

REGIONAL brain activity associated with intentional and incidental memory retrieval was studied with PET. Previously studied and new words were presented in either an intentional or an incidental memory task. Type of task was crossed with an encoding manipulation ('deep' *vs* 'shallow') which varied the probability that studied items would be remembered. In both tasks, deeply encoded items were associated with greater activation in the left hippocampus than were items that had received shallow encoding, suggesting that the involvement of the hippocampus in memory retrieval is independent of whether remembering is intentional or incidental. Right prefrontal and bilateral parietal cortex were more activated during the intentional task than during the incidental task, irrespective of encoding condition. Thus, these regions play a more extensive role in memory retrieval when remembering is intentional.

**Key words:** Episodic memory; Hippocampus; Incidental memory; Prefrontal cortex; Recognition memory; Recollection

## Brain regions supporting intentional and incidental memory: a PET study

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### Introduction

The findings from a number of functional neuroimaging studies converge to suggest that explicit retrieval of specific past events (episodic memory) is associated with activation of a distributed network of brain regions, notably the right prefrontal cortex, medial parietal cortex (precuneus) and, less consistently, the hippocampal formation and adjacent medial temporal cortex.<sup>1</sup> These findings have invariably been obtained with tasks that require information to be retrieved from memory intentionally. As is clear from everyday experience, however, memories are often retrieved incidentally, without a prior intention to remember. There is little evidence to indicate which components of the network engaged during intentional remembering are also active when retrieval is incidental. The answer to this question is of interest because of the light it would shed both on the neural substrates of incidental memory, and the more general issue of whether neural activity supporting episodic memory retrieval can be functionally, as well as neuroanatomically, dissociated.

The aim of the present study was to compare the patterns of brain activation associated with incidental and intentional remembering. This was accomplished by measuring regional cerebral blood flow (rCBF) during the performance of two tasks, both of which employed a high proportion of words that had been presented in an immediately preceding study phase. One of the tasks forced subjects to adopt an intentional retrieval strategy. In the other task memory

for the words was independent of the attribute that determined the correct response, thereby discouraging intentional memory. To manipulate the probability that studied items would be remembered two encoding conditions (deep *vs* shallow), which varied the degree to which items were encoded semantically, were employed. This manipulation exerts a strong effect on the probability of explicit retrieval on both intentional<sup>2</sup> and incidental<sup>3</sup> memory tests, but has little or no influence on implicit memory, as measured by indices such as repetition priming.<sup>4</sup> By crossing the factor of memory task (intentional *vs* incidental) with the factor of encoding condition (deep *vs* shallow) we were able to study the brain correlates of intentional and incidental remembering under conditions of high and low probability of retrieval, independently of any effects due to implicit memory.

### Materials and Methods

**Subjects:** Six healthy right-handed male subjects were employed, all of whom had given informed consent prior to participation. The study was approved by the local hospital ethic committee and the Administration of Radioactive Substances Advisory Committee of the UK.

**Data acquisition and analysis:** Measures of regional rCBF were obtained with <sup>15</sup>O PET, as described previously.<sup>5</sup> In brief rCBF estimates were obtained with a CTI-953B scanner (Siemens) operating in 3D

acquisition mode. The resulting images were corrected for movement, transformed into a standard stereotactic space, and tested for between-condition differences in rCBF with the method of statistical parametric mapping (SPM 95, Wellcome Department of Cognitive Neurology, UK). A statistical threshold of  $p < 0.001$ , uncorrected for multiple comparisons, was adopted for all contrasts.

**Stimuli:** Twelve pairs of study and test lists were created, each with a unique set of words. Each study list consisted of 18 words, of which either 13 (odd numbered lists) or 14 (even numbered lists) were inanimate, and the remainder animate. Test lists contained 24 words, 18 of which were inanimate and six animate. Eighteen of the test words also belonged to the study list and six were new. Of the 18 old words, 13 or 14 were inanimate, and the remainder were animate; either five or four of the new words were also inanimate. Thus, there was no correlation within the lists between study status and the animate/inanimate distinction. Each test list employed a different ordering of the four possible classes of item.

**Procedure:** The experiment was structured as a series of study–test blocks, in which two study tasks (deep and shallow) were crossed with two retrieval tasks (intentional and incidental). In the intentional task an old/new recognition judgement was required on each member of the test list. In the incidental task, an animate/inanimate judgement was required.

For each block, the first item of the study list was presented approximately 5 min before the onset of each scan, and presentation was self-paced thereafter. In the deep encoding condition, subjects were required to incorporate each word into a short spoken sentence before moving on to the next item. In the shallow condition, they were required to judge

whether the first and last letters of each word were in alphabetical order. The words were presented visually on a TV monitor suspended from a cradle approximately 45 cm in front of the subject. The interval between the completion of the study list and the onset of the test list was filled with counting to prevent rehearsal. Shortly before scanning commenced, presentation of the corresponding test list began. Words were presented on the monitor for 1 s, with a stimulus onset asynchrony of 2.5 s. Subjects were required to give a prompt verbal response to each item. In the intentional memory task, they were required to say 'yes' whenever they saw an item from the study list, and 'no' when they detected a new word. In the incidental task, the requirement was to respond 'yes' to each inanimate word and 'no' to each animate word. Subjects undertook each of the four combinations of task and encoding condition three times (with the exception of one subject, who, because of technical difficulties, undertook each combination twice). The mapping of lists to conditions, and the order in which the different task condition combinations were undertaken, were different for every subject.

## Results

**Performance:** Word categorization was near ceiling on both versions of the incidental task. As expected, subjects reported that they noticed the occurrence of deeply studied words more often than they did words subjected to shallow encoding. In the intentional memory task 96% of the deeply studied words were correctly recognized, with a false alarm rate of 6%. By contrast, subjects recognized only 65% of the shallowly studied words, and made false alarms to 17% of the new words. As measured by the index  $pHit - pFalse\ alarm$ , recognition memory was

**Table 1.** Z values, x,y,z coordinates,<sup>23</sup> and corresponding brain regions and approximate Brodmann areas (BAs) of peak activations identified by contrasts testing for the effects of deep vs shallow encoding

	Co-ordinates	Z	Cerebral region	BA
Intentional	–6,–34,–8	5.04	Left anterior cingulate cortex	32
	–46,16,36	4.65	Left middle/inferior frontal gyrus	9
	–52,18,16	4.19	Left inferior frontal gyrus	44
	–6,42,36	4.11	Left medial frontal cortex	8
	–42,–36,27	3.64	Left superior temporal gyrus	22
	–32,–38,4	3.56	Left hippocampus/parahippocampal gyrus	
	–10,–12,16	3.12	Left thalamus	
	–50,–12,40	3.11	Left precentral gyrus	4
	22,20,8	3.87	Right caudate/putamen	
	18,–50,4	3.76	Right parahippocampal/lingual gyrus	29/19
Incidental	–44,34,12	3.51	Left inferior frontal gyrus	44
	–42,4,–12	3.17	Left superior temporal gyrus	22
	–26,–24,–8	3.34	Left hippocampus	
	20,–82,36	3.49	Right superior occipital cortex	19

**Table 2.** Z values, x,y,z coordinates,<sup>23</sup> and corresponding brain regions and approximate Brodmann areas (BA) of peak activations identified by contrasts testing for the effects of intentional vs incidental retrieval

	Co-ordinates	Z	Cerebral region	BA
Deep	-54,14,16,	4.08	Left inferior frontal gyrus	44
	-42,28,32	3.88	Left middle frontal gyrus	9
	-10,-28,32	3.87	Left posteriorcingulate cortex	23/31
	-18,-68,24	4.37	Left precuneus	7
	14,-50,8	3.55	Right retrosplenial cortex	30
	42,36,28	3.88	Right middle frontal gyrus	46/9
	12,2,12	3.58	Right caudate nucleus	
	6,-72,20	3.45	Right precuneus/cuneus	31/18
	4,-74,12	4.03	Right medial cerebellum	
Shallow	-32,-54,32	3.96	Left precuneus/lateral parietal cortex	7
	24,50,8	3.34	Right prefrontal cortex	10
	40,32,24	3.95	Right middle frontal gyrus	46/9
	24,-66,24	5.04	Right precuneus/lateral parietal cortex	31/7
	38,-70,-20	3.90	Right lateral cerebellum	

significantly better for deeply studied words ( $t_5 = 4.41$ ,  $p < .01$ ).

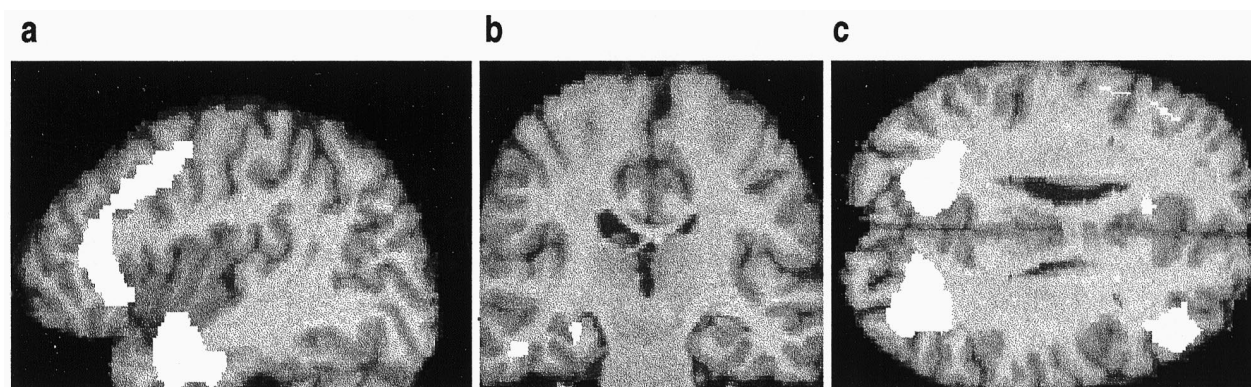
**PET data:** Tables 1 and 2 report the outcomes of tests for the four simple effects that result from the employment of a  $2 \times 2$  factorial design. The outcome of tests for the two main effects (task and encoding condition) are reported below for those brain regions that were reliably activated in both tests of the appropriate simple effects.

The results for the comparisons between the two encoding conditions are given in Table 1. Three regions of the left hemisphere (inferior prefrontal cortex, anterior superior temporal gyrus and hippocampus) were sensitive to the encoding manipulation irrespective of task. As illustrated in Fig. 1, all three regions also showed greater activation in the deep than in the shallow encoding condition when the contrast was performed collapsed over task (left prefrontal:  $x = -46$ ,  $y = 34$ ,  $z = 12$ ;  $Z = 4.85$ ; superior temporal gyrus:  $x = -44$ ,  $y = 4$ ,  $z = -12$ ;  $Z = 4.44$ , left hippocampus:  $x = -28$ ,  $y = -24$ ,  $z = -8$ ;  $Z = 4.05$ ).

Table 2 shows the outcome of the contrasts between intentional and incidental memory tasks. Irrespective of encoding condition, there was more activity during the intentional task in right dorsolateral prefrontal cortex and bilateral medial/lateral parietal cortex. Collapsed over encoding condition, the contrast between the two tasks revealed reliable activation in right dorsolateral prefrontal cortex ( $x = 40$ ,  $y = 32$ ,  $z = 24$ ;  $Z = 5.10$ ), and in the left ( $x = -8$ ,  $y = -68$ ,  $z = 24$ ;  $Z = 5.40$ ) and right ( $x = 22$ ,  $y = -66$ ,  $z = 24$ ;  $Z = 5.16$ ) precuneus (see Fig. 1).

## Discussion

The observation of greater hippocampal activation during retrieval of deeply studied words is consistent with previous reports that this structure is active during episodic retrieval.<sup>6,7</sup> It is also consistent with the proposal<sup>7</sup> that hippocampal activation is selectively associated with successful retrieval, rather than with the intention to retrieve. The present findings go beyond previous results by demonstrating that the



**FIG. 1.** Statistical parametric maps (threshold  $p < 0.01$ ) superimposed on to sections of a magnetic resonance brain image which has been transformed into standard stereotaxic space.<sup>23</sup> **(A)** Sagittal section ( $x = -40$ ) showing the main effect of encoding condition in left frontal and anterior temporal regions. **(B)** Coronal section ( $y = -24$ ) showing main effect of encoding condition in left hippocampus. **(C)** Transverse section ( $z = 24$ ) showing main effect of retrieval task on bilateral parietal and right prefrontal regions.

retrieval operations associated with hippocampal activation occur whether or not there is a prior intention to retrieve. This confirms a previous proposal to this effect,<sup>7</sup> and suggests that the everyday experience of memories seemingly 'popping to mind' may be a reflection of the relative automaticity of hippocampally mediated retrieval.<sup>8</sup>

This is only the third PET study (see also Refs 9 and 10) to describe activation of the left hippocampus during recognition memory for words. Notably, studies in which test lists containing high and low proportions of studied words have been contrasted have uniformly failed to find reliable differences in hippocampal activity,<sup>10–13</sup> despite the wealth of neuropsychological evidence implicating this structure in verbal recognition memory.<sup>14</sup> These negative findings may reflect the use of new words as a baseline against which to compare the effects of successful recognition. New test words are probably encoded automatically into memory, and encoding, like retrieval, is supported by and therefore activates the hippocampus.<sup>15,16</sup> This might explain why, in a recent study of recognition memory,<sup>10</sup> left hippocampal activation was found when a condition requiring recognition judgements on old words was contrasted with a rest condition, but not when it was contrasted with a condition requiring recognition judgements on new words. The present findings suggest that a more appropriate baseline is provided by previously studied words which fail to be recollected by virtue of their impoverished encoding. As a consequence either of the partial retrieval of episodic information, or a high level of perceptual 'fluency',<sup>17</sup> such words may engender sufficient familiarity to forestall further encoding.

The contrasts between deep and shallow encoding conditions revealed activations in two extra-hippocampal regions – left inferior cortex and the left superior temporal gyrus – that were common to both tasks. Activation of these regions has previously been reported in a variety of language tasks (e.g. Ref. 18). Given the nature of the deep encoding task (sentence generation), it is possible that activation of these regions during the retrieval of deeply encoded items reflects their role in recapitulating or reinstating the original encoding episode, perhaps in response to input from the hippocampus.<sup>19</sup> The present findings suggest that these operations are largely unaffected by whether retrieval is intentional or incidental, although it is noteworthy that the left inferior frontal cortex was more strongly activated in the intentional task (see Table 1).

In contrast to activity in the hippocampus and left temporal and frontal cortex, activity in right prefrontal and medial/lateral parietal regions was unaffected by depth of encoding, but instead differed

according to whether retrieval was intentional or incidental. Thus these regions appear to be relatively insensitive to both the probability of successful retrieval (but see Ref. 13), and to the conditions under which retrieved information was encoded. The role of the parietal cortex in memory retrieval is unclear,<sup>1,20</sup> and other than to indicate an association with intentional memory, the present findings do little to elucidate this role further.

The findings for the right dorsolateral prefrontal cortex are consistent with several proposals about the role played by this region in memory retrieval. The proposed functions include the control of 'retrieval effort',<sup>7,12</sup> the monitoring and verification of retrieved information,<sup>21</sup> and the use of retrieved information to guide behaviour.<sup>13,22</sup> All of these functions are intrinsic to intentional memory, leading to the prediction that the right prefrontal cortex should be engaged to a greater extent during intentional remembering than when memory is incidental to task demands. The present findings are fully in accord with this prediction.

## Conclusion

Differential activity was observed in several of the brain regions implicated in episodic memory retrieval by previous neuroimaging studies. Chief among these regions were the right dorsolateral prefrontal cortex, the precuneus and adjacent lateral parietal cortex, and the left hippocampus. By independently manipulating the intention to remember, and the probability of successful remembering, we were able to dissociate and help clarify the roles of these regions in memory retrieval. Whereas the role of the hippocampus appears to be independent of whether there is an intention to retrieve, parietal and right prefrontal cortex are engaged to a significantly greater extent when retrieval is intentional than when it is incidental. Together with the results of previous studies of the role of the right prefrontal cortex in memory, the present findings suggest that an important function of this region is to harness memory retrieval to current behavioural goals.

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ACKNOWLEDGEMENTS: M.D.R. is supported by a programme grant and research leave fellowship from the Wellcome Trust. P.C.F., C.D.F., R.S.J.F. and R.J.D. are supported by the Wellcome Trust.

**Received 12 November 1996;  
accepted 17 January 1997**

#### General Summary

We compared the regional brain activity associated with intentional and incidental memory. Sequences of previously studied and new words were presented in two different tasks: one in which the requirement was explicitly to recognize studied words, and one in which the words' study status was irrelevant. Type of task was combined with an encoding manipulation (deep vs shallow) which varied the probability that studied items would be remembered. In both tasks, deeply encoded items were associated with greater activation of the left hippocampus than were items that had received shallow encoding, suggesting that the involvement of the hippocampus in memory retrieval is independent of whether remembering is intentional or incidental. Activation of bilateral parietal and right prefrontal cortex was greater for the intentional memory task, irrespective of how items had been encoded. Thus these cortical regions have more of a role in memory retrieval when remembering is intentional than when it is incidental.