets remained on the screen. In addition to the 144 encoding trials, data from a further 76 randomly interleaved “jittered” rest trials were also collected. On these rest trials, only the basket image remained on the screen for the full 2.5-sec TR period. During the test phase, all 216 stimuli were used. Each was centrally presented and remained on the screen while participants made an old/new recognition memory judgment.

Image Acquisition

Image acquisition was undertaken on a 1.5-T whole body scanner (GE Healthcare) with a standard head coil. Cushions were used to minimize head movement. Anatomical images were acquired using a high-resolution 3-D spoiled gradient recalled echo sequence (124 sagittal slices, TE = 3.2 msec, TR = 8 msec, flip angle = 15°, voxel size = 1 × 1 × 1.6 mm). Functional images were collected in runs, each comprising 110 volumes using a gradient spin-echo, echo-planar sequence sensitive to BOLD contrast (TR = 2500 msec, TE = 40 msec, flip angle = 90°, 3.75 × 3.75 in-plane resolution). For each volume, 30 axial slices, 5-mm slice thickness and 0-mm skip between slices, were acquired allowing complete brain coverage.

RESULTS

Image Analysis

Preprocessing and analysis of the imaging data were performed using SPM2 (Wellcome Department of Cognitive Neurology, London, UK). First, functional data were time-corrected for differences in acquisition time between slices for each whole-brain volume and realigned to the first volume to minimize the effects of head movements on data analysis. Functional data were then transformed into a standard anatomical space (2-mm isotropic voxels) based on

the ICBM 152 brain template (MNI). Normalized data were then spatially smoothed (6 mm FWHM) using a Gaussian kernel. Statistical analyses were performed using the general linear model. An event-related design was modeled using a canonical hemodynamic response function and its temporal derivative. The model also included regressors for additional covariates of no interest (e.g., linear trends for each functional run). This analysis was performed individually for each participant, and resulting contrast images were subsequently entered in a second-level analysis, treating participants as a random effect. To minimize false-positive results, we ran a Monte Carlo simulation (see Slotnick, Moo, Segal, & Hart, 2003) to determine the minimum cluster size necessary to enforce an a priori threshold of $p < .05$ (corrected for multiple comparisons). This simulation effects were considered statistically significant using a criterion of 27 or more contiguous resampled voxels at a voxelwise threshold of $p < .0001$.

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 (MNI), which approximates Talairach and Tournoux's atlas space. Normalized data were then spatially smoothed using a Gaussian kernel (6 mm FWHM). For each participant, a general linear model specifying task effects (modeled with a function for the hemodynamic response) and runs (modeled as constants) was used to compute parameter estimates (β) and t contrast images for each comparison at each voxel. These individual contrast images were then submitted to a second-level, random-effects analysis to obtain mean t images. A direct contrast between the two conditions of interest (thresholded at $p < .0001$, uncorrected; $K > 27$; see Slotnick et al., 2003) revealed a network of brain areas more active for owned than not-owned objects. These regions are reported in Talairach atlas space.

Event-related fMRI Latency

To determine the latency or time to peak for each condition (i.e., self-owned vs. other-owned), functional activity was modeled using one regressor for each condition. The regressors were obtained by convolving the vector of onsets of each condition with a canonical hemodynamic response function, as described by SPM2. This resulted in two predictors of brain activity for each experimental run. This model was fitted to the fMRI time course data on a voxel-by-voxel basis. The fitted hemodynamic response for each condition and each participant in a number of ROIs (determined from the *self-owned* > *other-owned* contrast) was extracted. The individual fitted hemodynamic response curves were then averaged to produce a grand average hemodynamic response curve. The latency of each

condition in each ROI was therefore the time to peak of this grand average response curve (i.e., the time after stimulus onset where the maximum fitted signal amplitude occurred). This calculation affords a mechanism to determine the time at which each brain region reached its peak level of activation (Sun, Miller, & D'Esposito, 2005). This analysis can therefore be used to explore the temporal relationship in activity across regions of the ownership network.

Behavioral Data

Overall recognition rates were reasonable for this type of task (Hits Self = .55, Hits Other = .42, False Alarms = .21). Each participant's recognition score was corrected for baseline false alarm rate by subtracting the proportion of old responses to foils from the proportion of old responses to previously presented items. Participants' corrected scores were submitted to a single factor (ownership: self-owned or other-owned) paired t test. The analysis revealed a significant effect of ownership [$t(18) = 3.944, p < .001$, two-tailed], such that more self-owned than other-owned items were correctly recognized (mean = 0.34 ($SD = 0.14$) and mean = 0.21 ($SD = 0.11$), respectively).

fMRI Analysis

To explore differences in brain activation to owned and not-owned objects, two specific contrasts were conducted. First, we explored brain regions, in which BOLD signal was greater for owned than not-owned objects. This contrast revealed a network of areas including a large cluster of voxels on the medial surface of the superior frontal gyrus (SFG; BA 6) extending dorsally to a caudal region of the ACC (cACC; BA 24/32). In addition, activation was also observed in left insula (including frontal operculum), bilateral regions of the anterior inferior parietal lobe (BA 2, 40), and right superior temporal cortex (BA 22) (see Figure 1A and B). Significant BOLD increases were also observed in the cerebellum and in subcortical structures (e.g., bilateral thalamus, left putamen, left globus pallidus; see Table 1, top).

The second contrast examined brain regions showing greater BOLD signal for other-owned relative to self-owned items. This analysis revealed a number of brain regions more active during the encoding of other-object relations (see Table 1, bottom). Of particular interest, regions located along the cortical midline (see Figure 2C), previously shown to be important in self-referential processing, were more active during other than self-trials. Kelley et al. (2002) reported task-related decreases in posterior cingulate (BA 23/31) and vMPFC (BA 10) during explicit, evaluative encoding. The contrast BOLD difference in these regions was characterized by significantly greater deactivation on trials in which other-referential processing occurred relative to self-related activity. Task-related deactivation relative to rest in anterior and posterior cortical midline

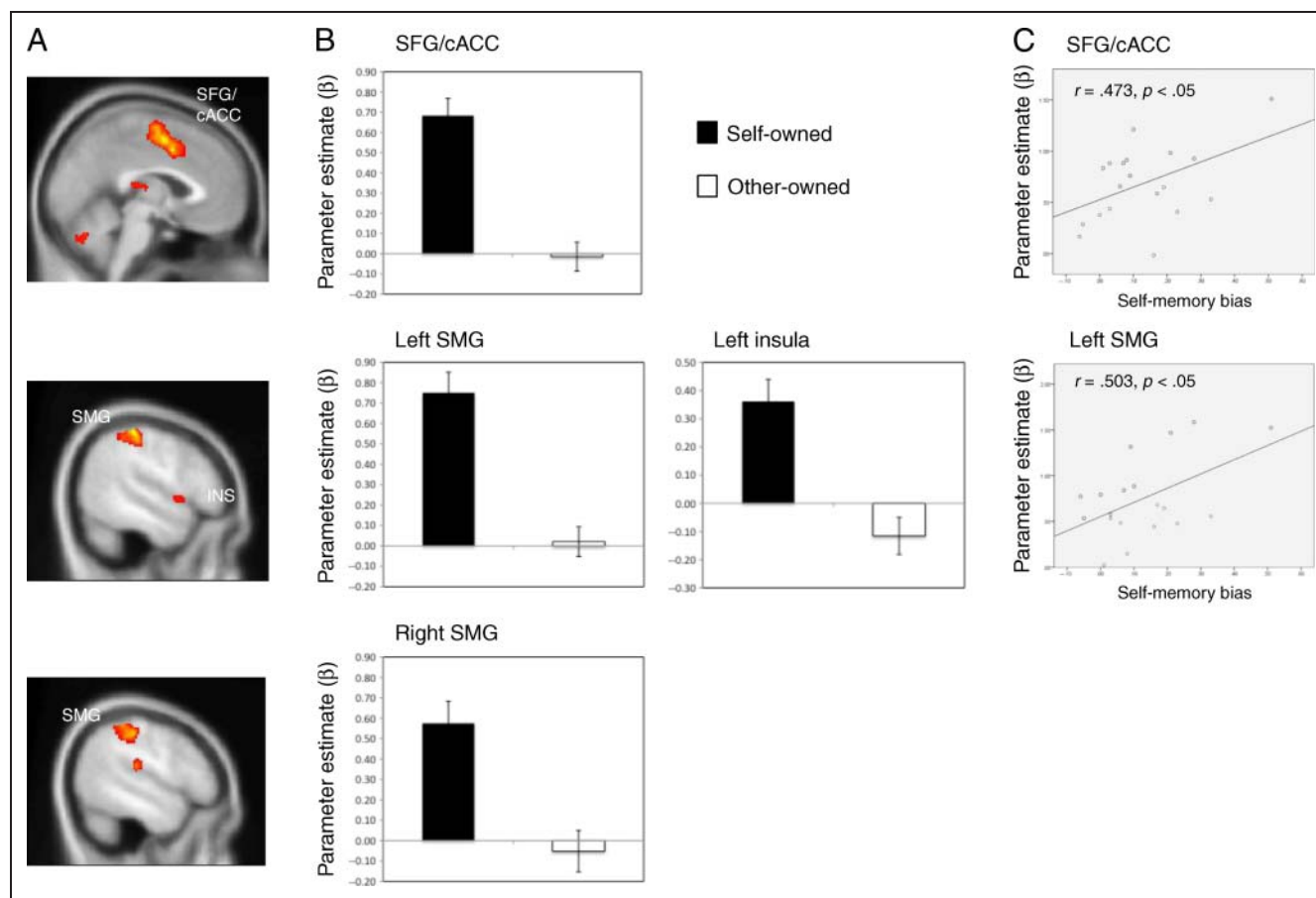


Figure 1. (A and B) Brain regions more active for self-owned than other-owned trials and their corresponding parameter estimates (calculated as the average for all voxels in the ROI). Error bars indicate *SEM*. (C) Areas that show a significant correlation between ROI parameter estimate and self-memory bias (self-other memory).

Table 1. Group Activations Associated with Ownership

Brain Region	Coordinates			<i>t</i>	BA
	<i>x</i>	<i>y</i>	<i>z</i>		
<i>Self Owned > Other Owned</i>					
Frontal cortex					
Medial surface of SFG	4	-3	50	13.39	6
Extending to cACC	-2	8	38	9.39	24/32
Left insula/frontal operculum	-42	-3	9	9.26	
Parietal cortex					
Right precentral gyrus	36	-9	59	10.83	4/6
Right precentral gyrus	42	-13	56	8.42	4
Right supramarginal/postcentral gyrus	51	-26	53	10.24	2/40
Left SMG	-46	-35	46	9.84	40
Extending to postcentral gyrus	-50	-27	46	8.80	2/40
Left postcentral gyrus	-65	-20	19	7.95	2
Right postcentral gyrus	60	-20	18	6.26	42/2

Table 1. (continued)

Brain Region	Coordinates			<i>t</i>	BA
	<i>x</i>	<i>y</i>	<i>z</i>		
Temporal cortex					
Right superior temporal gyrus	48	6	0	6.15	22
	55	10	-4	5.84	21
Cerebellum					
Cerebellum	0	-69	-22	6.85	
Cerebellum	4	-68	-10	6.14	
Cerebellum	-28	-67	-22	11.47	
Cerebellum	24	-63	-22	5.54	
Cerebellum	42	-52	-21	8.22	
Subcortical					
Left putamen	-28	2	0	8.11	
Left medial globus pallidus	-10	0	4	6.94	
Right thalamus	2	-19	10	6.36	
<i>Other Owned > Self Owned</i>					
Frontal cortex					
Left middle frontal gyrus	-44	8	49	8.17	6
Left middle frontal gyrus	-24	29	41	9.10	8
Right middle frontal gyrus	28	29	32	6.22	9
	24	33	44	6.01	8/9
	36	25	39	5.73	8
Anterior cingulate	6	31	6	4.94	24
Cingulate/callosal SMG	10	46	-7	5.7	32/10
Medial/SFG	18	49	10	8.06	10
dMPFC	10	54	27	7.26	9
vMPFC	-6	54	-6	6.25	10
vMPFC	-4	57	5	6.68	10
Parietal cortex					
Right angular gyrus	50	-70	29	6.63	39
Left posterior cingulate	-12	-55	21	8.43	31/23
Left precuneus extending to PCC	-4	-44	43	9.04	31/7
	-2	-63	14	8.08	31
Right postcentral gyrus	42	-11	23	5.77	43/41
Temporal cortex					
Right middle temporal gyrus	53	-69	11	6.46	39
Left superior occipital gyrus	-44	-51	25	8.01	19
Extending to					
Left superior occipital gyrus	-42	-65	25	7.65	19
Left superior temporal gyrus	-57	-59	23	6.81	39

Table 1. (continued)

Brain Region	Coordinates			<i>t</i>	BA
	<i>x</i>	<i>y</i>	<i>z</i>		
Right superior temporal gyrus	55	-59	23	7.43	37
Left middle temporal gyrus	-53	-49	1	6.96	21
Right hippocampal gyrus	30	-49	1	6.25	19
Left middle temporal gyrus	-61	-46	4	7.35	21
Left lingual gyrus	-22	-45	-4	6.77	19
Left middle temporal gyrus	-61	-27	-2	5.99	21
Right superior temporal gyrus	51	-14	-11	6.39	41/42
Right superior temporal gyrus	57	-6	10	5.54	42
Left superior temporal gyrus	-40	5	-14	8.39	38
Subcortical					
Left anterior commissure/hippocampus	-34	-9	-16	6.3	

Activations determined to be significant are listed along with the best estimate of their location. BA = approximate Brodmann's area. 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. Minimum cluster size = 27 voxels ($p < .0001$, uncorrected).

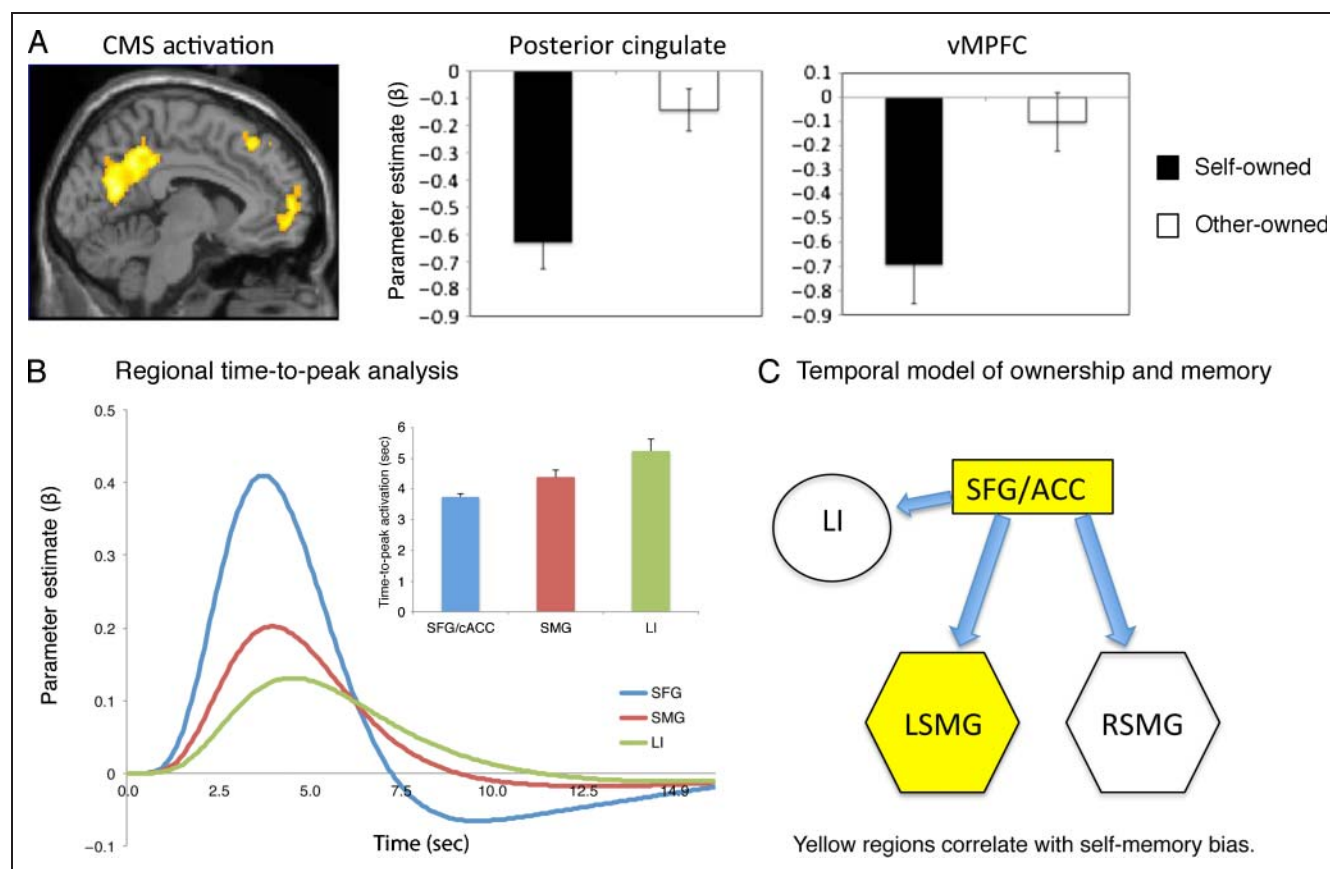


Figure 2. (A) Time-to-peak analysis of signal change across SFG/cACC (SFG), supramarginal cortex (SMG), and left insula (LI). (B) Temporal neural model of ownership. Activation in regions highlighted in yellow also predicted self-memory bias. (C) Specific regions of cortical midline (CMS) previously shown to be functionally important in explicit, evaluative self-referential encoding and memory (posterior cingulate and vMPFC). These regions show decreased activation on trials in which objects were owned by self.

sites has been also observed in previous studies exploring default brain state (Raichle & Snyder, 2007; Gusnard & Raichle, 2001; Raichle et al., 2001). What makes the current pattern of cortical midline activity particularly interesting is that in the deactivation observed was significantly greater for self-owned events. This finding is therefore in direct opposition to the pattern of CMS activation observed in previous studies investigating the neural correlates of self-referential processing (e.g., Kelley et al., 2002).

Self-memory Bias and the Ownership Network

To investigate the relationship between memory performance and the brain activity that accompanied self-owned trials, we examined the correlation between the BOLD response in the ownership network and self-memory bias (i.e., the difference in memory for self-owned vs. other-owned objects). This revealed a positive relationship between self-memory bias and brain activation in the SFG/cACC [$r(19) = .473, p < .05$] and left supramarginal cortex [$r(19) = .503, p < .05$] (see Figure 1C). However, there was no significant correlation between BOLD response and memory bias in right supramarginal cortex [$r(19) = .357, p = .13$] or in left insula [$r(19) = .312, p = .19$].

A Temporal Pattern of Activation in the Ownership Network

In addition to exploring the spatial extent of the ownership network, we also performed an analysis of the temporal aspects of the BOLD signal when processing self-owned objects. This analysis examined the time-to-peak latency in medial pFC (including SFG and cACC), averaged across bilateral parietal cortex (supramarginal and postcentral gyri) and left insular cortex (including frontal operculum).

In this analysis, differences in the latency of the peak hemodynamic response function were used to build a temporal model of activation during self-object association. The fitted hemodynamic response functions are presented in Figure 2A, along with a simplified temporal model of maximal neural activation in each region (see Figure 2B). For analysis of the time-to-peak data, we explored temporal differences in peak activation across dorsomedial frontal, parietal and fronto-temporal clusters. We submitted the time-to-peak data to a single factor (region: SFG/cACC, bilateral supramarginal gyri [SMG], left insula) repeated-measures ANOVA. This revealed a significant main effect of Region $F(1.29, 39.6) = 16.362, p < .001$. Post hoc pairwise t tests exploring the temporal relationship between these three brain regions demonstrated that time-to-peak was significantly faster in medial prefrontal than SMG regions [$t(18) = -3.191, p < .005$] and left insular cortex [$t(18) = -4.303, p < .001$]. The difference in time-to-peak between parietal cortex and insula also approached statistical significance [$t(18) = -1.96, p = .066 ns$]. These data suggest a temporal model in which initial activation

in dorsal midline areas promulgates secondary activity in lateral posterior and frontal brain regions.

DISCUSSION

Whereas previous research exploring the self-reference effect in memory and its neural basis has tended to utilize a directed approach to the formation of self-item associations (Macrae et al., 2004; Kelley et al., 2002; Rogers et al., 1977; see Symons & Johnson, 1997, for a full review), the current study supports the notion that self-memory biases can be generated under less evaluative encoding conditions such as object ownership (Van den Bos et al., 2010; Cunningham et al., 2008), unconstrained choice (Cloutier & Macrae, 2008), or the incidental presentation of the perceiver's own name or face with the task-relevant information (Turk et al., 2008). The present investigation explored the neural correlates of self-object associations formed through temporary ownership.

A Network of Brain Regions for Ownership

Brain regions exhibiting increased BOLD response to objects owned by self included posterior dMPFC extending ventrally to cACC (BA 6/24/32), bilateral areas in anterior inferior parietal cortex, including the supramarginal and postcentral gyri (BA 40/2), left insula (including the frontal operculum), and right superior temporal gyrus. In addition, BOLD signal increases were also observed bilaterally in the thalamus and in the left medial globus pallidus and putamen. In comparison with rest, activity in these ownership brain areas is characterized by increased BOLD signal, whereas for other-owned objects there appears to be no difference in evoked neural response. This suggests that activation in this network is specific to self-object associations. In addition, this ownership network was characterized by a distinct pattern of temporal onsets where early medial prefrontal activity was followed by activation in both posterior parietal cortex and insula. This suggests that multiple processes across a range of brain areas support temporary object ownership.

Dorsomedial SFG and cACC

Initially, self-ownership is characterized by increased activity in cACC and medial SFG. This region has been defined as functionally important in modulating attention to salient stimuli (Chiu et al., 2008; Carretié, Hinojosa, Martín-Loeches, Mercado, & Tapia, 2004), as well as in the signaling of positive reward (Liu et al., 2007). Activation of the cACC region has also been observed in studies involving simple cued responses (Winterer, Adams, Jones, & Knutson, 2002) attributable to motivational, volitional, and effortful task requirements (Winterer et al., 2000) and subsequent information processing and memory. In the current study, signal change in this region correlated with the ownership bias in memory. These dual processes of

attentional modulation and the experiencing of positive reward can be observed in temporal patterns of activity within the ownership network in which activation from this region occurs before activity in anterior inferior parietal cortex and insular cortex that have also been implicated in attentional and affective processing, respectively.

Anterior Inferior Parietal Cortex—Supramarginal and Postcentral Gyri

Activation in parietal cortex is generally associated with attentional processes (Milner & Goodale, 1995). Although posterior regions of the inferior and superior parietal lobe have been identified in spatial aspects of attentional orientation (Hopfinger, Buonocore, & Mangun, 2000; Corbetta, Miezin, Shulman, & Petersen, 1993; see also Corbetta & Shulman, 2002, for a review), the current study identified anterior aspects of the inferior parietal lobe as functionally important in self-object associations. Specifically, bilateral regions of the SMG (BA 40) and postcentral gyrus (BA 2) showed increased BOLD signal toward self-owned compared with other-owned objects. Several studies have also recorded activity in anterior inferior parietal cortex in perceiver-object associations. For example, Handy, Grafton, Shroff, Ketay, and Gazzaniga (2003) suggest that when the potential for acting upon objects is recognized (without specific instruction to do so) this signals increased activation in inferior parietal cortex, predominantly on the left. When compared with viewing or naming houses, faces, animals, or abstract shapes, viewing tools lead to increased activity in identical regions of supramarginal cortex (Chao & Martin, 2000). It has, therefore, been suggested that, in contrast to nonmanipulable objects, the perception of graspable items is accompanied by activation of the motor affordances associated with those objects (Martin, Wiggs, Ungerleider, & Haxby, 1996; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995) or in the simulation of actions associated with object use (Ruby & Decety, 2001) in anterior inferior parietal lobe.

In the current study, participants responded to objects found in any major supermarket (e.g., *apple, iPod, beer*). Although these items might not be considered as tools, they are all manipulable objects and as such have actions associated with them. It is these motor affordances that are represented in anterior inferior parietal cortex. Of note in the current study is that both self- and other-owned objects have similar action affordances (e.g., *apple vs. pear*) and yet, compared with rest, BOLD increases in action-related perceptual areas was uniquely associated with self-owned items. This may be because self-ownership signals the motor affordance of objects, whereas objects that belong to others should generally not be touched or used by self without prior approval. In this case, the potential for action upon graspable objects owned by others is not activated, and thus, concomitant perceptuo-motor action representations may be suppressed. Subsequent analysis of activity in SMG showed that left lateralized sig-

nal change in this region predicted the magnitude of the observed memorial advantage. Because our sample group was composed of right-handed participants, this finding suggests a possible link between activation of motor affordances associated with object use (by the dominant right hand) and self-memory effects.

Insula/Frontal Operculum

Previous research has suggested that the insula is involved in a diverse set of functions. When directly stimulated, some regions of the insula give rise to visceral, somesthetic, and gustatory responses (Penfield & Faulk, 1955). The insula appears to be important for emotional sensation, and projections to limbic regions suggest it plays an important function in the integration of emotion and behavior (Dupont, Boullieret, Hasboun, Semah, & Baulac, 2003) and the signaling of reward (Liu et al., 2007; see also Phan, Wager, Taylor, & Liberzon, 2002, for a review). Activation in a similar region of the insula was reported by Liu et al. (2007) to reflect the processing of positive reward resulting from gain in a gambling task. Although BOLD signal in left insula does differentiate self-owned from other-owned items, it does not predict subsequent memory bias. According to Ferraro, Escalas, and Bettman (2011), the monetary value of possessions may influence the perceived importance of those items but does not affect the strength of self-possession associations likely to support memory performance.

CMS and Ownership

We hypothesized that a network of cortical midline brain areas previously associated with self-referential encoding (see Northoff et al., 2006) as well as regions that have been shown to support hedonic aspects of item ownership might play an important role in forming associations between self and owned objects. Although dorsomedial aspects of the cortical midline did show increased BOLD signal for self-object associations, other previously identified brain areas associated with self-referential processing did not. Specifically, regions in vMPFC (Heatherston et al., 2006; Macrae et al., 2004; Johnson et al., 2002; Kelley et al., 2002; see also Northoff et al., 2006, for a review) and posterior cingulate that have been shown to predict self-referential encoding and memory (Macrae et al., 2004) showed greater neural responses to other-owned objects, characterized by smaller decreases from baseline. Specifically, vMPFC and posterior cingulate regions reported by Kelley et al. (2002) during self-referential encoding appear to be associated with other-object encoding in the present study. So why in this case do these putative self areas respond more to objects associated with others?

Sustained activity in cortical midline regions in posterior and anterior frontal cortex has been observed during periods of sustained rest (Shulman et al., 1997). Gusnard and Raichle (2001) suggest that this default state represents

“a stable, unified perspective of the organism relative to its environment (a *self*)” (p. 692). Activity is tonically high during rest, as this area may be ready to interpret, respond to, and perhaps predict future environmental events (Raichle & Snyder, 2007). Only when individuals are required to engage in specified cognitive tasks does metabolic activity decrease.

These regions (in addition to lateral parietal areas) are also characterized by their associative functions. In line with this preparatory or predictive function, Bar, Aminoff, Mason, and Fenske (2007) noted that tasks that manipulate the degree of association between stimuli also activate the default network. That is, highly associated items showed higher BOLD signal relatively to weakly associated items. They argue that this is because of unconstrained or stimulus-independent thoughts (SITs) that propagate such associations. These SITs are also referred to as mind wandering (Mason et al., 2007). The greater the association, the more mind wandering, the higher the metabolic rate recorded in posterior and anterior cortical midline. Mason et al. (2007) explored the impact of SITs on default activity by giving participants novel and practiced tasks to undertake. In addition, they probed participants during task performance to see if they were currently on task or mind wandering (i.e., having SITs). Because a practiced task requires less effort, it affords a greater opportunity for unconstrained thought and incidents of SITs. This level of mind wandering positively correlated with the magnitude of the BOLD response in areas of the default network. Conversely, stimulus-driven cognitive processes reduce BOLD signal in these networks (Burgess, Dumontheil, & Gilbert, 2007). Thus, it may be the nature of the thought process (i.e., unconstrained and spontaneous vs. constrained and task related) that governs activation in the default network rather than the referent to whom they are directed.

In the current study, there was a greater decrease in BOLD signal in posterior and anterior midline areas for self-owned relative to other-owned trials. This can be interpreted in the context of increased SITs during other-object associations than to self-object associations. As we have previously indicated, self-owned events appear to increase arousal, affective state and attentional processes. As a result, one might infer that such states are accompanied by increased stimulus-driven processes (e.g., “I own the iPod. I could listen to music on the way to work.”). Other-object associations do not result in changes in attentional processes nor do they offer a change in reward state. As such, it is possible that these events therefore lead to increased SITs and, therefore, sustained BOLD signal in default areas.

Conclusion

The current investigation explored the neural basis of nonevaluative self-referential encoding through the use of a novel temporary ownership paradigm. This revealed a

network of brain regions that appear to respond specifically to owned objects in a distinct temporal sequence. Given the functional specificity of these brain areas and the temporal order in which they appear to reach maximal activation, it is tempting to speculate upon a functional temporal model of object ownership, with the initial detection of object salience in caudal medial pFC followed by activation of motor affordances in parietal cortex and processing of reward in insula. Future research might profitably seek to expand upon this speculative model by determining the extent to which factors pertaining to the objects (e.g., value/valence or usability) or to self (e.g., whether or not self was the agent or mere recipient during the acquisition of the item or the degree to which self has prior association with the items) might modulate the activity in this ownership network. That these effects were obtained from temporary ownership of ordinary, low-value, common objects speaks to the potential usefulness of such a methodology in elucidating the mechanisms that underpin the nature of self reflected in material possessions.

Acknowledgments

D. J. T. was supported by grants from the BBSRC (RGA1149) and the European Research Council (202893). C. N. M. was supported by a Royal Society Wolfson Fellowship.

Reprint requests should be sent to David J. Turk, School of Psychology, University of Aberdeen, King's College, Aberdeen, UK, AB24 3FX, or via e-mail: david.j.turk@abdn.ac.uk.

REFERENCES

- Amodio, D. M., & Frith, C. D. (2006). Meeting of minds: The medial frontal cortex and social cognition. *Nature Reviews Neuroscience*, *7*, 268–277.
- Bar, M., Aminoff, E., Mason, M., & Fenske, M. (2007). The units of thought. *Hippocampus*, *17*, 420–428.
- Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, *50*, 7–15.
- Beggan, J. K. (1992). On the social nature of nonsocial perception—The mere ownership effect. *Journal of Personality and Social Psychology*, *62*, 229–237.
- Belk, R. W. (1988). Possessions and the extended self. *Journal of Consumer Research*, *15*, 139–168.
- Belk, R. W. (1991). The ineluctable mysteries of possessions. *Journal of Social Behavior and Personality*, *6*, 17–55.
- Breiter, H. C., Gollub, R. L., Weisskoff, R. M., Kennedy, D. N., Makris, N., Berke, J. D., et al. (1997). Acute effects of cocaine on human brain activity and emotion. *Neuron*, *19*, 591–611.
- Burgess, P. W., Dumontheil, I., & Gilbert, S. J. (2007). The gateway hypothesis of rostral prefrontal cortex (area 10) function. *Trends in Cognitive Sciences*, *11*, 290–298.
- Carretié, L., Hinojosa, J. A., Martín-Loeches, M., Mercado, F., & Tapia, M. (2004). Automatic attention to emotional stimuli: Neural correlates. *Human Brain Mapping*, *22*, 290–299.
- Chao, L. L., & Martin, A. (2000). Representation of manipulable man-made objects in the dorsal stream. *Neuroimage*, *12*, 478–484.

- Chiu, P. H., Holmes, A. J., & Pizzagalli, D. A. (2008). Dissociable recruitment of rostral anterior cingulate and inferior frontal cortex in emotional response inhibition. *Neuroimage*, *42*, 988–997.
- Cloutier, J., & Macrae, C. N. (2008). Self-involvement and the cognitive status of things past. *Consciousness & Cognition*, *17*, 125–135.
- Corbetta, M., Miezin, F. M., Shulman, G. L., & Petersen, S. E. (1993). A PET study of visual attention. *Journal of Biological Science*, *13*, 1202–1226.
- Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, *3*, 201–215.
- Cram, F., & Paton, H. (1993). Personal possessions and self-identity: The experiences of elderly women in three residential settings. *Australian Journal on Aging*, *12*, 19–24.
- Cunningham, S. J., Turk, D. J., & Macrae, C. N. (2008). Yours or mine? Ownership and memory. *Consciousness & Cognition*, *17*, 312–318.
- Damasio, A. (1999). *The feeling of what happens: Body and emotion in the making of consciousness*. New York: Harcourt Brace.
- Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York: Grosset/Putnam.
- Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences*, *351*, 1413–1420.
- David, S. P., Munafo, M. R., Johansen-Berg, H., Smith, S. M., Rogers, R. D., Matthews, P. M., et al. (2005). Ventral striatum/nucleus accumbens activation to smoking-related pictorial cues in smokers and nonsmokers: A functional magnetic resonance imaging study. *Biological Psychiatry*, *58*, 488–494.
- Dreher, J. C. (2007). Sensitivity of the brain to loss aversion during risky gambles. *Trends in Cognitive Sciences*, *11*, 270–272.
- Dupont, S., Boullieret, V., Hasboun, D., Semah, F., & Baulac, M. (2003). Functional anatomy of the insula: New insights from imaging. *Surgical & Radiologic Anatomy*, *25*, 113–119.
- Dyl, J., & Wapner, S. (1996). Age and gender differences in the nature, meaning, and function of cherished possessions for children and adolescents. *Journal of Experimental Child Psychology*, *62*, 340–377.
- Elliott, R., Friston, K. J., & Dolan, R. J. (2000). Dissociable neural responses in human reward systems. *Journal of Neuroscience*, *20*, 6159–6165.
- Etzioni, A. (1991). The socioeconomics of property. *Journal of Social Behavior & Personality*, *6*, 465–468.
- Farrer, C., Frey, S. H., Van Horn, J. D., Tunik, E., Turk, D., Inati, S., et al. (2008). The angular gyrus computes action awareness representations. *Cerebral Cortex*, *18*, 254–261.
- Feinberg, I. (1978). Efference copy and corollary discharge: Implications for thinking and its disorders. *Schizophrenia Bulletin*, *4*, 636–640.
- Ferraro, R., Escalas, J. E., & Bettman, J. R. (2011). Our possessions, our selves: Domains of self-worth and the self-possession link. *Journal of Consumer Psychology*, *21*, 169–177.
- Frith, C. (1992). *The cognitive neuropsychology of schizophrenia*. London: Erlbaum.
- Frith, U., & Frith, C. D. (2003). Development and neurophysiology of mentalizing. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences*, *358*, 459–473.
- Gallagher, S. (2000). Philosophical conceptions of the self: Implications for cognitive science. *Trends in Cognitive Sciences*, *4*, 14–21.
- Gusnard, D. A., & Raichle, M. E. (2001). Searching for a baseline: Functional imaging and the resting human brain. *Nature Reviews Neuroscience*, *2*, 685–694.
- Handy, T. C., Grafton, S. T., Shroff, N. M., Ketay, S., & Gazzaniga, M. S. (2003). Graspable objects grab attention when the potential for action is recognized. *Nature Neuroscience*, *6*, 421–427.
- Heatherton, T. F., Wyland, C. L., Macrae, C. N., Demos, K. E., Denny, B. T., & Kelley, W. M. (2006). Medial prefrontal activity differentiates self from close others. *Social Cognitive & Affective Neuroscience*, *1*, 18–25.
- Hopfinger, J. B., Buonocore, M. H., & Mangun, G. R. (2000). The neural mechanisms of top-down attentional control. *Nature Neuroscience*, *3*, 284–291.
- James, W. (1890). *Principles of psychology*. New York: Holt, Rinehart and Winston.
- James, W. (1929). *The varieties of religious experience: A study in human nature*. Being the Gifford Lectures on Natural Religion Delivered at Edinburgh in 1901–2. Toronto: Random House.
- Jeannerod, M. (2003). Agency and self awareness. In J. Roessler & N. Eilan (Eds.), *Issues in philosophy and psychology* (pp. 128–149). Oxford: Oxford University Press.
- Johnson, S. C., Baxter, L. C., Wilder, L. S., Pipe, J. G., Heiserman, J. E., & Prigatano, G. P. (2002). Neural correlates of self-reflection. *Brain*, *125*, 1808–1814.
- Kahneman, D., Knetsch, J. L., & Thaler, R. (1991). The endowment effect, loss aversion and status quo bias. *Journal of Economic Perspectives*, *5*, 193–206.
- Kelley, W. M., Macrae, C. N., Wyland, C. L., Caglar, S., Inati, S., & Heatherton, T. F. (2002). Finding the self? An event-related fMRI study. *Journal of Cognitive Neuroscience*, *14*, 785–794.
- Knetsch, J. L., & Sinden, J. A. (1984). Willingness to pay and compensation demanded: Experimental evidence of an unexpected disparity in measures of value. *Quarterly Journal of Economics*, *99*, 507–521.
- Koepp, M. J., Gunn, R. N., Lawrence, A. D., Cunningham, V. J., Dagher, A., Jones, T., et al. (1998). Evidence for striatal dopamine release during a video game. *Nature*, *393*, 266–268.
- Kringelbach, M. L., & Rolls, E. T. (2004). The functional neuroanatomy of the human orbito-frontal cortex: Evidence from neuroimaging and neuropsychology. *Progress in Neurobiology*, *72*, 341–372.
- Liu, X., Powell, D. K., Wang, H. B., Gold, B. T., Corbly, C. R., & Joseph, J. E. (2007). Functional dissociation in frontal and striatal areas for processing of positive and negative reward information. *Journal of Neuroscience*, *27*, 4587–4597.
- Macrae, C. N., Moran, J. M., Heatherton, T. F., Banfield, J. F., & Kelley, W. M. (2004). Medial prefrontal activity predicts memory for self. *Cerebral Cortex*, *14*, 647–654.
- Martin, A., Haxby, J. V., Lalonde, F. M., Wiggs, C. L., & Ungerleider, L. G. (1995). Discrete cortical regions associated with knowledge of color and knowledge of action. *Science*, *270*, 102–105.
- Martin, A., Wiggs, C. L., Ungerleider, L. G., & Haxby, J. V. (1996). Neural correlates of category-specific knowledge. *Nature*, *379*, 649–652.
- Mason, M. F., Norton, M. I., Van Horn, J. D., Wegner, D. M., Grafton, S. T., & Macrae, C. N. (2007). Wandering minds: The default network and stimulus-independent thought. *Science*, *315*, 393–395.
- Menon, V., & Levitin, D. J. (2005). The rewards of music listening: Response and physiological connectivity of the mesolimbic system. *Neuroimage*, *28*, 175–184.
- Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford: Oxford University Press.

- Montemayor, R., & Eisen, M. (1977). The development of self-conceptions from childhood to adolescence. *Developmental Psychology, 13*, 314–319.
- Northoff, G., Heinzl, A., Greck, M., Bennpohl, F., Dobrowolny, H., & Panksepp, J. (2006). Self-referential processing in our brain—A meta-analysis of imaging studies on the self. *Neuroimage, 31*, 440–457.
- Ortigue, S., Grafton, S. T., & Bianchi-Demicheli, F. (2007). Correlation between insula activation and self-reported quality of orgasm in women. *Neuroimage, 37*, 551–560.
- Penfield, W., & Faulk, M. E. (1955). The insula: Further observations on its function. *Brain, 78*, 445–470.
- Phan, K. L., Wager, T., Taylor, S. F., & Liberzon, I. (2002). Functional neuroanatomy of emotion: A meta-analysis of emotion activation studies in PET and fMRI. *Neuroimage, 16*, 331–348.
- Pierce, J. L., Kostova, T., & Dirks, K. T. (2003). The state of psychological ownership: Integrating and extending a century of research. *Review of General Psychology, 7*, 84–107.
- Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., & Shulman, G. L. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences, U.S.A., 98*, 676–682.
- Raichle, M. E., & Snyder, A. Z. (2007). A default mode of brain function: A brief history of an evolving idea. *Neuroimage, 37*, 1083–1090.
- Rogers, T. B., Kuiper, N. A., & Kirker, W. S. (1977). Self-reference and the encoding of personal information. *Journal of Personality & Social Psychology, 35*, 677–688.
- Ruby, P., & Decety, J. (2001). Effect of the subjective perspective taking during simulation of action: A PET investigation of agency. *Nature Neuroscience, 4*, 546–550.
- Sartre, J. P. (1969). *Being and nothingness: An essay on phenomenological ontology* (H. E. Barnes, Trans.). London: Methuen. (Original work published in 1943.)
- Shimada, S., Hirakia, K., & Oda, I. (2005). The parietal role in the sense of self-ownership with temporal discrepancy between visual and proprioceptive feedbacks. *Neuroimage, 24*, 1225–1232.
- Shulman, G. L., Fiez, J. A., Corbetta, M., Buckner, R. L., Miezin, F. M., Raichle, M. E., et al. (1997). Common blood flow changes across visual tasks: 2. Decreases in cerebral cortex. *Journal of Cognitive Neuroscience, 9*, 648–663.
- Slotnick, S. D., Moo, L. R., Segal, J. B., & Hart, J. (2003). Distinct prefrontal cortex activity associated with item memory and source memory for visual shapes. *Cognitive Brain Research, 17*, 75–82.
- Stein, E. A., Pankiewicz, J., Harsch, H. H., Cho, J. K., Fuller, S. A., Hoffmann, R. G., et al. (1998). Nicotine-induced limbic cortical activation in the human brain: A functional MRI study. *American Journal of Psychiatry, 155*, 1009–1015.
- Sun, F. T., Miller, L. M., & D'Esposito, M. (2005). Measuring temporal dynamics of functional networks using phase spectrum of fMRI data. *Neuroimage, 28*, 227–237.
- Symons, C. S., & Johnson, B. T. (1997). The self-reference effect in memory: A meta-analysis. *Psychological Bulletin, 121*, 371–394.
- Talairach, J., & Tournoux, P. (1988). *Co-planar stereotaxic atlas of the human brain*. New York: Thieme.
- Thut, G., Schultz, W., Roelcke, U., Nienhusmeier, M., Missimer, J., Maguire, R. P., et al. (1997). Activation of the human brain by monetary reward. *NeuroReport, 8*, 1225–1228.
- Turk, D. J., Cunningham, S. J., & Macrae, C. N. (2008). Self-memory biases in explicit and incidental encoding of trait adjectives. *Consciousness & Cognition, 17*, 1040–1045.
- Van den Bos, M., Cunningham, S. J., Conway, M. A., & Turk, D. J. (2010). Mine to remember: The impact of ownership on recollective experience. *Quarterly Journal of Experimental Psychology, 63*, 1065–1071.
- Winterer, G., Adams, C. M., Jones, D. W., & Knutson, B. (2002). Volition to action—an event-related fMRI study. *Neuroimage, 17*, 851–858.
- Winterer, G., Ziller, M., Dorn, H., Frick, K., Mulert, C., Wuebben, Y., et al. (2000). Frontal dysfunction in schizophrenia: A new electrophysiological classifier for research and clinical applications. *European Archives of Psychiatry & Clinical Neuroscience, 250*, 207–214.