Retrieval of Relational Information: A Role
for the Left Inferior Prefrontal Cortex

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Neuroimaging studies have implicated different areas of prefrontal cortex and medial temporal lobe structures (MTL) in episodic retrieval tasks. However, the role of specific regions in particular aspects of episodic memory is still unclear. In this experiment we studied changes in regional cerebral blood flow (rCBF) associated with relational and nonrelational retrieval of studied pairs of words. For relational retrieval, a list of either studied or rearranged pairs was presented and subjects (*n* = 8) were asked to indicate whether pairs had appeared on the study list. Under the nonrelational retrieval condition they indicated whether one or both words of the pair had appeared on the study list. As compared to the baseline condition (looking at a cross-mark), increased rCBF was observed in the left inferior prefrontal cortex (LIPFC) for both studied pairs and rearranged pairs under the relational retrieval condition. Under the nonrelational condition, an increase was observed in right inferior frontal gyrus. The MTL showed a trend for increased rCBF in the rearranged-pair condition. This increase was probably associated with the encoding that accompanies retrieval of novel stimuli. Results suggest that the lateralized activation of prefrontal cortex observed in episodic memory tasks may be related to the degree of relational processing involved. The LIPFC appears to be associated with relational retrieval and the right prefrontal cortex with nonrelational retrieval.   © 2002 Elsevier Science (USA)

INTRODUCTION

Binding different pieces of information, often referred to as relational processing, is one of the critical functions of memory (Cohen and Squire, 1980; Eichenbaum, 1997). Based primarily on the findings of lesion studies, it has been suggested that medial temporal lobe (MTL) structures (particularly the hippocampus) are critically involved in relational processing. It has been observed that rats with a damaged hippocampus are selectively impaired in the tasks that encourage learning of relationships among stimuli (Alvarez *et al.,* 2001; Sutherland *et al.,* 2001). Similar deficits in relational processing have been reported in patients who have hippocampal lesions (Fernandez and Tendolkar, 2001; Savage *et al.,* 2002; Scoville and Milner, 1957).

Recent neuroimaging studies have questioned the exclusivity of hippocampal involvement in processing of relational information. A number of these studies have failed to find hippocampal activation in tasks that involve relational processing (Mottaghy *et al.,* 1999; Rugg *et al.,* 1999; Simons *et al.,* 2001), whereas others have reported increased activation, in both the prefrontal and the MTL regions (Dolan and Fletcher, 1997; Henke *et al.,* 1997; Lepage *et al.,* 2000; Sperling *et al.,* 2001). These studies indicate that both prefrontal cortex and MTL structures may be involved in relational processing, although perhaps at different stages. It is possible, for example, that one of these structures is associated with the formation of associations, and the other with their retrieval.

A number of experiments have reported increased activation in the MTL region during tasks that involve encoding of relational information (Dolan and Fletcher, 1997; Lepage *et al.,* 2000). In contrast, this increase was not observed in experiments that have used relational retrieval tasks (Mottaghy *et al.,* 1999; Rugg *et al.,* 1999; Simons *et al.,* 2001). Instead, these experiments found increased activation in the left prefrontal cortex during relational retrieval tasks. A notable exception is a recent fMRI study that has reported left hippocampal activation during retrieval of related pictures (Yonelinas *et al.,* 2001). In this study, after subjects had studied pictures of colored objects, they were shown monochromatic images of the same objects and asked to recall the original color. Thus, the monochromatic test stimuli possessed novel perceptual properties compared with the studied items. Because presentation of novel stimuli is known to initiate significant

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encoding processes during retrieval (Buckner *et al.,* 2001), it is not clear whether the hippocampal activation reported in this study was associated with the encoding or retrieval activity. Previous neuroimaging studies have generally failed to directly implicate either the prefrontal or the MTL region in relational encoding or retrieval process, because these experiments either lack a nonrelational control condition or did not control for the encoding that accompanies retrieval (Buckner *et al.,* 2001). Similarly, relational encoding experiments have failed to control for the retrieval processing that occurs in an encoding task during the rehearsal phase (Smith and Jonides, 1997).

In the present experiment we examined the pattern of cortical activations during relational retrieval by comparing changes in the regional cerebral blood flow (rCBF) induced by the relational and nonrelational retrieval of unrelated studied word pairs. For the study of relational retrieval, we used a paired-associate paradigm while nonrelational retrieval involved single item recognition (described in details under Materials and Methods). To distinguish the areas associated with retrieval from those associated with the encoding processes activated during retrieval, we tested relational retrieval under two separate conditions. Under one condition, only studied word pairs were presented during retrieval (studied-pair condition), and in the other, novel pairs (constructed by rearranging the words of studied pairs; rearranged-pair condition). Because novel stimuli elicit greater encoding activity than the studied stimuli (Buckner *et al.,* 2001), comparison of the activations observed in the studied and rearranged-pair condition should help specify areas associated with retrieval-related encoding.

MATERIALS AND METHODS

The experimental protocol was approved by institutional review boards of Harvard University and Massachusetts General Hospital, Boston. Experiments were conducted using native English speaking young volunteers ($n = 8$) who were right handed, as assessed by Edinburgh handedness inventory (Raczkowski *et al.,* 1974). All subjects had normal or corrected to normal vision and hearing. In a prescan interview, they were screened to rule out a history of neurological or psychiatric disturbance, prolonged use of a prescription or recreational drug, claustrophobia, and significant prior radiation exposure. They were advised to remain alcohol free for at least 24 h and tobacco free for 3 h prior to the scan.

Eight volunteers (mean age, 20.0 years; range, 18–22; male, 4; female, 4) participated in this study. In the study phase, subjects studied 220 unrelated pairs of word. They were asked to determine whether the two words in each pair (presented for 3 s each) are associated to one another either by rhyme or by their use in a similar context. The pairs were constructed to ensure that the two words were not semantically related; any other kind of relation between the words in a pair was accidental. Volunteers were told to try to remember the pairs and were informed that in subsequent trials they would be required to recall the pairs. Following the study phase, subjects were scanned using positron emission tomography (PET) under three test conditions: *studied-pair, re-arranged-pair,* and *nonrelational*. There were two test blocks for each of these conditions. In each test block 40 word pairs were presented, each for 3 s. Out of these 40 pairs, 20 were presented in the prescan window. Subjects were scanned during presentation of the last 20 pairs of words. Under the studied-pair condition, both studied and rearranged pairs were presented in the prescan window. In the scan window, 15 studied and 5 rearranged pairs were mixed randomly. Rearranged pairs were constructed by using studied words in a different combination than they had appeared on the study list. Under the rearranged-pair condition, both studied and nonstudied pairs were presented in the prescan window and 15 rearranged and 5 studied pairs were presented in the scan window. Studied and rearranged pairs were mixed in each block to avoid automatic and anticipatory responses. Under the nonrelational condition, the prescan window consisted of 5 studied pairs, 5 rearranged pairs, and 10 novel pairs having a studied and a novel word. In the scan window 15 studied and 5 rearranged pairs were presented.

Under both the studied-pair and the rearranged-pair condition, subjects were instructed to indicate whether a presented pair had appeared earlier on the study list in the same format (i.e., the same pairing). Under the nonrelational condition subjects were asked to indicate whether one or both of the presented words came from the study list—irrespective of the pairing. Under all three conditions, they were asked to respond as quickly and as accurately as possible. Behavioral responses and response times were recorded for each trial.

Subjects were also scanned under a baseline condition in which they were asked to look at a cross-mark presented on the monitor, and relax. They were not required to make any response under this condition. Test conditions and list of words were counterbalanced across subjects and scan sequences.

Procedures used for data acquisition were similar to those used in the earlier experiments (Badgaiyan *et al.,* 1999, 2000; Schacter *et al.,* 1999). Briefly, scans were obtained using a GE Scanditronix (Uppsala) Model PC4096 (15-slice) whole body tomograph. An individually molded plastic facemask was used to minimize head motion during the experiment. At Time 0, the task was started. The PET camera was started at 30 s and continued for 90 s. At 60 s, radioactive tracer inhalation (^{15}O-labeled carbon dioxide) and emission data acquisition began. Tracer inhalation and data acquisition

lasted for 60 s. The camera recorded data in 5-s epochs for a total of 90 s. The data before radioactivity is started were used to correct for background activity from prior scans. For analysis and image formation, only the data collected between 60 and 120 sec were used. A washout period of approximately 10 min was allowed between successive scans.

After image reconstruction, PET data were analyzed using SPM99 (from the Wellcome Department of Cognitive Neurology, London, UK). The PET data at each voxel, normalized by the global mean, were considered to be the independent variable and analyzed using a univariate linear statistical model. The statistical model considered subjects (eight) as block effects, and scan conditions (four) as the main effects (residual $df = 53$), explicitly accounting for replicate measurements in a fashion equivalent to repeated measures ANOVA. It was assumed that there was no interaction between subjects (i.e., block effect) and scan conditions. Hypothesis testing was performed using the method of planned contrasts at each voxel.

We set thresholds for significance according to the theory of Gaussian fields (Friston *et al.,* 1991, 1995; Worsley *et al.,* 1992). When no localizing hypothesis or prior experimental data were available, a threshold of $z = 4.2$ was considered significant. We settled for this value because a threshold of 4.2 is considered significant for unplanned comparisons according to the theory of Gaussian fields (for calculation and discussion, see Friston *et al.,* 1991; Worsley *et al.,* 1996). When we had a priori hypotheses that localized the putative activation to a specific anatomic region, we considered a threshold of $z = 3.09$ to be significant. This threshold ($z = 3.09$) constitutes a compromise between a low threshold, uncorrected for multiple comparisons ($z = 1.96$), and a higher threshold ($z = 4.2$) suggested for unplanned comparisons (see Worsley *et al.,* 1996).

RESULTS

Behavioral data

The experiment included two conditions of relational retrieval—studied-pair and rearranged-pair. Under the studied-pair condition subjects had to remember the specific pairing of studied words to indicate whether a pair had appeared earlier on the study list. Under the rearranged-pair condition, both words of a pair were drawn from the study list, but they were paired differently. During debriefing, subjects confirmed that under the rearranged-pair condition, they had to recall the original studied pair in order to make a decision whether a pair had appeared on the study list. None of the volunteers, however, indicated awareness of the fact that the presentation of studied and rearranged pairs was blocked.

TABLE 1

Correct Response (% ± SEM) and Response Time (ms ± SEM) under Relational (Studied-Pair and Rearranged-Pair) and Nonrelational Retrieval Conditions

Condition	Correct response	Response time
Studied-pair	85.0 ± 2.4%	1713 ± 109
Rearranged-pair	81.9 ± 2.1%	1871 ± 182
Nonrelational	89.7 ± 2.2%	1643 ± 102

The percentages of pairs correctly identified under the studied and rearranged pair conditions were 85.0 and 81.9, respectively. Under the nonrelational condition subjects correctly recalled 89.7% of studied words. Differences in correct responses, however, were statistically significant ($P < 0.01$) only between rearranged-pair and nonrelational condition. Response times were shortest under the nonrelational (1643 ms) and longest under the rearranged-pair condition (1871 ms). Response time was 1713 ms under the studied-pair condition (Table 1).

Imaging Data

Relational retrieval. As compared to the baseline condition (cross-mark), significantly increased rCBF was observed under both the studied and the rearranged pair condition in the left inferior frontal gyrus (BA 47; LIPFC), Broca's area, and left fusiform gyrus. Additional increases in the orbitofrontal cortex (BA 11) under the studied-pair condition, and in the inferior frontal gyrus, medial temporal gyrus, and caudate under the rearranged-pair condition did not reach significance level (Table 2). Decreased rCBF (as compared to the baseline) was observed in left dorsal frontal gyrus (BA 10) under both studied and rearranged-pair conditions. Under the studied-pair condition left inferior frontal gyrus also showed reduced rCBF. A direct contrast between studied and rearranged pair conditions did not reveal any area of significant rCBF change. A trend for increased rCBF ($z = 3.03$) in the left hippocampus was observed under the rearranged pair condition.

Nonrelational retrieval. During nonrelational retrieval, increased rCBF (in comparison with the baseline) was observed in the right inferior frontal gyrus, left fusiform gyrus, and in Broca's area (Table 2). Significantly decreased rCBF was observed only in the left dorsal frontal gyrus, in the same region where decreases were noted under the two relational retrieval conditions (studied and rearranged-pair). Additional decreases that did not reach significance level were observed in the middle and superior temporal gyri bilaterally.

Direct contrast between relational and nonrelational conditions revealed significantly increased rCBF in the left inferior frontal gyrus (LIPFC) under both condi-

TABLE 2

Regions Showing rCBF Changes under Different Contrast Conditions

Condition and cortical area	MNI coordinate x,y,z	Talairach coordinate x,y,z	z score
Studied-pair >baseline			
1. Fusiform gyrus	−26,−90,−14	−24,−91,−17	6.66
2. Inferior frontal gyrus (BA 47)	−30,24,−2	−27,20,−1	4.34
3. Orbitofrontal (BA 11)	32,38,−34	27,34,−28	3.34
4. Broca's area (BA 44)	−36,10,24	−32,6,21	3.11
Studied-pair <baseline			
1. Dorsal frontal gyrus (BA 10)	−2,64,−2	−3,59,1	4.80
2. Inferior frontal gyrus (BA 9)	−8,48,0	−8.43.2	4.63
3. Inferior temporal gyrus (BA20)	58,−8,−28	50,−11,−25	3.62
Rearranged-pair >baseline			
1. Fusiform gyrus	−26,−92,−12	−24,−93,−1	6.00
2. Inferior frontal gyrus (BA 47)	−32,24,−3	−29,20,−3	5.07
3. Broca's area (BA 44)	−40,8.28	−36,4,25	3.67
4. Inferior frontal gyrus (BA 9/45)	−44,26,22	−40,22,20	3.17
5. Caudate	28,20,2	24,16,2	3.17
6. Medial temporal lobe	−28,−30,4	−25,−32,2	3.16
Rearranged-pair <baseline			
1. Dorsal frontal gyrus (BA 10)	−6,60,−4	−6,55,−1	5.44
2. Insula	−44,−12,−2	−40,−15,−3	3.29
3. Cingulate (BA 23)	8,−52,20	6,−54,15	3.24
4. Superior temporal gyrus (BA 22)	54,−32,22	47,−34,17	3.23
Nonrelational >baseline			
1. Fusiform gyrus	−26,−90,−14	−24,−91,−17	6.65
2. Inferior frontal gyrus (BA44/45)	46,12,24	40,8,21	4.42
3. Broca's area (BA 44)	−40,24,18	−36,4,21	3.17
Nonrelational <baseline			
1. Dorsal frontal gyrus (BA 10)	−2,46,−4	−3,41,−2	4.79
2. Middle temporal gyrus (BA 21)	−72,−54,−4	−64,−56,−7	3.46
3. Middle temporal gyrus (BA 21)	70,−54,−18	61,−56,−19	3.26
4. Superior temporal gyrus (BA 22)	60,−30,22	52,−32,17	3.25
5. Superior temporal gyrus (BA 22)	−64,10,−16	−57,6,−14	3.23
Studied-pair > rearranged pair:	None		
Studied -pair < Rearranged pair:			
1. Medial temporal lobe	−30,−32,0	−27,−34,−2	3.03
Nonrelational > studied pair			
1. Inferior frontal gyrus (BA44/45)	36,12,24	31,8,21	3.74
Nonrelational < Studied pair			
1. Inferior frontal gyrus (BA47)	−56,28,−16	−50,24,−13	3.19
Nonrelational > Rearranged pair			
1. Inferior frontal gyrus (BA44/45)	44,24,26	38,20,24	3.64
Nonrelational < Rearranged pair			
1. Inferior frontal gyrus (BA47)	−50,34,−12	−45,30,−9	3.49

Note. When no localizing hypothesis or prior experimental data were available, a threshold of $z = 4.2$ was considered significant. When we had a priori hypotheses that localized the putative activation to a specific anatomic region, we considered a threshold of $z = 3.09$ to be significant. The table, however, lists all areas having a $z > 3.0$. The MNI coordinates were generated by SPM99 while Tailarach coordinates are rough estimations.
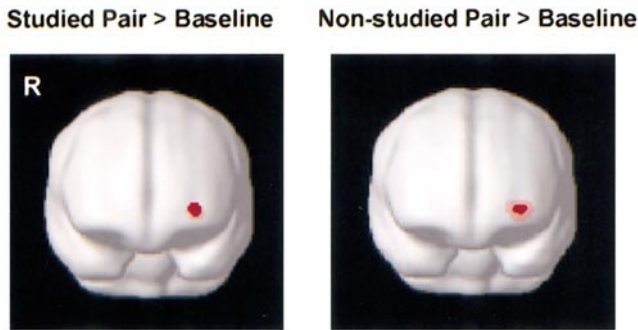
tions of relational retrieval. This contrast also revealed significantly increased rCBF in the right inferior frontal gyrus under the nonrelational condition as compared to both studied and rearranged pair conditions. These contrasts suggest that the main difference in the pattern of rCBF changes elicited under the relational and nonrelational conditions was in the lateralization of prefrontal activation. rCBF increases were lateralized on the left hemisphere during relational retrieval and on the right during nonrelational retrieval (Fig. 1).

Increased rCBF compared to the baseline condition was observed in Broca's area under all three test conditions. This finding could be attributable to the fact that subjects had to make verbal responses under the test conditions but not under the baseline condition.

DISCUSSION

We observed increased rCBF in the LIPFC under both conditions of relational retrieval (studied-pair and

Relational Retrieval

Studied Pair > Baseline   **Non-studied Pair > Baseline**

Non-relational Retrieval

Non-relational > Baseline

FIG. 1. Statistical parametric maps (SPM) showing significant rCBF changes in inferior frontal gyri under two conditions of relational retrieval (Studied-pair and Rearranged-pair condition) and under nonrelational retrieval condition. The maps are superimposed over MNI images. MNI and approximate Tailarach coordinates are provided in Table 2.

rearranged-pair). During retrieval under the nonrelational condition, there were no rCBF changes in this area. Under this condition, an increase was observed in the right inferior frontal gyrus (Fig. 1). A trend for increased rCBF in the MTL was observed under only one condition of relational retrieval (rearranged-pair).

As discussed earlier, the rearranged-pair condition was expected to elicit stronger encoding activity during retrieval because most of the word pairs presented under this condition were novel. We therefore assume that the rCBF changes observed under the rearranged condition reflect changes associated with attempted relational retrieval as well as with the encoding (Buckner *et al.,* 2001). Changes under the studied pair condition, on the other hand, should reflect primarily or entirely changes associated with relational retrieval. Thus, the area where rCBF changes were observed under both conditions (LIPFC) should be associated with relational retrieval; the area showing a change only under the rearranged-pair condition (left MTL) should be associated with the encoding activity.

The lack of rCBF changes in LIPFC under the nonrelational condition suggests that the activities of this area are predominantly associated with relational processing. Relational retrieval, however, involves two distinct processes, retrieval of the individual items (item memory) and retrieval of the link between the items. Since the right prefrontal cortex, where rCBF changes were observed during retrieval of individual items (nonrelational retrieval), was not involved in relational retrieval, it appears that the LIPFC is associated with the retrieval of both the individual items that are necessary for relational retrieval and the link between these items.

The association of LIPFC activity with relational retrieval is consistent with the observations of earlier experiments that have associated LIPFC with functions such as response selection (Thompson-Schill *et al.,* 1997), reflective and systematic processing (Nolde *et al.,* 1998), and retrieval of perceptually detailed information (Ranganath *et al.,* 2000). Because the relational retrieval task used in the present experiment includes all of these attributes, our finding appears to be in agreement with the observations of these experiments.

Based on the results of earlier studies, it is difficult to conclude whether LIPFC is involved only in relational retrieval and not in relational encoding, because increased activation in this area has been reported during retrieval (Maril *et al.,* under review; Mottaghy *et al.,* 1999; Rugg *et al.,* 1999; Simons *et al.,* 2001) as well as during encoding (Dolan and Fletcher, 1997; Mottaghy *et al.,* 1999). Because we observed increased rCBF under both conditions of relational retrieval (studied-pair and rearranged-pair), and because intensive encoding activity is not expected under the studied pair condition, our results most likely implicate LIPFC activity with relational retrieval. It is possible that increased rCBF observed in the encoding task in the previous studies were elicited by induction of retrieval processes during rehearsal, which is a part of encoding activity (Smith and Jonides, 1997).

The area of left prefrontal cortex where we observed increased rCBF during retrieval however is located more ventrally than the areas that have been reported to be active during relational encoding (Dolan and Fletcher, 1997; Mottaghy *et al.,* 1999). It is therefore possible that different areas of left prefrontal cortex are involved in different aspects of relational processing: more inferior or ventral parts might mediate retrieval, whereas the dorsal part could be more involved in encoding. This possibility is supported by the studies that have reported activation in the ventral part of left prefrontal cortex in the tasks of relational retrieval, and that of the dorsal part during relational encoding. Thus, increased activation in the inferior prefrontal region has been reported in the tasks involving association between word pairs (Maril *et al.,* under review), name and face (Simons *et al.,* 2001), item and category (Lepage *et al.,* 2000), item and context (Rugg *et al.,*

1999), semantic words (Demb *et al.,* 1995) noun and verb (Raichle *et al.,* 1994), and word and meaning (Nolde *et al.,* 1998). Relational encoding tasks that have reported increased activation in the dorsal part of left prefrontal cortex include encoding for verbal and visual associations (Opitz *et al.,* 2000), and word-pair associations (Dolan and Fletcher, 1997; Krause *et al.,* 1998; Mottaghy *et al.,* 1999). This functional specificity of dorsal and ventral regions of LIPFC, however, needs closer evaluation, particularly in view of the studies that have reported increased activation in the ventral LIPFC under certain encoding conditions (Kopelman *et al.,* 1998; Wagner *et al.,* 1998).

Our observation of increased rCBF in right inferior frontal gyrus during nonrelational retrieval condition is also in agreement with the findings of previous neuroimaging experiments that have used non relational retrieval tasks (Allan *et al.,* 2000; Badgaiyan *et al.,* 1999, 2000, 2001; Henson *et al.,* 1999; Ragland *et al.,* 2000; Rugg *et al.,* 1997; Schacter *et al.,* 1999; Wiggs *et al.,* 1999). It appears that one of the factors that determine lateralization of prefrontal activations during episodic memory retrieval is the demand for relational processing. Tasks that require processing of a significant relational information would be expected to activate the left prefrontal cortex while those that involve little or no relational processing are more likely to activate the right prefrontal cortex. There are, however, experiments that have reported increased activation in the LIPFC during single item recognition (Braver *et al.,* 2001; Otten *et al.,* 2001; Rugg *et al.,* 1999). But these experiments have used tasks that require some degree of relational processing. For example, LIPFC activation was reported during retrieval of a word that was semantically encoded when contrasted with the retrieval of the word that was alphabetically encoded (Otten *et al.,* 2001). Between these two conditions, the retrieval of semantically encoded words would likely require more relational processing because of the necessity (during retrieval) to associate these words with the semantic feature with which they were encoded.

The trend for increased rCBF observed in the MTL in the rearranged condition may be associated with encoding activity, as discussed above. This association is supported by the findings of previous experiments that have studied relational encoding. Most of these experiments have reported increased rCBF in the left hippocampal region (Dolan and Fletcher, 1997; Mottaghy *et al.,* 1999). Further, experiments concerning relational retrieval that have not used novel stimuli during a retrieval task have failed to find hippocampal activation (Krause *et al.,* 1999a; Mottaghy *et al.,* 1999). On the other hand, the experiments that have exposed subjects to novel stimuli in the retrieval tasks (and therefore activated encoding activity) have reported increased activation in this region (e.g., Yonelinas *et al.,* 2001).

It is interesting to note that under the rearranged-pair condition of the present experiment, as well as in the earlier experiments, the stimuli presented during the retrieval task possessed only contextual novelty. In the present study, the words used under the rearranged-pair condition were not novel but the pairs were. In the study reported by Yonelinas *et al.* images presented during retrieval were not novel, but they were monochromatic whereas studied pictures were colored. The sensitivity of the system to detect subtle changes in the features of stimuli raises the question of whether MTL activations observed in these experiments are associated with relational encoding, as discussed above, or whether they represent cortical processes of 'novelty detection'. The left hippocampal activations have previously been associated with detection of novel stimuli (Tulving *et al.,* 1996). The localization of increased rCBF in the posterior hippocampus suggests its association with encoding processes because in most of the published neuroimaging studies, posterior hippocampal activations were associated with encoding activities (Schacter & Wagner, 1999).

Our finding of a trend for increases rCBF in hippocampus requires cautious interpretation not only because the z-score (3.03) of this increase was below the statistical cutoff ($z = 3.09$), but also because a number of previous neuroimaging studies have reported increased rCBF in this area during a variety of episodic retrieval tasks e.g., (Schacter *et al.,* 1996; Squire *et al.,* 1992). Nonetheless, it may be interesting to explore whether some aspects of encoding processes were invoked during retrieval in these experiments.

We observed increased rCBF in the left fusiform gyrus under both relational and nonrelational retrieval conditions. Activation in this area has been reported in a variety of memory tasks that involve visual stimuli. These tasks include face recognition (Dubois *et al.,* 1999; Kapur *et al.,* 1995), object recognition (Gerlach *et al.,* 1999; Kohler *et al.,* 1998), pattern recognition (Roland and Gulyas, 1995), and word identification (Jernigan *et al.,* 1998). Increased activation has also been reported in the tasks of picture encoding (Stern *et al.,* 1996), and selective attention (Coull *et al.,* 1996). These studies however have mostly reported bilateral activations while we observed increased rCBF only in the left fusiform area. Increased activation in or around left fusiform has been reported in the tasks of relational retrieval (Krause *et al.,* 1999b; Mottaghy *et al.,* 1999) as well as relational encoding (Lepage *et al.,* 2000). Since we observed increases under both relational and nonrelational conditions, it appears that this activation is not associated with relational processing. Instead, it probably represents nonspecific activation caused by mnemonic processing of visual stimuli.

Clearly, further experiments are needed to understand the precise nature of its involvement in memory tasks.

Decreased rCBF in the left dorsal frontal gyrus and a trend for a decrease in lateral temporal areas were observed under all three conditions of the present study. The significance of these rCBF changes is unclear and may be associated with verbal or semantic processing of retrieved words. It may also be a reflection of the "priming effect" induced by representation of stimuli (Badgaiyan, 2000; Badgaiyan and Posner, 1997). We have earlier observed similar attenuation in this area in an auditory priming task (Badgaiyan *et al.,* 1999).

Our findings thus suggest that the lateralized activation of prefrontal cortex reported in a number of explicit memory tasks may be related to the degree of relational processing involved in the task. It appears that the left inferior prefrontal cortex is associated with relational retrieval and the right prefrontal with nonrelational retrieval. The results also suggest that the hippocampal activations observed in relational retrieval tasks could be associated with the encoding processes that are invoked when novel stimuli are used in the task.

ACKNOWLEDGMENTS

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