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## Brain Activation during Word Identification and Word Recognition

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Previous memory research has suggested that the effects of prior study observed in priming tasks are functionally, and neurobiologically, distinct phenomena from the kind of memory expressed in conventional (explicit) memory tests. Evidence for this position comes from observed dissociations between memory scores obtained with the two kinds of tasks. However, there is continuing controversy about the meaning of these dissociations. In recent studies, Ostergaard (1998a, *Memory Cognit.* 26:40-60; 1998b, *J. Int. Neuropsychol. Soc.*, in press) showed that simply degrading visual word stimuli can dramatically alter the degree to which word priming shows a dissociation from word recognition; i.e., effects of a number of factors on priming paralleled their effects on recognition memory tests when the words were degraded at test. In the present study, cerebral blood flow changes were measured while subjects performed the word identification (reading) and recognition memory tasks used previously by Ostergaard. The results are the direct comparisons of the two tasks and the effects of stimulus degradation on blood flow patterns during the tasks. Clear differences between word identification and word recognition were observed: the latter task evoked considerably more prefrontal activity and stronger cerebellar activation. Stimulus degradation was associated with focal increases in bilateral fusiform regions within the occipital lobe. No task, degradation, or item repetition effects were demonstrated in mesial temporal regions, no repetition effects were observed in any region, and there was no evidence for different effects of stimulus degradation in the priming and recognition memory conditions. Power limitations may have contributed to the null effects. © 1998

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### INTRODUCTION

Dissociations have been observed between performance on memory tasks requiring explicit, or conscious, recollection of prior events (such as recall and recognition tests) and performance on tasks in which

prior experience affects subsequent performance without the requirement of explicit recollection (implicit memory) (for reviews see Richardson-Klavehn and Bjork, 1988; Roediger and McDermott, 1993). Tasks requiring conscious recollection of prior events are often referred to as "explicit" memory tasks, and tasks that do not require such recollection are called "implicit" memory tasks. Implicit memory tasks usually measure some change in performance on an information processing task (e.g., word or picture identification) that results from recent prior exposure to the stimulus material. A form of implicit memory of particular interest is word priming, that is, increased facility for processing recently encountered words relative to novel words. In a word priming task, subjects may be shown words in a degraded or fragmented form. In such experiments, words that have been studied recently are named faster, or identified more accurately, than are words that were not previously studied, even if the subject is unable to recall consciously the previously studied words. This difference between performance with "new" (not recently studied) words and "old" (recently studied) words is called the priming effect.

In studies with normal individuals, several experimental manipulations have affected explicit memory measures and priming effects differently. For example, words that have been studied semantically (e.g., rated for pleasantness) are remembered better on explicit memory tests than items that have been processed at a more superficial level (e.g., studied while the subject is asked to judge whether words are written in upper- or lowercase letters) (Hyde and Jenkins, 1973). This manipulation is usually found to have little or no effect on priming measures (Jacoby, 1983; Jacoby and Dallas, 1981). Other variables that affect explicit memory measures, while having little effect on priming measures, include focused vs divided attention during study and amount of study time allowed for each item (Challis and Sidhu, 1993; Jacoby and Dallas, 1981; Parkin *et al.*, 1990). These dissociations have been interpreted as evidence that independent mechanisms mediate explicit memory and priming. Furthermore,

memory systems theorists have suggested that word priming is intact in amnesic patients with severe deficits in explicit memory and known damage to limbic structures thought to subservise explicit memory (Schacter *et al.*, 1993; Squire *et al.*, 1993; Tulving and Schacter, 1990). They interpret this to mean that the kind of memory that is reflected in word priming is mediated by an independent memory system in the brain, which is spared in amnesia, probably involving neocortical mechanisms.

An alternative explanation is that the same memory representations are involved in explicit memory and priming tasks, but that different patterns of performance arise because the different tasks engage, in addition to memory functions, other (nonmemory) cognitive processes to varying extents. Priming tasks often involve stimulus identification. Such tasks can be completed in the absence of a specific episode of prior exposure to the stimuli on the basis of perceptual information and retrieval of lexical/semantic information from memory. Explicit memory tasks, on the other hand, with their requirement that items be linked to a specific encoding event, rely almost exclusively on episodic memory for the prior exposure. Therefore, information from a prior study episode may affect performance in implicit memory tasks to a far less extent than in explicit memory tasks. Conversely, the influence of other cognitive processes may be considerably greater in priming than in explicit memory tasks.

Ostergaard (1998a) has shown that when priming tasks are constructed in which less perceptual stimulus information is available, and therefore performance is more heavily dependent on the information available in memory, priming effects are much larger and variability in priming is well correlated with performance on explicit recognition memory tasks. These effects have been demonstrated in amnesic patients as well as in normal subjects, and Ostergaard (1998b) has also shown that, under such circumstances, amnesic patients may demonstrate significantly reduced priming effects. These data are consistent with the hypothesis that the same form of memory is responsible for the study effects in word priming and recognition memory tasks and that the dissociations can best be explained in terms of the differing demands of the tasks and the amount of relevant information of different kinds (i.e., perceptual, lexical, etc.) available to the subject. A detailed description of word priming effects in these terms has been referred to as the Information Availability Model (Ostergaard, 1998a).

Anatomical evidence relevant to this model was obtained in a study by Jernigan and Ostergaard (1993). Patients with caudate nucleus damage were shown to have deficits in stimulus identification on priming tasks. These patients also showed increased priming,

consistent with the idea that due to their stimulus-processing deficits they relied more heavily on information from the prior study episode. When deficits in stimulus identification were taken into account, priming performance was shown to be correlated with explicit memory performance and with degree of mesial temporal lobe damage.

The work described below is an attempt to delineate the neural bases of the processes involved in those word identification and recognition memory tasks used in the previous experiments by Ostergaard and to examine specifically the effects of stimulus degradation (i.e., reduction of the amount of stimulus information available to the subject) on brain activation during word identification and word recognition. Positron emission tomography (PET) was used to examine cerebral blood flow during six word identification and four recognition memory conditions in each of eight normal volunteer subjects. The effects of stimulus degradation and previous exposure to the presented items were examined for both tasks, and the pattern of brain activation during recognition memory performance was directly compared to that during word identification.

This study is primarily exploratory; however, some tentative predictions can be advanced based on the IA model. In describing the IA model in neurological terms it is useful to distinguish between neural events occurring at study and those occurring at test. It is assumed that exposure to the study materials leads to specific neural changes in the regions of the brain that participate in the processing of the materials during the study episode. Such changes are considered to be the substrate of any study effects observed behaviorally in subsequent tests, whether implicit or explicit. Dissociations observed in behavioral measures from implicit and explicit memory tasks are considered to arise because the two kinds of paradigms invoke different cognitive processes at test and these processes interact with the study-related neural changes differently. The distinction between our model and those of others is that we think that the neural changes underlying the study effects are the same in the implicit and explicit case, whereas systems theorists assert that different memory traces are "read out" during implicit and explicit memory tests. We would predict significant differences between the patterns of activation produced by recognition and word identification because of the different arrays of cognitive processes invoked by these test conditions. We would also predict study-, or repetition-, related deactivation in regions contributing to the processing of the materials in both tasks. We would predict increased activation of regions contributing to the processing of the materials at study when the materials are degraded.

## MATERIALS AND METHODS

### Subjects

Eight right-handed volunteers (six male, two female) ranging in age from 20 to 35 years (mean age, 24) participated in this study. All were reportedly free of serious previous or current medical, psychiatric, or neurological illness. Informed consent was obtained according to the Declaration of Helsinki II and the study was approved by the local ethics committee of Copenhagen (J. No. (KF) 01-339/94).

### Cognitive Tasks

The tasks involved the visual presentation of words on a computer screen. There were 12 scans, 6 while the subjects read aloud words as they were presented, 4 while subjects responded "old" to words previously presented and "new" to words not presented earlier, and 2 while the subjects simply fixated on a central cross on the screen. The words used were all high-frequency nouns selected from a list of the 10,000 most frequently used words in Danish (compiled from the text of newspapers, magazines, and books by the Institute of General and Applied Linguistics at Copenhagen University). Word lists used in the different conditions were matched for word frequency and word length.

Approximately 4 min before each of the 12 scans, a study list of 30 novel words was presented for the subject to read. Within both the read and the recognize scanning conditions, stimulus sets were presented that were almost all (90%) old (i.e., from the immediately preceding study list) or almost all new (not from any presented list) words. In half of the conditions the words were presented in visually degraded form and in the other half in an undegraded form. In addition, half of the old-word reading trials followed the presentation of degraded study lists and half followed the presentation of undegraded study lists. The first and last conditions were always fixation conditions. The remaining 10 conditions were therefore as follows: (1) undegraded novel words—read, (2) degraded novel words—read, (3) undegraded old words—read (study words undegraded), (4) degraded old words—read (study words degraded), (5) undegraded old words—read (study words degraded), (6) degraded old words—read (study words undegraded), (7) undegraded novel words—recognize, (8) undegraded old words—recognize, (9) degraded novel words—recognize, and (10) degraded old words—recognize. The 6 identification conditions were always blocked, as were the 4 recognition memory conditions; however, within blocks the order of the conditions was varied and balanced as well as possible across eight subjects. Half of the subjects received the identification

block first and the other half received the recognition block first.

The critical "uptake" epoch contained almost all novel or old words as stipulated, but these stimuli were embedded within a stream of words containing novel and repeated words, so that the subjects were unlikely to have changed "set" during uptake. Specifically, beginning 45 s before each injection a continuous stream of 38 words was presented. The first 18 words contained 9 new and 9 old words and these were presented in a random order. Thus up until injection, old and new words were equally likely. Then began a series of 20 words, only 2 of which were discordant with the specified condition. Thus from the point of injection until 50 s after, either 90% of the words were old or 90% were new. At the end of the 50 s, the fixation cross appeared in the center of the screen.

For all trials, both at study and at test, naming latency was measured in the experiment with a voice-activated switch, and the examiner recorded all recognition responses and any reading errors.

Words were presented centrally in block letters for 2 s each, and each was followed by a blank screen lasting 500 ms. Thus each trial lasted 2.5 s. Stimulus degradation was achieved by superimposing a masking stimulus over the words such that the contours of the mask eroded the coinciding contours of the words. Thus degraded words appeared fragmented, with parts of some of the letters missing. An example of the degraded stimuli is shown in Fig. 1.

### PET Procedures

PET scans were obtained with an 18-ring GE-Advance scanner operating in 3D acquisition mode, producing 35 image slices with an interslice distance of 4.25 mm. The total axial field of view was 15.2 cm with an approximate in-plane resolution of 5 mm. The technical specifications have been described elsewhere (DeGrado *et al.*, 1994).

Each subject received 12 intravenous bolus injections of 200 MBq (5.7 mCi) of  $H_2^{15}O$  with an interscan interval of 10–12 min. Before the activation session a 10-min transmission scan was performed for attenuation correction. Images were reconstructed with a 4.0-mm Hanning filter transaxially and an 8.5-mm ramp filter axially. The resulting distribution images of time integrated counts were used as indirect measurements of the regional neural activity (Fox and Mintun, 1989).

Image analysis was performed using statistical para-



FIG. 1. Example of a degraded word stimulus.

metric mapping software (SPM-95; MRC cyclotron unit, London, UK) (Frackowiak and Friston, 1994). All intra-subject images were aligned on a voxel-by-voxel basis using a 3D automated six-parameter rigid body transformation (AIR software) (Woods *et al.*, 1992) and transformed into the standard stereotactic atlas of Talairach and Tournoux (Friston *et al.*, 1995; Talairach and Tournoux, 1988). The stereotactically normalized images consisted of 31 planes of  $2 \times 2 \times 4$ -mm voxels. Before statistical analysis, images were filtered with a 16-mm isotropic Gaussian filter to increase the signal-to-noise ratio and accommodate residual variability in morphological and topographical anatomy that was not accounted for by the stereotactic normalization process (Friston, 1994). Differences in global activity were removed by proportional normalization of global brain counts to a value of 50.

Two simple subtraction analyses were performed to attempt to characterize the basic pattern of brain activation observed (relative to fixation) in the two tasks, i.e., word identification and word recognition. The major analyses, however, treated the dataset as a  $2 \times 2 \times 2$  (task, identification vs recognition; stimulus degradation, degraded vs undegraded; and repetition, old vs new) analysis of variance. The main effects of task, stimulus degradation, and repetition were examined, as were the two-way and three-way interactions. Since two of the identification conditions involved stimulus degradation at study, and none of the recognize conditions did, these two identification conditions were omitted from the major analyses so that the design was balanced. The main effects and interactions were examined in SPM by comparing averages of the scans within each of the contrasted conditions on a voxel-by-voxel basis. The resulting set of voxel values constituted a statistical parametric map of the  $t$  statistic,  $SPM(t)$ . By transforming values from the  $SPM(t)$  into the unit Gaussian distribution using a probability integral transform changes could be reported in  $Z$  scores ( $SPM(Z)$ ). The threshold for  $P(Z \max > u)$  was set at  $<0.05$  and for  $P(n \max > k)$  at  $<0.05$ , and the resulting foci were then characterized in terms of the number of contiguous voxels with uncorrected  $P < 0.001$  and peak  $Z$  score, as well as the position in Talairach coordinates of the voxel with maximum  $Z$ . In other words, a corrected (for multiple comparisons)  $Z$  score with  $P < 0.05$ , or a corrected  $Z$  score for extent of the activation with  $P < 0.05$ , was required to define a focus of significant activation. Descriptions below of the locations of the significant activations delineate their extent in Talairach space using conventional anatomical nomenclature. Approximate location relative to Brodmann's areas has been added when such labeling would help to identify subregions into which the activations extended.

## RESULTS

### Behavioral Results

Comparison of baseline naming latency (for new words) in the degraded conditions to those in the undegraded conditions revealed significantly longer latencies in the former condition than in the latter (means, 815 and 653 ms, respectively;  $F = 191.6$ ,  $P < 0.001$ ). In both conditions, latencies were reduced for recently studied items relative to novel items. There was on average a 37-ms priming effect for undegraded words and a 104-ms priming effect for degraded words (main effect of priming,  $F = 31.6$ ,  $P < 0.001$ ). Furthermore, a significant study by degradation effect was obtained, revealing that priming effects were significantly larger for degraded than for undegraded words ( $F = 13.5$ ,  $P < 0.01$ ).

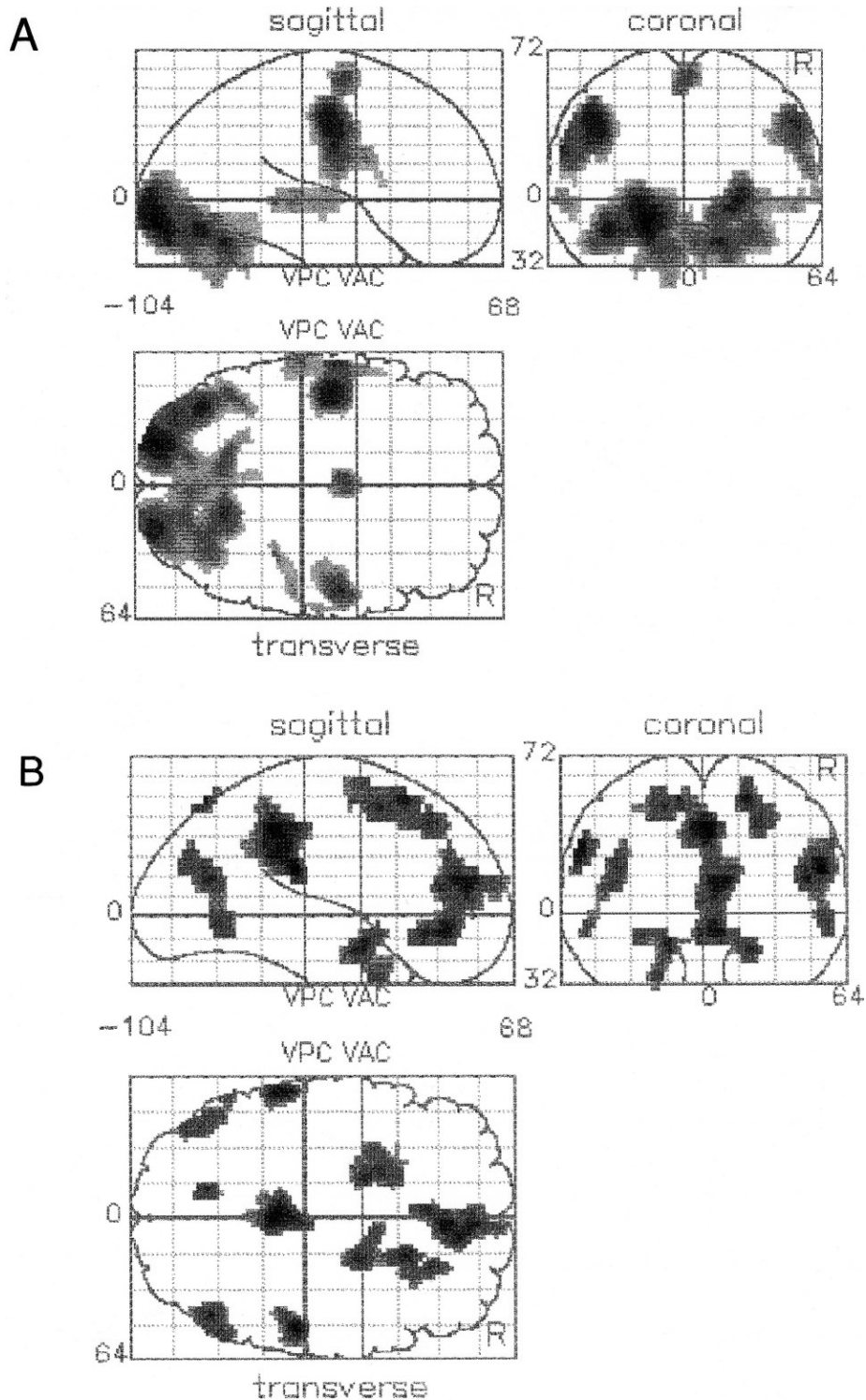
### Brain Activation during Word Identification

The six conditions during which the subjects identified words were contrasted with the two fixation conditions. The areas significantly activated by word identification are listed in Table 1, and the pattern of activation is shown schematically as projected within three orthogonal views in Fig. 2A. Extensive bilateral occipital and cerebellar activation was noted, apparently more prominent on the left. The areas activated included Brodmann's areas 17, 18, 19, and 37. Bilateral activation of middle temporal gyrus (area 21) was also observed, again apparently stronger on the left. There was also extensive bilateral activation of the pre- and

TABLE 1

Word Identification vs Fixation

Region	Size ( $k$ )	$P$ ( $n \max > k$ )	$Z$	$P$ ( $Z \max > u$ )	$x$	$y$	$z$
Increased in identification							
Bil occ./cerebellum	3415	0.000	7.72	0.000	-18	-94	-8
L precentral G	647	0.000	7.35	0.000	-44	-14	40
R precentral G	379	0.000	6.18	0.000	52	-10	36
Medial frontal G	118	0.030	5.57	0.000	-2	-8	56
R middle temp G	75	0.110	4.61	0.034	34	-40	0
L middle temp G	125	0.024	4.46	0.061	-60	-30	0
Increased in fixation							
Post cingulate G	285	0.014	5.51	0.000	2	-40	40
R postcentral G	151	0.076	5.37	0.000	52	-30	20
Medial frontal G	571	0.001	5.15	0.001	4	36	-8
R superior frontal G	216	0.032	5.06	0.002	18	18	52
L inferior parietal L	110	0.137	5.04	0.002	-56	-38	28
R middle temp G	174	0.055	4.79	0.006	46	-68	16
L precuneus	29	0.512	4.75	0.008	-12	-70	52
L entorhinal cortex	151	0.076	4.69	0.010	-18	0	-12
R entorhinal cortex	113	0.131	4.62	0.013	20	-2	-16
L medial frontal G	147	0.080	4.58	0.015	-18	8	48
L middle temp G	151	0.076	4.33	0.042	-40	-72	20



**FIG. 2.** The projections of regions with increases in activity during word identification relative to fixation (A) and during fixation relative to word identification (B), with  $P < 0.05$  (corrected) in three orthogonal planes.

postcentral gyri (areas 6 and 4), also stronger on the left where it extended into area 44, "Broca's area." A focus of midline medial frontal (area 6) activation was also observed.

Because a pattern of activation is meaningful only in the context of a specific "control" task, significant decreases during identification are also given. A number of areas were more active during fixation than

TABLE 2

## Word Recognition vs Fixation

Region	Size (k)	P (n max > k)	P (Z max > u)				
			Z	x	y	z	
Increased in recognition							
Bil. occ./cerebellum	4327	0.000	8.45	0.000	-36	-72	-16
L precentral G	362	0.000	6.48	0.000	-44	-12	40
R inferior frontal G	229	0.002	5.86	0.000	44	14	4
R precentral G	180	0.006	5.78	0.000	50	-10	36
Midline med frontal G	326	0.000	5.61	0.000	0	-4	60
L anterior insula	84	0.083	5.21	0.002	-30	20	4
R middle temp G	75	0.110	4.90	0.010	50	-32	-4
Increased in fixation							
R postcentral G/post cingulate G	1528	0.000	7.25	0.000	52	-30	20
L inferior parietal L	307	0.011	6.78	0.000	-56	-34	28
Medial frontal G	934	0.000	6.10	0.000	4	36	-8
L middle temp G	353	0.006	5.99	0.000	-44	-66	12
R middle temp G	248	0.021	5.46	0.000	44	-70	16
L entorhinal cortex	162	0.065	5.17	0.001	-16	-2	-16
L middle frontal G	130	0.102	4.89	0.004	-28	16	44
R entorhinal cortex	267	0.017	4.74	0.008	22	-2	-16
L middle frontal G	47	0.376	4.65	0.011	-34	32	24

identification (Table 1, Fig. 2B). These include bilateral regions in postcentral and middle temporal cortices, posterior cingulate, bilateral entorhinal cortex adjacent to the amygdala, medial frontal gyri, left inferior parietal lobule, left precuneus, and right superior frontal gyrus.

### Brain Activation during Word Recognition

Relative to fixation, the activation during word recognition, summarized in Table 2 and Fig. 3A, was very similar to that observed during word identification: Bilateral occipital and cerebellar foci, apparently stronger on the left, were observed in this contrast as in the previous. A small focus of right hemisphere middle temporal (area 21) activation was noted. As in the previous contrast, bilateral precentral gyrus (area 6) activation was observed, as was a medial area 6 activation. However, the midline activation extended more ventrally into the anterior cingulate region. Word recognition also evoked bilateral activation of inferior frontal regions (primarily area 45), which was apparently stronger within the right hemisphere.

A number of areas were more active during fixation than during recognition (Table 2, Fig. 3B). These were very similar areas to those more active during fixation than during identification. The areas included bilateral regions in postcentral and middle temporal cortices, posterior cingulate, bilateral entorhinal cortex adjacent to the amygdala, medial frontal gyri, and left inferior parietal lobule. In addition there were areas of activation in the left middle frontal gyrus in BA 8 and 9.

### Main Effect of Task

The direct comparison of the word recognition conditions with word identification conditions in the SPM analysis of variance produced a pattern of positive blood flow changes during recognition described in Table 3 as increased in recognition and illustrated in Fig. 4. Recognition produces more activation in left cerebellum. Frontal lobe activation was also more extensive in the recognition conditions, particularly within the right hemisphere. Ventrally, a right insular and inferior frontal area of activation (area 45) and another frontal polar (area 10) activation were observed. More insular activation was also noted in the ventral left insula and inferior frontal gyrus (area 47). The right cingulate and medial frontal gyrus (areas 32 and 6) were also more activated by recognition than word identification. Finally, there was a more dorsal, right hemisphere, activation in the middle frontal gyrus (area 9).

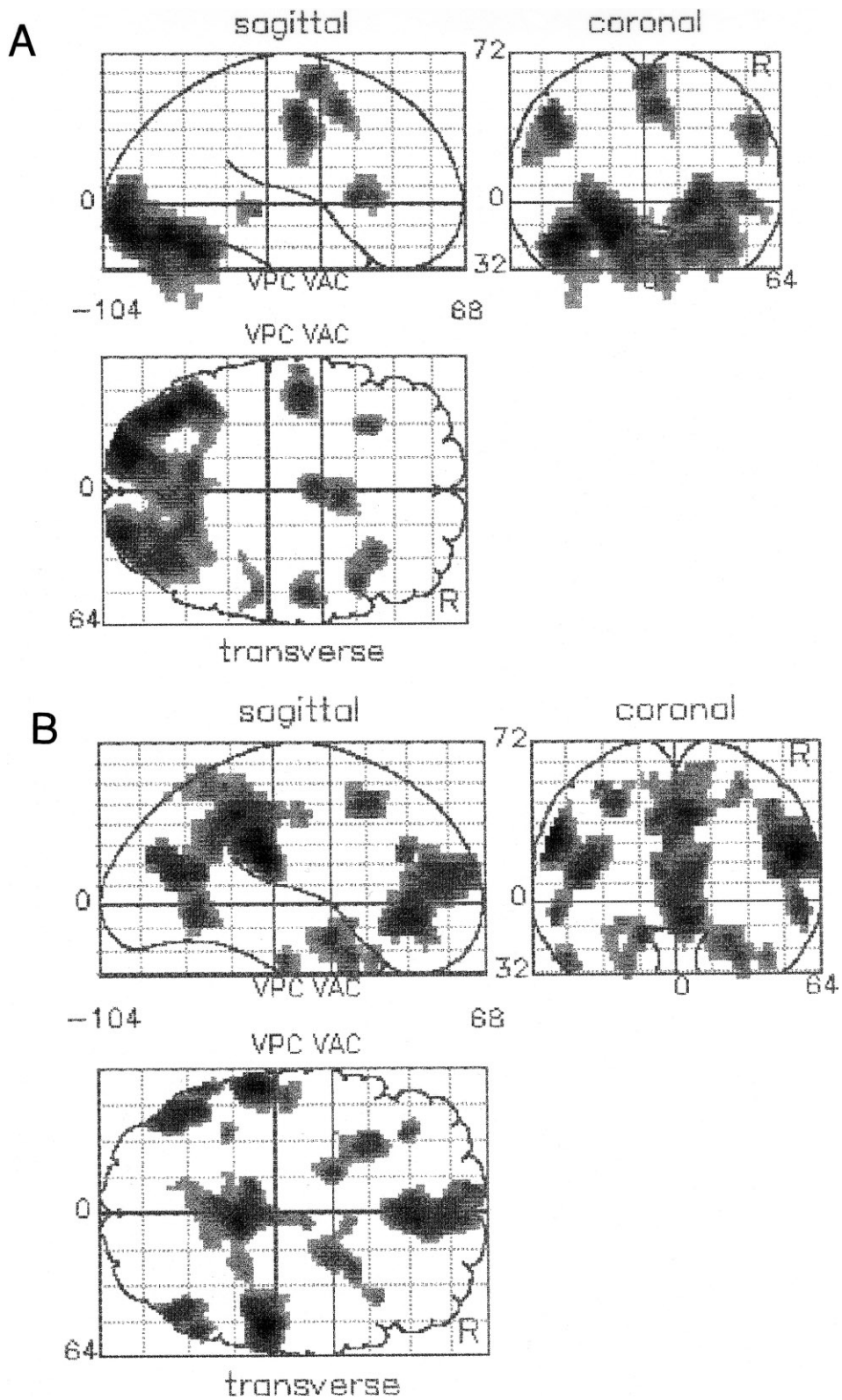
There were a number of areas that were significantly more active during word identification than during word recognition conditions (Table 3, Fig. 4). These areas, referred to in the table as increased in identification were predominantly within the left hemisphere. A region in the left frontal operculum (areas 6, 44) which extended ventrally into the left temporal pole (area 22) was more active during word identification. A nearby region in the left middle temporal (angular) gyrus (area 39) was also activated. There were bilateral areas of increased activity in the inferior parietal lobule (area 40) which stretched ventrally into areas 41 and 42 of the superior temporal gyrus, more extensively on the left.

### The Effect of Degrading the Visual Word Stimuli

The main effect of stimulus degradation was increased blood flow in bilateral occipital lobe during degraded stimulus conditions (Table 4). The pattern obtained was very similar for both identification and recognition and the task by stimulus degradation interaction analysis revealed no areas of significant interaction. Degraded words produced greater activation than undegraded words bilaterally in the fusiform gyri (Fig. 5). No areas of increased activation for undegraded relative to degraded words were detected.

### Comparison of Novel Word to Studied Word Conditions

The analysis of the main effect of repetition (old vs new words) failed to produce any areas of flow increase or decrease that approached the criteria for significance. Exploratory post hoc analyses examining medial temporal regions with relaxed statistical criteria also failed to reveal any convincing activations in these regions. In addition, none of the interaction analyses



**FIG. 3.** The projections of regions with increases in activity during word recognition relative to fixation (A) and during fixation relative to word recognition (B), with  $P < 0.05$  (corrected) in three orthogonal planes.



**TABLE 3**  
Word Recognition vs Word Identification

Region	Size (k)	P (n max > k)	P (Zmax > u)				
			Z	x	y	z	
Increased in recognition							
L lateral cerebellum	406	0.000	5.79	0.000	-36	-64	-36
R anterior cingulate	373	0.000	5.72	0.000	8	12	44
R inferior frontal G	347	0.000	5.72	0.000	44	14	4
R midfrontal G (10)	235	0.001	5.42	0.001	26	38	-4
L anterior insula	142	0.008	5.01	0.008	-30	22	0
R midfrontal G (9)	119	0.016	4.25	0.165	44	28	32
Increased in identification							
L posterior insula	289	0.000	5.08	0.005	-38	-6	16
L middle temp G	112	0.020	5.07	0.006	-42	-60	16
R inferior parietal L	256	0.000	4.90	0.012	40	-26	28
L inferior parietal L	259	0.000	4.62	0.040	-50	-30	24

involving repetition produced evidence of significant interactions.

## DISCUSSION

### Task Performance Measures

Behavioral results with this small group of subjects are entirely consistent with those obtained by Ostergaard (1998a) using a very similar word priming paradigm. They revealed that priming effects can be markedly increased in size by increasing the difficulty of the baseline task, in this case, by visual degradation of the word stimuli. In previous studies it has been shown that the larger priming effects associated with degraded stimuli also vary as a function of the level of processing during study and the number of study repetitions, factors known to influence explicit memory performance. Ostergaard (1998b) has also shown that priming under stimulus degradation conditions is significantly impaired in amnesic patients, who have been thought to have normal priming.

### Single-Word Processing and Recognition Memory

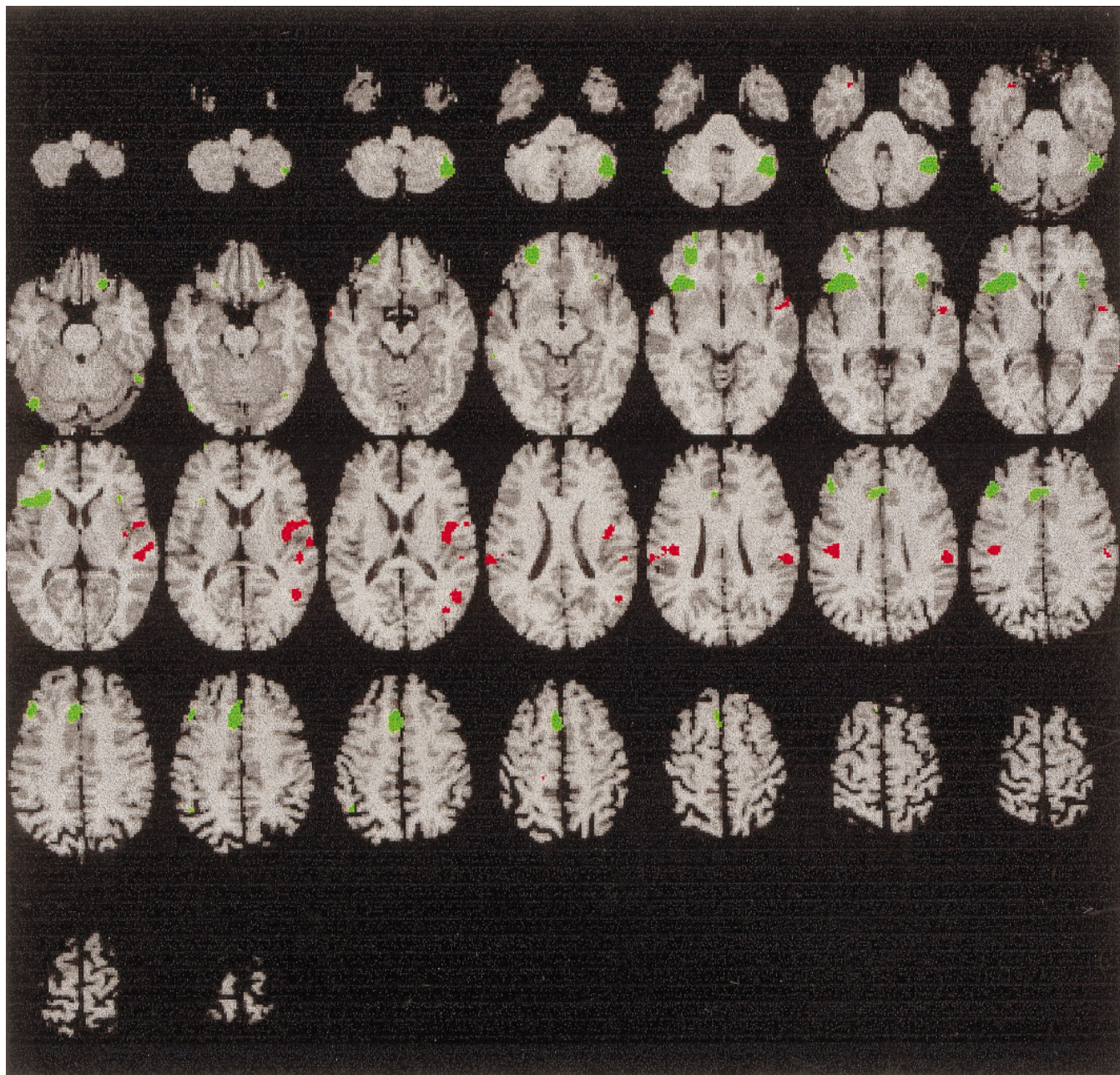
In many respects, the patterns of activation obtained in the word identification and word recognition conditions (relative to fixation) resemble those obtained previously in functional imaging studies of reading and verbal memory retrieval. Spoken identification of visually presented words has previously been shown to activate cerebellar, occipital, middle temporal, and precentral sites (Petersen *et al.*, 1990; Petersen and Fiez, 1993). It is of some interest that although spoken word identification produced strong and extensive activation in supplementary motor areas bilaterally (and more strongly on the left), activation of more anterior areas was very limited. In only one small region (near

area 44 on the left) did activation fall anterior to the plane of the anterior commissure. No ventrolateral prefrontal activation, e.g., in area 45, such as was observed in a repetition task (Petrides *et al.*, 1995) was obtained. This supports the contention that more anterior ventrolateral regions are involved only in more active retrieval of verbal responses (Petrides *et al.*, 1995) or in retrieval of information that is not strongly associated in memory with the stimuli (Petersen and Fiez, 1993). In the present word identification task, the response retrieved is overlearned and is prompted exogenously by the visual stimulus. Task demand for retrieval of a word response does not appear to be sufficient to evoke ventrolateral prefrontal activation (relative to fixation).

The contrasts between old/new word recognition and word identification are also largely consistent with a number of hypotheses about the neural bases of retrieval from verbal episodic memory. The most striking aspect of the additional activation induced by the recognition memory task was the appearance of several right prefrontal sites of activation, accompanied by a strong left cerebellar activation. There were four distinct prefrontal sites of activation. There was a strong activation in cingulate cortex and adjacent medial frontal gyrus that was situated slightly, but consistently, to the right of the midline. There were also two areas of ventrolateral activation. One of these appeared bilaterally within the ascending ramus of the lateral sulcus. The extent of this activation was quite different in the right and left hemispheres. On the right it covered the entire posterior surface of the insular segment of the inferior frontal gyrus from its lateral to its most mesial extent. On the left the activation was limited to a small region in the most mesial part of the gyrus at the anterior tip of the insula. The second ventrolateral activation was at the same axial level as these insular activations, but occurred more anteriorly in the right frontal pole (area 10). Finally, there was a more dorsally lying region of increased activity in the right middle frontal gyrus within area 9.

These, predominantly right hemisphere, prefrontal activations are consistent with a recent model of hemispheric asymmetry in memory retrieval which posits that retrieval from episodic memory invokes the function of right prefrontal structures (Tulving *et al.*, 1994; Nyberg *et al.*, 1996), and they are also consistent with many previous observations of right prefrontal activation by tasks requiring retrieval of recently studied material (see Nyberg *et al.*, 1996, for review).

It is interesting to compare the results of the present study with those of Petrides *et al.* (1995). These authors posit that a left ventrolateral frontal region near area 45 is involved in the "strategic retrieval" of verbal information from long-term or episodic memory. They contrast the function of this region with that of a more



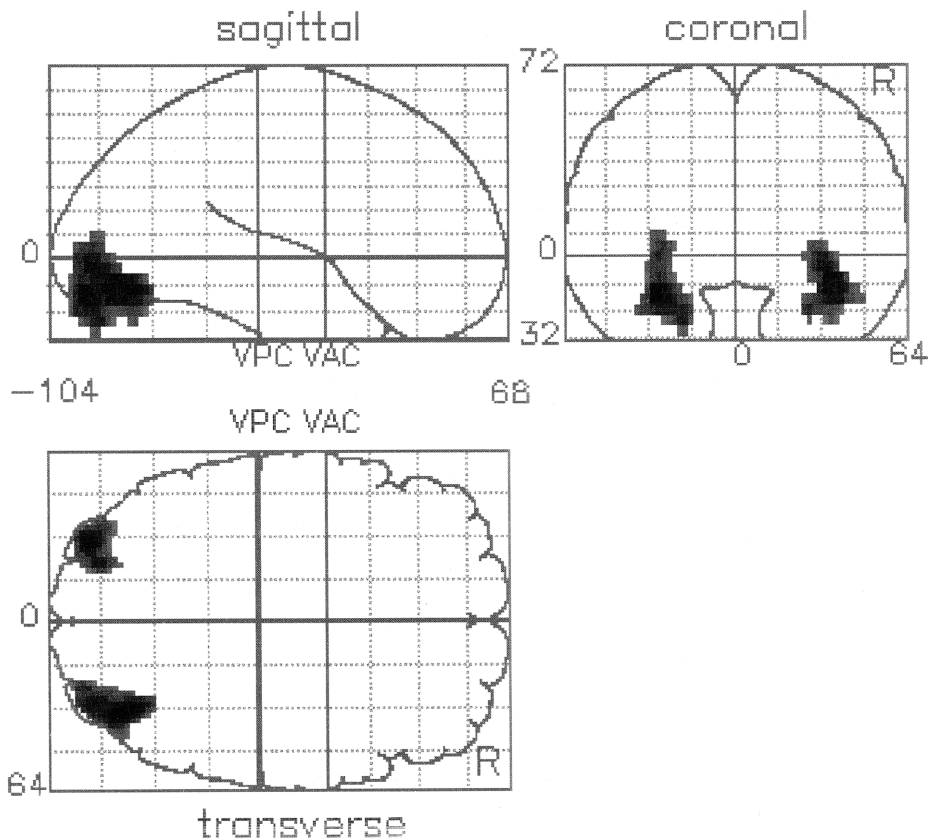
**FIG. 4.** The SPMs of the main effect of task (recognition vs identification) overlaid on anatomical template sections. Regions mapped in green were more active in recognition than identification, those in red more active in identification.

**TABLE 4**

Identification of Degraded vs Undegraded Words

Region	Size ( $k$ )	$P$ ( $n \max > k$ )	$Z$	$P$ ( $Z \max > u$ )	$x$	$y$	$z$
R fusiform G	355	0.000	5.21	0.003	36	-78	-12
L fusiform G	254	0.000	4.96	0.009	-30	-90	-16

dorsal area near areas 9 and 46, which they propose may be involved specifically in the monitoring of memory responses in working memory. As evidence for this distinction, they have reported results with PET showing area 9/46 activation by several tasks requiring the subject to keep track of recent responses, whereas the ventrolateral region has been more consistently activated by tasks requiring retrieval of verbal information (Petrides *et al.*, 1993, 1995). Both regions were significantly more activated by the word recognition than by



**FIG. 5.** The projections of regions activated ( $P < 0.05$ , corrected) by degraded relative to undegraded word conditions in three orthogonal planes.

the word identification conditions in the present experiment. The ventrolateral frontal activation is consistent with the earlier reports, as the recognition task may place heavier demands on retrieval of verbal information in long-term memory than the identification task. However, the laterality of the present results would appear to differ from that observed in the earlier study by Petrides *et al.* (1995) in which verbal recall activated left, but not right, ventrolateral frontal cortex. In the present experiment, bilateral activation was obtained, but the right hemisphere activation was considerably stronger and more extensive. The difference could be due to a number of differences between the studies, including the use of identification vs repetition as a baseline and the requirement for recognition vs recall from memory, among other things. However, one clear difference that may relate to the different laterality results is intensity of study. The words in the present experiment had been studied only once in a list administered before the scan began. In contrast, in the Petrides *et al.* (1995) study, the words were administered in six learning trials and were probably well-learned before scanning of recall performance began. This suggests that the right hemisphere may be differentially activated not by episodic memory retrieval per

se, but by more difficult retrieval of incompletely learned material in episodic memory.

The activation of area 9/46 by the recognition task is somewhat difficult to reconcile with the "monitoring" hypothesis, because it is not clear how old/new recognition performance requires monitoring of responses in working memory. Perhaps such activation is more closely tied to the selection of the appropriate old vs new verbal response or to the contextual memory processing that must be necessary to disambiguate recently studied words from unstudied, but commonly encountered, words in single-word recognition experiments such as this.

Largely null effects were obtained for most comparisons of old word and new word conditions. This may primarily be due to the complexity of the study design and the resulting lack of repetitions of critical conditions (i.e., low power). It may also be due to the fact that the words used in the present experiment are fairly common words encountered by most subjects fairly often. Under these circumstances, processing effects of a single additional encounter (during the study episode) may be subtle and may fall below the threshold of change detectable with these methods. It should be noted that others have observed significant differences

between retrieval conditions with novel and recently studied items. Schacter *et al.* (1996) reported activation of the hippocampal region during retrieval of studied, relative to unstudied, words in a cued recall task with word-stem stimuli. These authors also reported deactivation in extrastriate cortex associated with priming (completion of previously studied words). We were unable to detect significant deactivation of extrastriate cortex during word identification of studied words or hippocampal activation associated with recognition of studied words.

Squire *et al.* observed right hippocampal activation during cued recall (Squire *et al.*, 1992) relative to word-stem completion, and this result was partly replicated by Buckner *et al.* (1995). In both studies, when primed stem completion (half of the stems could be completed with studied words) was compared to unprimed stem completion, extrastriate deactivation was also observed. In the present experiment no significant hippocampal activation associated with retrieval in the recognition conditions was observed (relative to the word identification conditions). Thus, in this context, an explicit memory condition did not necessarily activate hippocampal structures relative to an implicit condition. However, even in studies that contrasted explicit memory retrieval conditions with nonmemory baseline conditions, hippocampal activations have not always been observed (Tulving *et al.*, 1994; Shallice *et al.*, 1994; Moscovitch *et al.*, 1995; Kapur *et al.*, 1995; Haxby *et al.*, 1993). The lack of such effects in the present study (as well as some others) may be related to limited power. Another possibility is that recall, particularly difficult recall, may rely more heavily on the hippocampal region than recognition.

In this study, as in several previous studies, changes in cerebellar activity were observed in a number of contrasts. Both word identification and recognition memory evoked bilateral cerebellar activity relative to fixation, perhaps as a result of the verbal response demands of these tasks. Both tasks evoked activity in medial cerebellar regions. However, a strong left hemisphere *lateral* cerebellar activation was observed for the recognition memory task only. Since the motor response demands of the two tasks are very similar, the increased activation of left lateral cerebellum is likely to be related to task differences on more purely cognitive dimensions. Such lateral cerebellar activations have been observed in combination with prefrontal activations in a number of previous studies (Petersen and Fiez, 1993; Price *et al.*, 1994; Buckner *et al.*, 1995; Fiez *et al.*, 1996), and these have sometimes appeared when there were no clear motoric differences between experimental and baseline tasks. Some authors have suggested that frontal and cerebellar regions form a functional network subserving working memory or verbal rehearsal. It is not clear how the recognition

task of the present experiment places greater demands on these functions; however, it is possible that subjects rehearse items from the study list during the recognition task. The recognition task does place greater demands on internal response generation and selection and on comparison of the visual stimuli with memorized representations of a specific episode. Thus it is possible that lateral cerebellar regions, as well as prefrontal regions, contribute to these functions.

### Effects of Stimulus Degradation

The comparison of conditions with degraded vs undegraded words showed a strong area of increased activation in bilateral occipital regions, mainly in the fusiform gyrus. It is interesting that the increase in activity was lateral, in light of earlier findings by Petersen *et al.* (1990) suggesting that false font and nonword letter strings produce equivalent activation relative to words and pseudowords in lateral extrastriate areas, but the latter produce increased activation in medial extrastriate areas. This was considered by these authors to be evidence that such medial extrastriate areas may constitute a visual word form region. If so, visual degradation of word forms does not apparently alter the activity in such a region, but it does evoke additional activity in more lateral extrastriate areas, particularly on the right, that may be disproportionately involved in the processing of nonlinguistic visual stimuli. Bookheimer *et al.* (1995) have suggested that medial occipital regions are specialized not for word forms per se, but for more familiar visual stimuli. If so then the increase in lateral occipital activity may be because degraded words are less familiar visual stimuli.

The increase in fusiform gyrus activity observed in the present study would appear to be in conflict with a decrease in activity in this region associated with stimulus degradation in a face-matching task (Grady *et al.*, 1996). However, a number of differences between the studies may account for this discrepancy. In the face-matching study, the trials were paced by the subjects' responses, so that fewer stimuli were presented during highly degraded than during lightly degraded conditions. The subjects' responses were both slower and less accurate during high-degradation conditions, so that it is likely that no actual face recognition was achieved during some trials, and more of such trials would have occurred in association with high levels of degradation. In contrast, in the present study the rate of stimulus presentation was constant for all subjects and across the degradation conditions. Also, although the subjects' naming latencies were longer for degraded words, very few naming errors occurred during either condition, and virtually all were self-corrected immediately. Therefore it is likely that the actual number of successfully decoded stimuli was similar in the degraded and undegraded conditions.

Another difference is that the perceptual task employed in the face-matching study is considerably more complex and likely recruits a number of additional processing modules distinct from those recruited by word identification. It may be the interaction between these additional processes and those performed in the fusiform region that accounts for the difference.

The IA model of word identification posits that increases in priming associated with visual degradation of word stimuli occur because the need for increased perceptual processing of the stimuli provides greater opportunity for information in memory (including any increase in such information that may have resulted from a recent study episode) to influence the identification process. When words are presented clearly, identification is accomplished so efficiently, based primarily on the orthographic information alone, that there is very limited scope for performance facilitation due to a recent increase in memory strength for the studied items. Therefore, priming effects in these conditions are small, and little variability in the size of the priming effect is attributable to factors normally affecting memory strength. The present results suggest that identification of degraded words does increase perceptual processing demands and that such demands evoke increased activity in lateral extrastriate regions. Increases in naming latency, and in priming for degraded relative to undegraded words, were observed in this, as well as numerous other, experiments (Ostergaard, 1998a).

The fact that only extrastriate activity differentiated the processing of degraded from that of undegraded stimuli is consistent with the notion that memory retrieval mechanisms proceed in a similar manner, i.e., with similar degrees of activation of contributing structures, in the two conditions. However, increased naming latency for degraded words, induced by heavier perceptual processing demands, allows the output of such retrieval mechanisms to have a greater influence on the subject's identification performance, since more information from memory accumulates before identification is possible. There is no evidence from this experiment that identification of degraded words recruits an explicit memory system that is not active during the identification of undegraded words. That is, there were no significant increases in the activity in mesial temporal, diencephalic, or prefrontal regions during identification of degraded, relative to undegraded, words. Neither was there evidence of an interaction of the factor "stimulus degradation" with task or repetition. It should be noted, however, that, given the conservative criteria adopted for defining an activation difference, interpretation of such null effects is ill-advised. Although relaxing the criteria did not result in obvious additional activations or deactivations in memory-related structures, underlying differences in

memory system activation cannot be ruled out by these results.

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