

Research Article

IN SEARCH OF THE SELF: A Positron Emission Tomography Study

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Abstract—Previous work using positron emission tomography (PET) has shown that memory encoding processes are associated with preferential activation of left frontal regions of the brain, whereas retrieval processes are associated predominantly with right frontal activations. One possible reason for the asymmetry is that episodic retrieval necessarily involves reference to the self, and the self-concept may be represented (at least partially) in right frontal regions. Accordingly, the present study investigated the possibility that encoding of self-related material might also activate right frontal areas. Eight right-handed volunteers judged trait adjectives under four separate PET scan conditions: (a) relevance to self, (b) relevance to a well-known public figure, (c) social desirability, and (d) number of syllables. The results showed that self-related encoding yielded left frontal activations similar to those associated with other types of semantic encoding, but also specific activations in the right frontal lobe. It is concluded that the concept of self involves both general schematic structures and further specific components involved in episodic memory retrieval.

It is well established that encoding and retrieval processes in episodic memory involve different regions in the frontal lobes of the cerebral cortex. Specifically, encoding processes differentially engage left prefrontal areas, whereas retrieval processes for the same materials predominantly involve right prefrontal areas. This observed difference was embodied in the hemispheric encoding/retrieval asymmetry model (HERA; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994), and the empirical observations on which the model is based have since been replicated many times (for reviews, see Buckner, 1996; Nyberg, Cabeza, & Tulving, 1996; Tulving, 1998).

One question that can be asked is whether these asymmetrical cortical activations reflect the processes of memory encoding and retrieval as such, or whether they reflect the involvement of necessary constituents of encoding and retrieval, respectively. It is known, for example, that effective encoding processes typically involve deep, elaborate, semantic-processing operations (Craik & Tulving, 1975), and also that such types of processing are consistently associated with activation of the left lateral prefrontal cortex, most commonly around Brodmann's Areas (BA) 46 and 47 (Cabeza & Nyberg, 1997). It seems possible, therefore, that one major function of the left prefrontal cortex is the processing of meaning. This type of processing, in turn, is associated with good episodic memory for the processed event (Kapur et al., 1994; Petersen, Fox, Posner, Mintun, & Raichle, 1988). It should be noted that this confluence of meaningful processing, left prefrontal activation, and high levels of subsequent episodic memory

performance is not restricted to verbal information; the same results have been reported for pictures (Grady, McIntosh, Rajah, & Craik, 1998).

What are the necessary constituents of memory retrieval? James (1890, Vol. I, p. 650) made the point that for a mental event to be experienced as a personal memory, the imagined event must, first, be referred to the past and, second, be associated with feelings of self; that is, it must be dated in the rememberer's own personal past. Recent work involving positron emission tomography (PET) has shown that the retrieval of episodic memories is associated with activation of the prefrontal cortex, predominantly on the right (for reviews, see Cabeza & Nyberg, 1997; Nyberg, 1998; Nyberg et al., 1996). One interpretation of this right prefrontal activation is that it represents a set to interpret incoming stimuli as memory retrieval cues—a "retrieval mode" (Tulving, 1983) or "retrieval attempt" separable from the actual processes of successful retrieval (Kapur et al., 1995). In turn, it can be argued that the major constituents of retrieval mode are pastness and the involvement of self.

One major purpose of the present study was to examine the possibility that the association of episodic memory retrieval with activation of the right prefrontal cortex is attributable (in part at least) to the representation of self in this area of the brain. This conjecture receives some support from studies of brain-damaged patients with disturbances of self-awareness; such disorders are often associated with lesions of the right frontal cortex (Luria, 1973; Stuss, 1991; Wheeler, Stuss, & Tulving, 1997). Also, a PET study in which subjects retrieved emotional memories from their past showed activation of right prefrontal areas as well as other regions in the right hemisphere (Fink et al., 1996). We investigated this question by inducing participants to carry out self-related processing in the context of a memory encoding paradigm. If the involvement of self activates right frontal regions regardless of the nature of the cognitive operation, then self-referential encoding should also be associated with PET activations that are predominantly right lateralized. Alternatively, if self-referential encoding is associated with activations in left frontal regions, this finding would extend the generality of the HERA model, and suggest that self-referential encoding is not different in kind from other types of deeper processing.

A related purpose of the study was to gather evidence on the neural correlates of self-referential processing. It has been shown that words processed with reference to the self are very well remembered, usually even better than words processed in general semantic terms (Symons & Johnson, 1997). Thus, a person would remember the word *stubborn* better after answering the self-referential question "Does the word *stubborn* describe you?" than after answering the general semantic question "Does *stubborn* mean the same as *obstinate*?" (Rogers, Kuiper, & Kirker, 1977). This self-reference effect has been investigated extensively in the past 20 years. Its explanation is still debated, but one reasonable account is that the concept of self provides a rich

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schematic cognitive structure, and that new information learned with reference to self is encoded in a rich and distinctive manner. Furthermore, the organized, interdependent nature of the self-schema facilitates the formation of organizational links among the events to be remembered (Klein & Kihlstrom, 1986; Klein & Loftus, 1988), and the high accessibility of the self-schema facilitates the construction of compatible retrieval operations at the time of remembering (Wells, Hoffman, & Enzle, 1984). In the present study, we were interested in the neural correlates of self-referential encoding, as indexed by PET neuroimaging. The comparison between self-referential and general semantic encoding enabled us to determine whether these two types of encoding are associated with the same or different processes in the brain.

Participants in the PET scanner made judgments about lists of personality trait adjectives. Four types of judgments were made (only one type during any one scan); in all cases, participants rated each word on a 4-point scale by pressing one of four response keys. The four types of judgments were (a) *self* ("How well does the adjective describe you?"), (b) *other* ("How well does the adjective describe Brian Mulroney?"—a former Canadian prime minister), (c) *general* ("How socially desirable is the trait described by the adjective?"), and (d) *syllable* ("How many syllables does the adjective contain?"). Processing words in terms of the number of syllables reflects a relatively shallow type of verbal processing with little involvement of meaning; activations from these scans formed the baseline for PET measurements. The *other* condition was included to see whether personal judgments not related to self would be associated with activations different from those associated with self-referential and general semantic encoding. Behavioral studies have shown that subsequent memory for words judged with reference to another person depends on how well known the target person is to the participant. When the other in question is well known (e.g., parent, best friend), subsequent memory levels are almost as high as those associated with self judgments (Bower & Gilligan, 1979; Keenan & Baillet, 1980); but when the other is a public figure (e.g., Walter Cronkite, Jimmy Carter, John Major), memory for self-referential judgments is consistently higher than memory for other-related judgments (Bower & Gilligan, 1979; Conway & Dewhurst, 1995; Keenan & Baillet, 1980). In the present study, the other was also a public figure (Brian Mulroney), so we expected to find higher memory levels associated with self than with other judgments (see also Symons & Johnson, 1997, for recent meta-analytic support for this prediction).

METHOD

Participants

Eight right-handed volunteers (4 men and 4 women) were recruited for participation in the present investigation. The volunteers were between the ages of 19 and 26 years ($M = 22.8$), and had a mean education of 15.5 years. All participants were screened for a history or current evidence of any serious medical, neurological, or psychological disorder; they were also screened for recreational drug abuse. Informed consent was obtained from all volunteers before they participated, and they received a \$50 reimbursement for their participation. The study was approved by the local ethics committee of the University of Toronto.

Task Design

Relative regional cerebral blood flow (rCBF) was measured while participants performed one of four encoding tasks; each task was performed twice, for a total of eight relative rCBF measurements (i.e., scans). The four tasks were presented in an ABCDDCBA design (counterbalanced across participants) to minimize order effects. Each task involved making judgments about personality trait adjectives on a 4-point scale. Sixteen similar lists of 32 personality trait adjectives were constructed using the personality trait adjectives found in Anderson (1968) and Kirby and Gardner (1972). These lists were used in the encoding tasks and in a subsequent recognition test. Each adjective occurred in only one list. Within each list, half of the words were positive and half were negative. A word was considered to be positive if it was one of the first 253 words listed by Anderson (1968; his words were ordered according to their likability ratings) or if it fell within the first five deciles of Kirby and Gardner's (1972) ratings of evaluation and social desirability; words occurring later in these lists were considered to be negative. Additionally, each list contained approximately equal numbers of two-, three-, four-, and five-syllable positive and negative adjectives. Eight additional lists of 8 personality trait adjectives were constructed for the practice trials. These practice lists were constructed using criteria similar to but less strict than the criteria used to construct the sixteen 32-adjective lists (e.g., some of the practice adjectives were from Allport & Odbert, 1936). Eight of the 32-word lists were shown for the participants' judgments during the scans, and eight served as distractors on a recognition test at the end of scanning. Half of the participants made judgments on Lists 1 through 8; in this case, Lists 9 through 16 contributed distractors for the recognition test. The remaining participants made their initial judgments on Lists 9 through 16; in this case, Lists 1 through 8 contributed distractors for the recognition test. The lists were presented in a pseudorandom order, counterbalanced across subjects. The words within each list were randomly presented. Each word was presented in the center of a computer screen suspended a comfortable viewing distance from the participant.

In one task, representing encoding of self-referential information (*self* task), participants were requested to judge how well they thought each trait adjective described them. To indicate their judgment, they were instructed to press one of the four keys on the keypad beneath their right fingers. More specifically, they were requested to press the key beneath their index, middle, ring, or little finger if they thought that the trait adjective almost never, rarely, sometimes, or almost always described them, respectively. In a second task, representing encoding of information about another person (*other* task), participants were requested to judge how well they thought each trait adjective described Brian Mulroney by responding in the same way as in the *self* task. In a third task, representing encoding of semantic information not specific to a person (*general* task), participants were requested to judge how socially desirable the trait described by each adjective was. They judged each trait as being almost never, rarely, sometimes, or almost always socially desirable by pressing designated keys. In a fourth task, representing the encoding of nonsemantic information (*syllable* task), participants were requested to judge the number of syllables in each trait adjective. They pressed one of four keys depending on whether the adjective had two, three, four, or five syllables.

Each trial consisted of a 500-ms fixation point followed by an adjective with a maximum duration of 2,000 ms. If the participant made his or her judgment within the 2,000 ms, then the screen went

blank for the duration of the 2,000 ms, and then a fixation point appeared for 1,500 ms. If the participant did not make his or her judgment within 2,000 ms, the adjective was replaced with the fixation point. The fixation point was displayed continuously for the 1,500 ms at the end of one trial and throughout the 500 ms preceding the next adjective; participants thus had a total of 4,000 ms to perceive and respond to each adjective. Participants were told that if they had not made a judgment by the time the fixation point appeared, they should do so quickly because the next trait adjective was about to appear. If a judgment had not been made within the 4,000-ms window, then the next adjective automatically appeared. This strict timing was used to ensure that each participant made the same number of judgments during each scan. The behavioral data and verbal reports from the participants confirmed that 4,000 ms was a comfortable window within which the various tasks could be performed.

Approximately 10 min after the last scan, participants were given an unexpected yes/no recognition test. The recognition test was divided into four blocks, one for each type of judgment. We made this division so that we could determine variations in the criterion participants used to recognize the adjectives from a particular judgment type. Block order was pseudorandom, counterbalanced across participants. Within each block, half of the adjectives from the two lists for a particular judgment and half of the adjectives from two distractor lists (i.e., 64 words/block) were randomly presented one at a time on a computer screen (half of the participants saw half of the adjectives, and the other half of the participants saw the remaining half of the adjectives from the encoding and distractor lists). Each adjective remained on the screen until the participant pressed one of two keys to indicate whether or not he or she recognized the adjective as one that had been presented during scanning.

PET Scanning Techniques

Relative rCBF was measured by recording the regional distribution of cerebral radioactivity using a GEMS-Scanditronix PC-2048 head scanner. Full details of the method may be obtained from other PET scanning articles from the Toronto group (e.g., Kapur et al., 1994; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994). Each task lasted approximately 2 min; data acquisition for each scan occurred in the middle 1 min of the task. The scans were 11 min apart to allow for adequate decay of the radioactivity. Three minutes before each scan, participants were given instructions for the next task and some practice trials.

Statistical Parametric Mapping (SPM 94) software (provided by the MRC Cyclotron Unit, Hammersmith Hospital, London, England)

was used to realign, normalize, and smooth the images (using a 15-mm filter) from each participant. The data were statistically analyzed on a voxel-by-voxel basis. A given voxel was considered to be significantly activated if, in comparison with a reference task, there was an increase in relative rCBF and the corresponding z score was 4.10 or above. This z score corresponded to a p value of approximately .05 (corrected for multiple comparisons). Note, however, that we report significantly activated voxels only if they fell in a region (i.e., spatially contiguous set of voxels) that both was significantly activated ($z > 4.10$) and consisted of at least 20 voxels. Six planned comparisons (all possible pairs of conditions) were made; in all cases, the reverse comparison was also made so that both increases and decreases in relative rCBF could be assessed.

In addition to the SPM analysis, we carried out a partial least squares (PLS) analysis on the PET data (McIntosh, Bookstein, Haxby, & Grady, 1996). This multivariate analysis operates on the covariance between brain voxels and the experimental design to identify a new set of variables (latent variables, or LVs) that optimally relate the two sets of measurements. In general, PLS is a more powerful analysis than SPM because it uses all the information from the two sets of measurements in a single step. In the present report, the PLS analysis is treated as an adjunct to the SPM analysis because it yielded an interesting result, relevant to our hypotheses; fuller details of the method are provided by McIntosh et al. (1996).

RESULTS

Behavioral Data

Participants made a judgment about a trait adjective within the allotted 4-s window 99.5% of the time. Table 1 (left column) shows the mean times taken to make the judgments for each encoding condition; the *general* (social desirability) judgments were made most rapidly ($M = 1,321$ ms), and the *other* (Brian Mulroney) judgments were made most slowly ($M = 1,657$ ms). An analysis of variance (ANOVA) on these four means yielded a significant effect, $F(3, 21) = 8.78$, $p < .001$. Subsequent pair-wise comparisons (least squares means) revealed significant differences (uncorrected $p < .05$) between the *general* and *other* tasks, *general* and *syllable* tasks, and *self* and *other* tasks.

Table 1 (right column) also shows the mean times taken to make correct recognition decisions in the retrieval phase. An ANOVA showed no significant differences among the four means, $F(3, 21) = 1.45$, $p > .05$, but the table shows that self-related encoding was

Table 1. Mean values of initial encoding time, recognition memory proportions (hits minus false alarms), and recognition latency

Task	Encoding reaction time (ms)	Hits – false alarms	Recognition reaction time (ms)
Self	1,454 (70)	.59 (.06)	1,349 (145)
Other	1,657 (123)	.50 (.06)	1,614 (223)
General	1,321 (79)	.51 (.06)	1,516 (198)
Syllable	1,542 (84)	.29 (.06)	1,483 (143)

Note. Standard errors are given in parentheses.

associated with the fastest subsequent recognition reaction time (RT). Deeper encoding conditions typically lead to faster recognition latencies (Vincent, Craik, & Furedy, 1996). Recognition memory performance was indexed by the proportion of hits minus false alarms for each condition. Table 1 (center column) shows that the *syllable* condition yielded the lowest recognition score, and that the *self* condition was associated with the highest level of recognition performance. An ANOVA revealed a significant effect of encoding task, $F(3, 21) = 5.35, p < .01$, and subsequent pair-wise comparisons showed that recognition was significantly higher on the *self*, *other*, and *general* tasks than on the *syllable* task, but that there were no reliable differences among the three semantic tasks. Thus, in the present data, the *other* and *general* tasks yielded very similar levels of recognition memory, and the *self* condition yielded a somewhat higher level. The lack of statistical significance for this latter result is likely attributable to the lack of power associated with a study involving only 8 participants.

SPM Analysis

Tables 2 and 3 show the increases and decreases, respectively, in brain activity associated with the planned comparisons between the different encoding conditions. With respect to the three semantic conditions (*self*, *other*, and *general*), Table 3 shows that there were no significant decreases in relative rCBF between the conditions, and Table 2 shows only one significant effect: The right anterior cingulate area was more activated in the *self* than in the *general* condition.

Self-syllable comparison

Table 2 lists two regions of relative rCBF increase in this comparison. Increases occurred in the left hemisphere only—in the medial aspect of the superior frontal gyrus (BA 8/9) and in the inferior frontal gyrus (BA 47). These regions are shown in Figure 1a. Four regions of relative rCBF decrease were also observed (Fig. 2a). These regions were located in the left inferior parietal gyrus (BA 40), right superior parietal lobule (BA 7), left fusiform gyrus (BA 37), and right precen-tral gyrus (BA 6). The coordinates of the points of maximal activation are given in Table 3.

Other-syllable comparison

Table 2 lists the anatomical coordinates, brain regions, and z statistics associated with relative rCBF increases in this comparison; the six areas are illustrated in Figure 1b. Increases occurred in the left hemisphere only—in the medial aspect of the superior frontal gyrus (BA 8/9 and 10), superior temporal gyrus (BA 38), middle temporal gyrus (BA 39), and posterior (BA 23) and anterior (BA 32) cingulate gyrus. Table 3 and Figure 2b show the regions associated with relative rCBF decreases in this comparison. Decreases occurred in the right superior frontal gyrus (BA 6), left inferior parietal lobule (BA 40), left and right superior parietal lobules (BA 7), and left fusiform gyrus (BA 37).

General-syllable comparison

Table 2 and Figure 1c show the regions associated with relative rCBF increases in this comparison. These regions were all in the left hemisphere—in the medial aspect of the superior frontal gyrus (BA 8/9 and 10), the inferior frontal gyrus (BA 47), and the middle

Table 2. Increases in brain activity associated with encoding of self-related, other-related, general semantic, and phonological information

Task comparison and region	Side	Coordinates			z statistic
		x	y	z	
<i>Self versus other</i>					
No significant increases					
<i>Self versus general</i>					
Anterior cingulate (BA 24)	Right	6	34	4	4.47
<i>Other versus general</i>					
No significant increases					
<i>Self versus syllable</i>					
Medial frontal lobe (BA 8/9)	Left	-4	46	36	7.25
Inferior frontal gyrus (BA 47)	Left	-32	24	-8	5.77
<i>Other versus syllable</i>					
Medial frontal lobe (BA 10)	Left	-6	52	-4	6.09
Medial frontal lobe (BA 8/9)	Left	-6	44	40	7.16
Anterior cingulate (BA 32)	Left	-4	20	-8	4.50
Superior temporal gyrus (BA 38)	Left	-38	10	-16	6.44
Posterior cingulate (BA 23)	Left	-6	-54	16	4.84
Middle temporal gyrus (BA 39)	Left	-44	-68	20	5.23
<i>General versus syllable</i>					
Medial frontal lobe (BA 10)	Left	-8	52	-4	5.13
Medial frontal lobe (BA 8/9)	Left	-6	44	36	6.58
Inferior frontal gyrus (BA 47)	Left	-36	36	-4	5.60
Middle temporal gyrus (BA 39)	Left	-42	-66	20	4.97

Note. BA = Brodmann's Area, as identified in Talairach and Tournoux (1988).

Table 3. Decreases in brain activity associated with encoding of self-related, other-related, general semantic, and phonological information

Task comparison and region	Side	Coordinates			z statistic
		x	y	z	
<i>Self versus other</i>					
No significant decreases					
<i>Self versus general</i>					
No significant decreases					
<i>Other versus general</i>					
No significant decreases					
<i>Self versus syllable</i>					
Precentral gyrus (BA 6)	Right	40	6	24	4.43
Inferior parietal lobule (BA 40)	Left	-56	-38	32	5.56
Superior parietal lobule (BA 7)	Right	32	-54	36	5.50
Fusiform gyrus (BA 37)	Left	-44	-62	-12	5.46
<i>Other versus syllable</i>					
Middle frontal gyrus (BA 6)	Right	20	-2	48	5.07
Inferior parietal lobule (BA 40)	Left	-58	-38	32	4.62
Superior parietal lobule (BA 7)	Right	32	-54	36	6.07
Fusiform gyrus (BA 37)	Left	-44	-58	-12	6.39
Superior parietal lobule (BA 7)	Left	-22	-66	40	5.02
<i>General versus syllable</i>					
Anterior cingulate (BA 24)	Right	4	10	32	4.51
Inferior parietal lobule (BA 40)	Left	-54	-40	36	4.49
Inferior parietal lobule (BA 40)	Right	38	-46	36	5.53
Fusiform gyrus (BA 37)	Left	-42	-58	-12	6.34
Superior parietal lobule (BA 7)	Left	-22	-66	40	5.09

Note. BA = Brodmann's Area, as identified in Talairach and Tournoux (1988).

temporal gyrus (BA 39). Relative decreases in rCBF were seen in the left and the right inferior parietal lobules (BA 40), left superior parietal lobule (BA 7), right anterior cingulate gyrus (BA 24), and left fusiform gyrus (BA 37). These areas are shown in Table 3 and Figure 2c.

Summary

A summary of the comparisons between the semantic (*self*, *other*, *general*) and nonsemantic (*syllable*) tasks is provided in Table 4. Given the general absence of differences among the semantic tasks, the similarity of their contrasts with the nonsemantic task is not surprising. In a sense, however, the different tasks serve as replications of semantic-nonsemantic differences, and together they yield a rather coherent picture. First, Table 4 emphasizes the fact that all significant increases were associated with left-hemisphere activations. This finding strikingly corroborates the HERA model. Second, increases in activation tended to occur in frontal areas (8 out of 12 cases), whereas decreases in activation were concentrated in posterior areas (11 out of 14 cases). Third, decreases in frontal areas were all right-sided, in contrast to the frontal increases, which were all left-sided. Fourth, there was some tendency for the posterior decreases to be bilateral (BA 40 and 7), apart from the consistent activation in the left fusiform gyrus. Finally, given the present investigation's focus on activations relating to self, it is worth noting that every significant activation in the *self-syllable* contrast was also found in either the *other-syllable* contrast or the *general-syllable* contrast, or both.

PLS Analysis

Table 5 shows the major areas of maximum activation associated with the three LVs. In this additional analysis, we show only areas in the frontal lobes, given the present hypotheses of interest. Also, Table 5 is restricted to clusters of 100 voxels or more, and to contrasts with positive salience. For example, the first latent variable (LV1) accounted for 66% of the variance and shows cortical areas that were relatively more active in the contrast when the combination of the *self*, *other*, and *general* conditions was compared with the *syllable* condition. The preceding SPM analysis and Figure 1 would lead one to expect that this contrast should be associated with strong left frontal activation, and Table 5 shows that this is the case. In addition, LV1 includes a smaller area in the right inferior frontal gyrus (BA 47).

The second latent variable (LV2) accounted for 18% of the variance, and Table 5 shows frontal areas of activation associated with the contrast in which the *general* condition was greater than the combination of the *self*, *other*, and *syllable* conditions. These areas are both in the left frontal cortex and appear to be specifically related to general semantic encoding.

The third latent variable (LV3) accounted for 15% of the variance and contrasts the *self* condition with the other three conditions (i.e., *self > other*, *general*, *syllable*). The first area Table 5 shows for this contrast is in the frontal pole; its maximum activation is slightly left of the midline, but the cluster spreads upward and to the right. The other two areas of activation are in right frontal areas, one in the middle frontal gyrus (BA 10) and the other in the inferior frontal gyrus (BA 45). Thus, the areas of the frontal lobes that were more activated in the

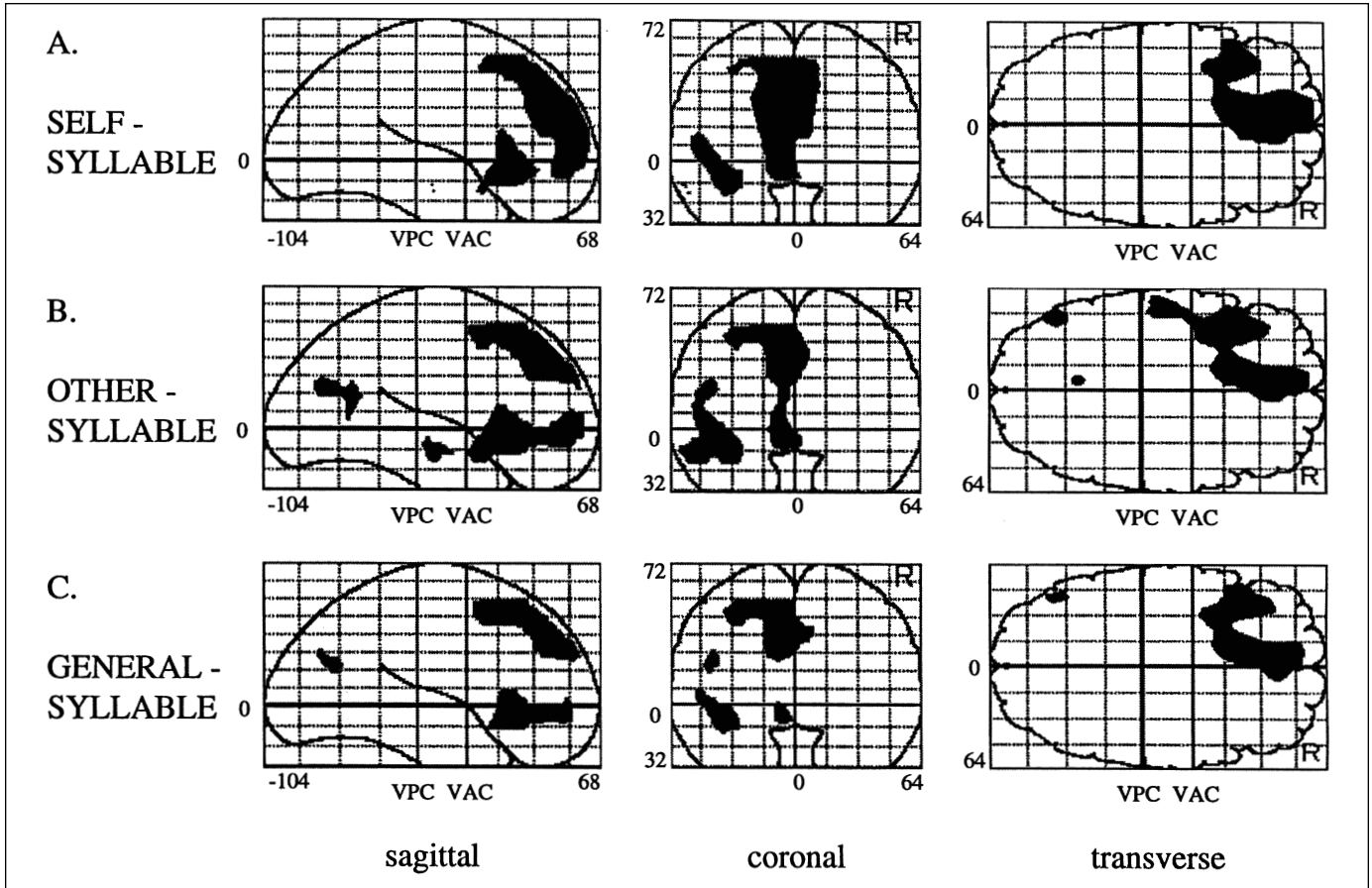


Fig. 1. Areas of significant increase in relative regional cerebral blood flow during the encoding of self-referential information (a; *self* minus *syllable* condition), other-referential information (b; *other* minus *syllable* condition), and general semantic information (c; *general* minus *syllable* condition). The anatomical space corresponds to that of Talairach and Tournoux (1988). R = right hemisphere; VPC = vertical line through posterior commissure; VAC = vertical line through anterior commissure.

self condition, contrasted to the other three conditions, were situated in either medial or right frontal locations.

DISCUSSION

The behavioral results showed that adjectives judged semantically (*self*, *other*, and *general* tasks) were better recognized in a later test than adjectives judged in terms of number of syllables (Table 1). Also, adjectives in the *self* condition were somewhat better recognized than those in the *other* and *general* conditions; that is, the present results showed a self-reference effect in memory, in line with previous work (Symons & Johnson, 1997).

The SPM analysis of the neuroimaging data is striking primarily because of the similarity among the *self*, *other*, and *general* conditions when compared with the *syllable* condition. As shown in Table 4 and Figure 1, the increases in activation in these three semantic tasks compared with the *syllable* task were restricted to the left hemisphere and were predominantly located in the left prefrontal cortex.

The common areas of relative activation in the three semantic conditions included the medial aspect of the superior frontal gyrus (BA 8/9, 10), inferior frontal gyrus (BA 47), superior temporal gyrus (BA

38), middle temporal gyrus (BA 39), and cingulate gyrus (BA 23/32). These are the areas associated with meaningful processing of individual words in a number of previous studies (Buckner, 1996; Cabeza & Nyberg, 1997; Nyberg et al., 1996; Tulving et al., 1994). The decreases in relative rCBF shown in Table 4 may be interpreted as indicating the engagement of areas concerned with phonological analysis of visually presented words. The frontal activations (BA 6, BA 24) are associated with the motor programming of language. The posterior regions that are activated in the *syllable* task are those associated with directing attention (BA 7, BA 40) to the visual word form area (BA 37); this allocation of attention may precede and accompany processing of the printed word into syllables. The preferential activation of left frontal and temporal areas during encoding in all three semantic tasks provides additional support for the HERA model (Tulving et al., 1994).

The similarity in cortical activation patterns between the *self* condition and the *other* and *general* conditions suggests that thoughts of self may largely involve a generalized “conceptual self”—a schematic representation abstracted from many personal episodes. In this sense, then, self-related judgments may not differ substantially from other judgments requiring retrieval from semantic memory. The conclusion that the self is simply “an unusually rich and highly organized

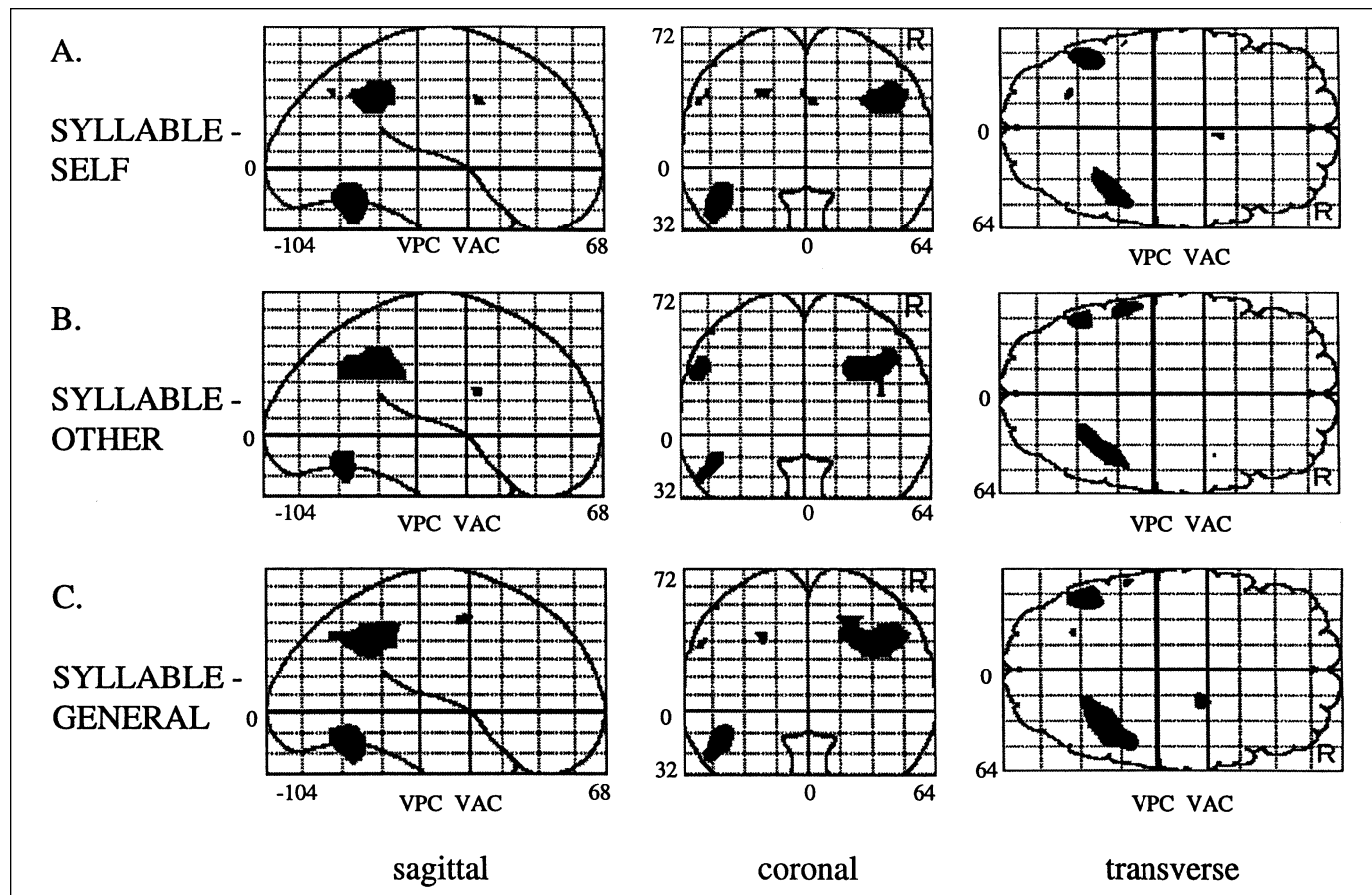


Fig. 2. Areas of significant decrease in relative regional cerebral blood flow during the encoding of self-referential information (a; *syllable minus self* condition), other-referential information (b; *syllable minus other* condition), and general semantic information (c; *syllable minus general* condition). The anatomical space corresponds to that of Talairach and Tournoux (1988). R = right hemisphere; VPC = vertical line through posterior commissure; VAC = vertical line through anterior commissure.

cognitive structure" (Higgins & Bargh, 1987, p. 389) abstracted from individual instances is in line with observations that brain-damaged patients with a complete absence of episodic memory can nonetheless make accurate judgments about their personality characteristics (Klein, Loftus, & Kihlstrom, 1996; Tulving, 1993).

However, the PLS analysis, while substantially corroborating the conclusions from the SPM analysis, also demonstrated frontal activations specific to the *self* condition when contrasted with the other three conditions. Moreover, these specific self-related activations were located predominantly in the right frontal lobe. There is thus good evidence for an encoding manipulation activating right prefrontal regions when encoding involves the person's self-concept. This conclusion was also reached by Velichkovsky, Klemm, Detmar, and Volke (1996) in a study involving evoked coherence of electroencephalograms.

In a recent survey of frontal lobe functions, Grady (1998) listed activations from PET studies of episodic memory. Her survey shows that of the 39 activations reported in BA 10 and BA 9, all but one are associated with episodic retrieval. The first two activations listed for LV3 in the present Table 5 are in the same region as those listed by Grady in her Tables 6 and 7, yet the latter activations were overwhelmingly associated with episodic retrieval whereas the present activations were asso-

ciated with encoding. Our suggested conclusion is that episodic retrieval necessarily involves the concept of self, and that this involvement is signaled by neural activity in the right frontal lobe. An alternative possibility is that judgments concerning the self involve retrieval of episodic instances; this possibility is somewhat unlikely, however, given the evidence that patients with no episodic memory can make accurate self-assessments (Klein et al., 1996; Tulving, 1993).

In summary, the present study examined the neural correlates of the self-reference effect in the context of an episodic memory encoding experiment using verbal materials. The SPM analysis of the PET data showed that the *self* encoding condition was associated with left prefrontal activations similar to the activations associated with other-related and general semantic encoding. This finding suggests that part of the self-concept exists in the form of context-free schematic knowledge, similar in type to other forms of semantic knowledge (cf. Higgins & Bargh, 1987; Klein et al., 1996). In addition, however, the PLS analysis revealed some right-sided prefrontal activations related to the *self* condition in areas typically associated with episodic retrieval. We suggest that these activations signal the involvement of the self as a necessary component of episodic retrieval, much as suggested by William James more than a century ago.

Table 4. Regions of significant increased and decreased activation in comparisons between semantic and nonsemantic tasks

Region	Task comparison		
	<i>Self versus syllable</i>	<i>Other versus syllable</i>	<i>General versus syllable</i>
Increases			
Frontal			
Medial frontal lobe		L - 10	L - 10
Medial frontal lobe	L - 8/9	L - 8/9	L - 8/9
Inferior frontal gyrus	L - 47		L - 47
Anterior cingulate		L - 32	
Posterior			
Superior temporal gyrus		L - 38	
Middle temporal gyrus		L - 39	L - 39
Posterior cingulate		L - 23	
Decreases			
Frontal			
Frontal gyrus	R - 6	R - 6	
Anterior cingulate			R - 24
Posterior			
Inferior parietal lobule	L - 40	L - 40	L - 40 R - 40
Superior parietal lobule	R - 7	R - 7	
Fusiform gyrus	L - 37	L - 37	L - 7 L - 37

Note. Numbers represent Brodmann's Areas. L = left hemisphere; R = right hemisphere.

Table 5. Partial least squares (PLS) analysis: Areas of maximum frontal activation associated with positive saliences in three latent variables (LVs)

LV and region	Side	Coordinates			Voxel size	z statistic ^a
		x	y	z		
LV1 (<i>self, other, general</i> > <i>syllable</i>)						
Medial frontal lobe (BA 10)	Left	-8	52	0	5,073	8.0
Superior frontal gyrus (BA 8)	Left	-16	18	48		11.3
Frontal opercular (BA 47)	Left	-32	16	-8		10.6
Inferior frontal gyrus (BA 47)	Right	48	24	-4	157	4.3
LV2 (<i>general</i> > <i>self, other, syllable</i>)						
Superior frontal gyrus (BA 8)	Left	-8	24	48	158	3.2
Precentral gyrus (BA 6)	Left	-56	0	24	127	3.3
LV3 (<i>self</i> > <i>other, general, syllable</i>)						
Medial frontal lobe (BA 10)	Left	-6	56	8	281	4.7
Medial frontal lobe (BA 9)	Right	6	40	28		3.0
Middle frontal gyrus (BA 10)	Right	30	60	20	127	3.4
Inferior frontal gyrus (BA 45)	Right	52	26	4	110	3.7

Note. BA = Brodmann's Area, as identified in Talairach and Tournoux (1988).

^aThe statistic from PLS analyses is roughly analogous to a z statistic (see McIntosh, Bookstein, Haxby, & Grady, 1996).

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REFERENCES

- Allport, G.W., & Odbert, H.S. (1936). Trait-names: A psycho-lexical study. *Psychological Monographs*, 47.
- Anderson, N. (1968). Likableness ratings of 555 personality-trait words. *Journal of Personality and Social Psychology*, 9, 272–279.
- Bower, G.M., & Gilligan, S.G. (1979). Remembering information related to one's self. *Journal of Research in Personality*, 13, 420–432.
- Buckner, R. (1996). Beyond HERA: Contributions of specific prefrontal areas to long-term memory. *Psychonomic Bulletin & Review*, 3, 149–158.
- Cabeza, R., & Nyberg, L. (1997). Imaging cognition: An empirical review of PET studies with normal subjects. *Journal of Cognitive Neuroscience*, 9, 1–26.
- Conway, M.A., & Dewhurst, S.A. (1995). The self and recollective experience. *Applied Cognitive Psychology*, 9, 1–19.
- Craik, F.I.M., & Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of Experimental Psychology: General*, 104, 268–294.
- Fink, G.R., Markowitsch, H.J., Reinkemeier, M., Bruckbauer, T., Kessler, J., & Heiss, W. (1996). Cerebral representation of one's own past: Neural networks involved in autobiographical memory. *The Journal of Neuroscience*, 16, 4275–4282.
- Grady, C.L. (1998). Neuroimaging and activation of the frontal lobes. In B.L. Miller & J.L. Cummings (Eds.), *The human frontal lobes: Functions and disorders* (pp. 196–230). New York: Guilford Press.
- Grady, C.L., McIntosh, A.R., Rajah, M.N., & Craik, F.I.M. (1998). Neural correlates of the episodic encoding of pictures and words. *Proceedings of the National Academy of Sciences, USA*, 95, 2703–2708.
- Higgins, E.T., & Bargh, J.A. (1987). Social cognition and social perception. *Annual Review of Psychology*, 38, 369–425.
- James, W. (1890). *The principles of psychology*. New York: Henry Holt.
- Kapur, S., Craik, F.I.M., Jones, C., Brown, G.M., Houle, S., & Tulving, E. (1995). Functional role of the prefrontal cortex in memory retrieval: A PET study. *NeuroReport*, 6, 1880–1884.
- Kapur, S., Craik, F.I.M., Tulving, E., Wilson, A.A., Houle, S., & Brown, G.M. (1994). Neuroanatomical correlates of encoding in episodic memory: Levels of processing effect. *Proceedings of the National Academy of Sciences, USA*, 91, 2008–2111.
- Keenan, J.M., & Baillet, S.D. (1980). Memory for personally and socially significant events. In R.S. Nickerson (Ed.), *Attention and performance* (Vol. 8, pp. 651–669). Hillsdale, NJ: Erlbaum.
- Kirby, D.M., & Gardner, R.C. (1972). Ethnic stereotypes: Norms on 208 words typically used in their assessment. *Canadian Journal of Psychology*, 26, 140–154.
- Klein, S.B., & Kihlstrom, J.F. (1986). Elaboration, organization, and the self-reference effect in memory. *Journal of Experimental Psychology*, 115, 26–38.
- Klein, S.B., & Loftus, J. (1988). The nature of self-referent encoding: The contributions of elaborative and organizational processes. *Journal of Personality and Social Psychology*, 55, 5–11.
- Klein, S.B., Loftus, J., & Kihlstrom, J.F. (1996). Self-knowledge of an amnesic patient: Toward a neuropsychology of personality and social psychology. *Journal of Experimental Psychology: General*, 125, 250–260.
- Luria, A.R. (1973). *The working brain*. New York: Basic Books.
- McIntosh, A.R., Bookstein, F.L., Haxby, J.V., & Grady, C.L. (1996). Spatial pattern analysis of functional brain images using partial least squares. *Neuroimage*, 3, 143–157.
- Nyberg, L. (1998). Mapping episodic memory. *Behavioural Brain Research*, 90, 107–114.
- Nyberg, L., Cabeza, R., & Tulving, E. (1996). PET studies of encoding and retrieval: The HERA model. *Psychonomic Bulletin & Review*, 3, 135–148.
- Peterson, S.E., Fox, P.T., Posner, M.I., Mintun, M., & Raichle, M.E. (1988). Positron emission tomographic studies of the cortical anatomy of single-word processing. *Nature*, 331, 585–589.
- Rogers, T.B., Kuiper, N.A., & Kirker, W.S. (1977). Self-reference and the encoding of personal information. *Journal of Personality and Social Psychology*, 35, 677–688.
- Stuss, D.T. (1991). Self, awareness, and the frontal lobes: A neuropsychological perspective. In J. Strauss & G.R. Goethals (Eds.), *The self: Interdisciplinary approaches* (pp. 255–278). New York: Springer-Verlag.
- 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 Medical Publishers.
- Tulving, E. (1983). *Elements of episodic memory*. New York: Oxford University Press.
- Tulving, E. (1993). Self-knowledge of an amnesic individual is represented abstractly. In T.K. Srull & R.S. Wyer (Eds.), *Advances in social cognition* (Vol. 5, pp. 147–156). Hillsdale, NJ: Erlbaum.
- Tulving, E. (1998). Brain/mind correlates of human memory. In M. Sabourin, F.I.M. Craik, & M. Robert (Eds.), *Advances in psychological science: Vol. 2. Biological and cognitive aspects* (pp. 441–460). Hove, England: Psychology Press.
- Tulving, E., Kapur, S., Craik, F.I.M., Moscovitch, M., & Houle, S. (1994). Hemispheric encoding/retrieval asymmetry in episodic memory: Positron emission tomography findings. *Proceedings of the National Academy of Sciences, USA*, 91, 2016–2020.
- Velichkovsky, B.M., Klemm, T., Dettmar, P., & Volke, H.-J. (1996). Evozierte Kohärenz des EEG II: Kommunikation der Hirnareale und Verarbeitungstiefe [Evoked coherence of EEG II: Communication of brain areas and depth of processing]. *Zeitschrift für EEG-EMG*, 27, 111–119.
- Vincent, A., Craik, F.I.M., & Furedy, J.J. (1996). Relations among memory performance, mental workload and cardiovascular responses. *International Journal of Psychophysiology*, 23, 181–198.
- Wells, G.L., Hoffman, C., & Enzle, M.E. (1984). Self- versus other-referent processing at encoding and retrieval. *Personality and Social Psychology Bulletin*, 10, 574–584.
- Wheeler, M.A., Stuss, D.T., & Tulving, E. (1997). Toward a theory of episodic memory: The frontal lobes and autonoetic consciousness. *Psychological Bulletin*, 121, 331–354.

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