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Semantic Knowledge and Episodic Memory for Faces in Semantic Dementia

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Previous studies have documented poor recognition memory for faces in patients with semantic dementia. Preserved face recognition memory was found in this study, however, so long as atrophy was confined predominantly to the left temporal lobe. Patients with structural damage to the right temporal lobe were typically impaired, with the status of the hippocampus and parahippocampal gyrus (including the perirhinal cortex) on the right being critical. Two single-case studies of patients with predominantly left temporal lobe pathology confirmed good recognition memory for famous faces, even if semantic knowledge about the celebrities depicted was severely degraded. An effect of semantic knowledge on recognition memory became apparent only when perceptually different photographs of the famous people were used at study and test. These results support the view that new episodic learning typically draws on information from both perceptual and semantic systems.

Recent research on the syndrome of semantic dementia has offered a number of theoretical insights into the cognitive and neuroanatomical organization of episodic and semantic memory (Graham, Patterson, & Hodges, 1999; Hodges, Graham, & Patterson, 1995; Snowden, Griffiths, & Neary, 1996). In particular, recent investigations of recognition memory in patients with semantic dementia have demonstrated that new episodic learning for pictures of nameable objects can be normal, despite the severe breakdown of semantic knowledge that is the hallmark of the disease (Graham, Becker, & Hodges, 1997; Graham, Simons, Pratt, Patterson, & Hodges, 2000; Simons & Graham, 2000: Simons, Graham, & Hodges, 1999). These results are problematic for current theories of long-term memory organization (e.g., Tulving, 1995), which hold that normal episodic memory should not be possible in the context of degraded semantic knowledge about the to-be-remembered material.

Despite clear evidence that recognition memory for objects can be preserved in semantic dementia, other studies have indicated that recognition memory for faces may be impaired (Evans, Heggs, Antoun, & Hodges, 1995; Warrington, 1975). The research described in this article was designed to investigate recognition memory for faces in semantic dementia in more detail. More specifically, the two research questions examined (a) whether, as has been suggested, the status of right-hemisphere regions might be critical (De Renzi, 1986; Warrington, 1984); and (b) whether previously reported effects on recognition memory of manipulating perceptual information and semantic knowledge about objects (Graham et al., 2000) can be extended to memory for faces.

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Semantic Dementia: Selective Loss of Conceptual Knowledge

Semantic dementia is the clinical label given to the temporal variant of frontotemporal dementia (Graham, Patterson, & Hodges, 1999; Hodges, Patterson, Oxbury, & Funnell, 1992; Hodges et al., 1999; Miller et al., 1991; Snowden, Goulding, & Neary, 1989). Pathological and neuroradiological studies have reported progressive focal atrophy of the inferolateral aspect of the left and/or right temporal lobes, with relative sparing (at least at early stages of the disease) of structures in the hippocampal complex, such as the hippocampus, parahippocampal gyrus, and subiculum (Graham & Hodges, 1997; Harasty, Halliday, Code, & Brooks, 1996; Mummery et al., 1999; Schwarz, De Bleser, Poeck, & Weis, 1998). Although the structural abnormality at presentation may be apparent only unilaterally, atrophy is invariably bilateral by later stages (Graff-Radford et al., 1990; Hodges, Garrard, & Patterson, 1998; Mummery et al., 2000).

Semantic dementia results in impaired performance on any task that requires conceptual knowledge about objects, facts, concepts, and the meanings of words. For example, patients with the disorder perform poorly on tests such as category fluency (generating as many exemplars as possible from a particular category), naming familiar pictures, word-picture matching (pointing to the correct picture, in an array, that goes with a given name), word or picture sorting, and defining or drawing items after being given their name. This pattern of impairment reflects a progressive breakdown in central semantic knowledge that extends across all input and output modalities (Bozeat, Lambon Ralph, Garrard, Patterson, & Hodges, 2000; Hodges et al., 1995; Hodges, Patterson, & Tyler, 1994).

In contrast, there is relative sparing of other cognitive domains, such as the phonological and syntactic aspects of language, nonverbal problem solving, working memory, and visuoperceptual and spatial abilities, even at relatively late stages of the disease. In their clinical description of semantic dementia, Hodges et al. (1992) also suggested that autobiographical and day-to-day (episodic) memory was relatively preserved; this claim was based largely on observations that patients were able to remember appointments and keep track of family events, visits to the hospital, and so on.

Episodic Memory in Semantic Dementia

Of the few existing studies of episodic memory in semantic dementia, the majority have explored remote memory, but recent attention has also begun to focus on the capacity for new episodic learning (Graham et al., 1997, 2000; Simons & Graham, 2000; Simons et al., 1999). Studies of remote autobiographical memory in semantic dementia have revealed significantly better recall for recent events (especially those from the past 2 years) than for those from the more distant past (Graham & Hodges, 1997; Snowden et al., 1996). This pattern of relatively preserved recent memories is the reverse of the temporal pattern usually seen in amnesia and early-stage Alzheimer's disease, in which medial temporal lobe regions such as the hippocampus and parahippocampal gyms are affected and memory for recent events is most vulnerable (Graham & Hodges, 1997; Press, Amaral, & Squire, 1989; Scoville & Milner, 1957; Zola-Morgan, Squire, & Amaral, 1986).

The evidence for relatively preserved recent autobiographical memory suggests that the mechanisms for encoding new episodic memories may function adequately in semantic dementia. If true, this would run counter to Tulving's (1983, 1995) influential theory of long-term memory organization, which asserts that new episodic learning is dependent upon semantic knowledge of the items or concepts to be remembered. The prediction from this view, that semantically impaired patients should be unable to establish normal episodic memory for stimuli they fail to comprehend, has not, until recently, been addressed.

New Episodic Learning

The first reported assessment of episodic memory in semantic dementia (Warrington, 1975) demonstrated impaired recall of the Wechsler Memory Scale short story and virtually complete failure in free recall of 10-word lists in 3 patients with selective impairment of semantic memory. On forced-choice recognition memory tests for words and faces, the 2 patients tested performed as poorly as did 4 patients with amnesia. When their recognition memory for paintings was tested, however, both patients scored in the normal range, even though neither could identify any items depicted in the paintings. Preserved recognition memory for pictures was also reported by Diesfeldt (1992) and Graham, Becker, and Hodges (1997), despite consistently documented impairment of semantic memory.

Additional evidence comes from a more recent study in which 8 patients with semantic dementia showed preserved forced-choice recognition memory for color pictures of familiar objects and animals, despite impaired knowledge (as measured by picture naming) about the items depicted (Graham et al., 2000). The patients' recognition memory was impaired compared with that of controls only when perceptually different exemplars of the test items were used in the study and test phases (e.g., when a red dial telephone at study was replaced by a black touch-tone telephone at test). Graham et al. argued that this manipulation decreased the usefulness of perceptual information available from seeing the item in the study task and made the episodic decision more reliant on the integrity of conceptual knowledge.

Graham et al. (2000) also reported a single-case study of a patient with semantic dementia (J.H.) who, after an assessment of her conceptual knowledge about familiar objects, was given a recognition memory test for both items she still knew about and items for which she demonstrated severely degraded semantic knowledge. J.H. showed excellent recognition performance for perceptually identical items (i.e., the same drawings seen in the study and test phases) regardless of the state of her conceptual knowledge about them. If perceptually different exemplars were used at study and test, however, then J.H.'s recognition memory was good for items in the "known" set but impaired for those for which she had degraded semantic knowledge. Together with the findings of the studies described above, the data from the perceptually identical and perceptually different conditions of the recognition memory test suggest that episodic memory is *not* solely reliant on the integrity of semantic knowledge and that perceptual information regarding events plays a complementary role in providing a basis for recognition memory.

A view of long-term memory in which perceptual and semantic information work in concert to support new episodic learning can also account for the poor verbal learning noted in Warrington's (1975) study of semantic dementia. Compared with pictorial stimuli, words provide relatively little perceptual information to aid item discrimination in an episodic test. Recognition memory for verbal stimuli is, therefore, highly reliant on semantic knowledge about the studied items and so is more likely to be impaired in semantic dementia. A patient with degraded semantic knowledge about telephones is unlikely to recognize the word *telephone* as having been in a studied list but may still be able, on the basis of perceptual information, to identify a picture of a telephone as having been in a set of previously seen pictures. If perceptually different pictures of a telephone are used in the study and test phases, however, information from perceptual systems may not be sufficient to support recognition memory.

A Recognition Memory Deficit for Faces?

If patients with semantic dementia have preserved new episodic learning for nonverbal stimuli such as paintings (Warrington, 1975), line drawings (Graham et al., 1997; Simons et al., 1999), and color pictures (Graham et al., 2000), why were Warrington's (1975) 2 patients impaired on a test of face recognition memory? Although faces are certainly nonverbal stimuli, it has been argued that they cannot be placed in the same category as items such as objects, animals, and scenes, for example, because of the holistic, as opposed to part-based, nature of their representation (Farah, 1991; Farah, Wilson, Drain, & Tanaka, 1998). Many theories of object recognition emphasize the identification of the component parts of a stimulus object (e.g., Biederman, 1987; Marr, 1982; Pinker, 1984). Faces, in contrast, seem to depend far more on a gestalt, configural representation, with semantic information about the individual features (nose, eyes, etc.) being of limited use in discriminating between different faces (e.g., Rhodes, 1988; Sergent, 1984).

The only extensive investigation of episodic memory for faces in semantic dementia is a single-case study of a patient (V.H.) who had selective atrophy of the right temporal lobe (Evans et al., 1995). V.H.'s recognition memory performance was within the normal range for words and buildings as stimuli but was at chance for faces, although her face perception skills appeared to be intact (Evans et al., 1995). This pattern of results is in agreement with much of the literature implicating lesions of right temporal cortex in prosopagnosia and anterograde memory impairment for faces (De Renzi, 1986; Farah, 1991; Warrington, 1984). There is also functional imaging support for the view that right anterior temporal cortical regions are involved in face memory tasks (Andreasen et al., 1996; Haxby et al., 1996; Kanwisher, McDermott, & Chun, 1997; Simons, Graham, Owen, Patterson, & Hodges, in press).

The aim of the first experiment of this study was to assess the performance of patients with semantic dementia on recognition memory for unfamiliar faces and to examine the influence of different patterns of focal cortical pathology. We predicted that patients whose atrophy was mainly confined to the left temporal lobe would show preserved performance, drawing on perceptual information from exposure to the target faces during the study phase, but that pathology involving the right temporal lobe would be associated with impaired recognition memory for faces. On the basis of evidence that medial temporal lobe structures underlie recognition memory processes (Aggleton & Brown, 1999; Eichenbaum, Otto, & Cohen, 1994; Squire, 1992), we also predicted that the status of the right hippocampus and parahippocampal gyrus would be critical to recognition memory for faces. A second experiment addressed the role of semantic information in episodic memory by testing recognition memory for familiar faces.

Experiment 1

Method

Participants

Twenty-six individuals took part in the first experiment: 13 healthy elderly controls (4 men and 9 women) and 13 patients with semantic dementia (5 men and 8 women). The control participants were members of the Medical Research Council (MRC) Cognition and Brain Sciences Unit volunteer panel and were matched to the patients with semantic dementia in terms of age, $t(24) = 1.69$, *ns*, and years of education, $t(24) = 0.93$, *ns*.

The patients with semantic dementia presented to the Memory Clinic at Addenbrooke's Hospital, Cambridge, United Kingdom, complaining mainly of difficulties with word production and comprehension. All of the patients showed significant impairment on subtests from the Hodges and Patterson semantic battery (Hodges & Patterson, 1995), in which semantic knowledge about the same set of 48 familiar objects and animals is tested in a variety of different ways. As illustrated in Table 1, they were impaired (compared with 24 healthy controls; Hodges & Patterson, 1995) on tests of picture naming, word-picture matching, and category fluency, for example. Many of the patients have been assessed longitudinally over several years and have shown progressive deterioration of semantic memory in that time. In contrast, none has shown significant impairment on tests that tap other cognitive domains such as working memory, perceptual and visuospatial abilities, and nonverbal problem solving, at least not until very late into the progression of the disease.

Assessment of Hippocampal and Temporal Lobe Atrophy

Coronally oriented Tl-weighted magnetic resonance imaging (MRI) scans were used to evaluate the patterns of structural damage in the patients (except 1, T.G., for whom only axial MR images were available). The scans used were the closest available to the time of behavioral testing and dated, in some cases, from several years after initial presentation (see Figure 1 legend for scan dates and length of time after presentation). The degree of atrophy affecting the hippocampus and other medial and lateral temporal lobe subvolumes was assessed by raters who were unaware of both the experimental hypotheses and the patients' identities. The hippocampal rating scale (described in detail by Scheltens et al., 1992) is a 5-point measure (0 to 4) that involves visually assessing the width of the choroidal fissure, the width of the temporal horn, and the height of the hippocampal formation using the coronal slice that best depicts both hippocampal formations (usually at the level of the anterior pons). This method has been demonstrated to show good inter- and intrarater reliability and has been validated against both linear and volumetric measures using different MRI sequences (Scheltens, Launer, Barkhof, Weinstein, & Vangool, 1995; Scheltens et al., 1992; Vermersch, Leys, Scheltens, & Barkhof, 1994).

Table 1
Summary of Performance on a Range of Neuropsychological Tests of the Three Patient Groups Involved in Experiment 1

Test	Left		Bilateral		Right		ANOVA		Tukey's HSD
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	
MMSE (30)	27.5	3.1	19.6	4.0	24.5	4.2	4.96	<.05	L = R > B
Semantic Memory									
Picture naming (48)	30.8	20.0	13.6	13.6	16.5	13.0	1.46	*ns*	L = B = R
Word-picture matching (48)	45.5	3.0	37.2	9.1	31.5	11.2	2.7	*ns*	L = B = R
Category fluency	61.0	46.8	16.8	8.3	40.5	15.0	2.37	*ns*	L = B = R
PPT: pictures (52)	48.5	2.1	42.8	2.6	33.5	10.1	6.63	<.05	L = B > R
Episodic Memory									
Rey figure: 45-min recall (36)	17.5	7.4	9.5	7.4	8.9	6.8	1.83	*ns*	L = B = R
Logical memory (24)	4.1	3.1	2.3	1.7	3.0	4.2	0.38	*ns*	L = B = R
RMT: words (50)	37.3	3.0	38.0	5.7	36.3	8.3	0.06	*ns*	L = B = R
Visuoperceptual Ability									
Rey copy (36)	32.3	2.9	32.8	3.1	31.8	5.3	0.08	*ns*	L = B = R
Line Orientation (30)	24.0	7.9	26.8	2.9	22.0	10.3	0.39	*ns*	L = B = R
Object Matching (40)	39.3	0.6	37.0	2.9	36.3	0.6	1.94	*ns*	L = B = R
Working Memory									
Digit Span: forward	6.5	1.0	5.6	1.1	7.3	1.7	1.81	*ns*	L = B = R
Digit Span: backward	5.0	1.8	4.0	1.2	4.5	1.7	0.45	*ns*	L = B = R

Note. Maximum scores on tests are in parentheses. ANOVA = analysis of variance; Tukey's HSD = Tukey's honestly significant difference test; MMSE = Mini-Mental State Examination; L = left; R = right; B = bilateral; PPT = Pyramid and Palmtrees Test; RMT = Recognition Memory Test.

To assess the extent of atrophy in other temporal lobe structures, we used our own 4-point scale (Galton et al., in press), which involves the bilateral rating of three temporal subvolumes: (a) anterior temporal lobe, the cerebrospinal fluid space between the sphenoid wing and anterior temporal lobe (on a representative slice before the closure of the lateral fissure); (b) parahippocampal gyrus (including the perirhinal cortex), the depth of the collateral sulcus on the same coronal slice as that on which the hippocampus is assessed; and (c) lateral temporal lobe, the depth of the lateral sulci, again on the same coronal slice. This rating scale has been validated against volumetric measures of individual temporal lobe subvolumes (Galton et al., in press). Volumetric analyses could not be conducted in the present cohort because the MRI data sets in some of the cases were collected before three-dimensional acquisition was available.

The results of the radiology assessments are illustrated in Figure 1, which indicates for each patient the extent of atrophy in the right and left anterior temporal lobe, hippocampus, parahippocampal gyrus, and lateral temporal lobe subvolumes. Diagrams are also provided for two representative age-matched control participants. The ratings range from 0, which indicates no significant atrophy (represented by a completely filled sector), to 3, which indicates severe atrophy (represented by a sector with only one filled segment). For ease of comparison across regions, ratings of 3 and 4 (the most severe) on the hippocampal scale have been combined in the diagrams in Figure 1.

The relative laterality of structural damage was assessed for each patient from a dichotomized scale (0-1 = *minimal atrophy; 2* or above = *severe atrophy)* by looking for differences in severity for each brain region. To ensure reliability, a patient had to fulfill two criteria to be categorized as "predominantly left" or "predominantly right:" One or more brain subvolumes had to show a laterality difference on the dichotomized scale, and this difference had to be graded as 2 or greater on the full scale. A patient was classified as "bilateral" if no subvolume had a laterality difference of 2 or greater on the full scale. By this method, 4 patients were classified as predominantly left, 5 as bilateral, and 4 as predominantly right (see Figure 1).

Procedure

The participants were administered a longitudinal battery of neuropsychological tests to assess the status of cognitive functions such as episodic and semantic memory, visuoperceptual ability, and working memory (see Table 1). This battery included the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) and the 50-item version of the Recognition Memory Test for Faces (RMF; Warrington, 1984). The MMSE was used to screen for differences in disease severity that might contribute to any group effects on RMF performance. The RMF was administered according to standard procedures, with the unfamiliar faces presented one at a time and participants asked to make a judgment as to whether each face was pleasant or unpleasant. Immediately after the presentation of the 50 faces, memory was assessed with a two-alternative forced-choice recognition memory test in which the participants were asked to point to the face seen in the previous study phase.

Results

The results were analyzed with one-way factorial analyses of variance (ANOVAs), which revealed a significant effect of patient group on MMSE performance, $F(2, 12) = 4.96$, $p < .05$. Post hoc Tukey's honestly significant difference (HSD) pairwise comparisons showed that the bilateral group (MMSE score: $M = 19.6$, $SD = 4.0$) was significantly impaired compared with the predominantly left group ($M = 27.5$, $SD = 3.1$), but that there was no significant difference between the predominantly left group and the predominantly right group ($M = 24.5$, $SD = 4.2$). Analysis of performance on tests of episodic memory for words (Warrington, 1984; Wechsler, 1987), and for the Rey figure (Osterrieth, 1944), visuoperceptual abilities (Benton, Hamsher, Varney, & Spreen, 1983; Humphreys & Riddoch, 1984; Osterrieth, 1944), and working memory (Table 1)

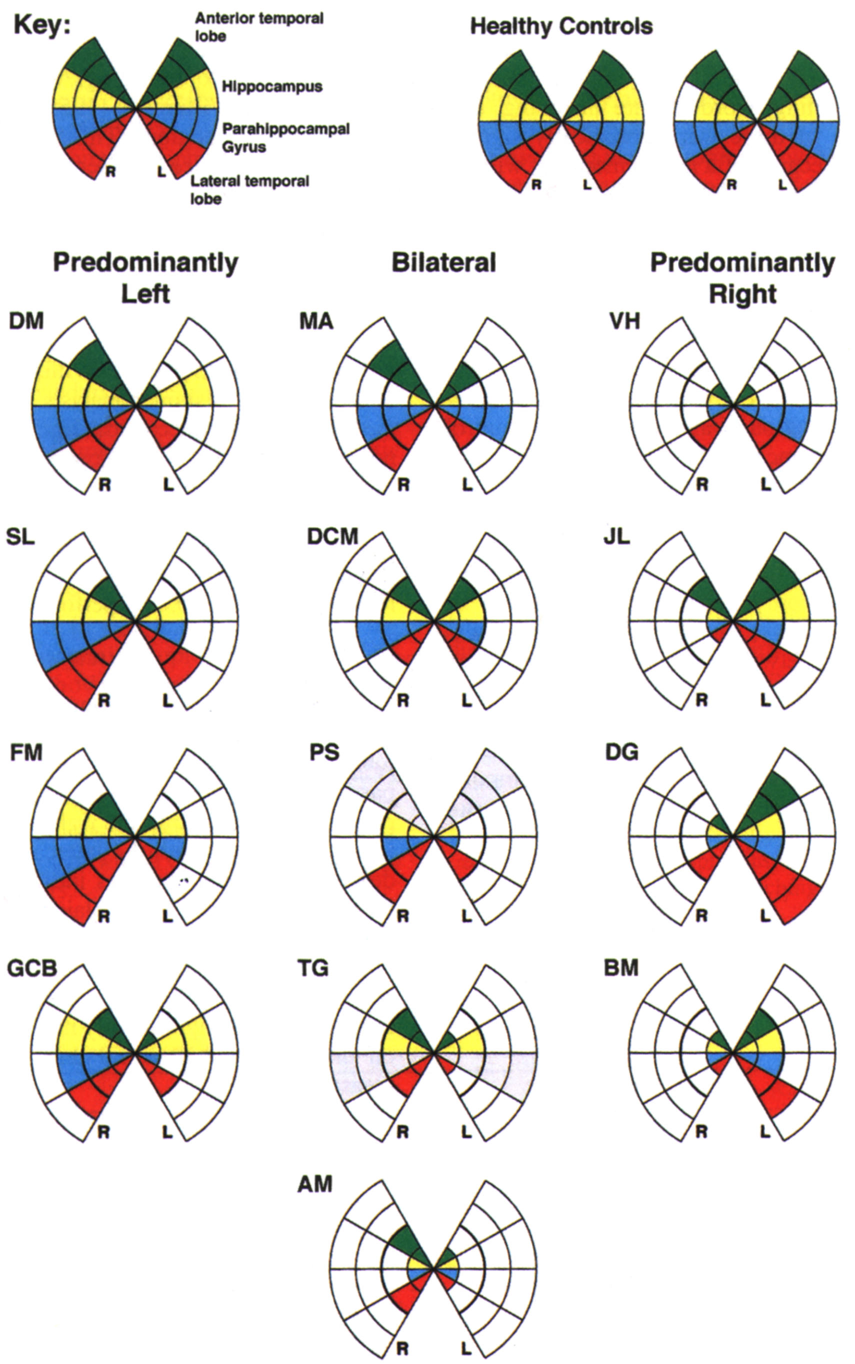

Figure 1. Diagrams showing the extent of rated atrophy in the right and left anterior temporal lobe (green). hippocampus (yellow), parahippocampal gyrus (blue), and lateral temporal lobe (red) for each of the patients with semantic dementia and 2 age-matched control participants. Note that gray sections indicate a brain structure that could not be rated because of the poor quality of the available magnetic resonance imaging scans. See text for methodological details concerning rating technique, Dates of scans (years since presentation) were as follows: D.M., April 1997 (2); S.L., December 1997 (0): F.M., November 1994 (3.5); G.C.B., December 1995 (3); M.A., May 1994 (2); D.C.M., May 1993 (0); P.S., February 1994 (0); T.G., June 1993 (0); A.M., February 1995 (1); V.H., January 199 (1.5); J.L., April 1991 (0); D.G., September 1997 (1): and B.M., March 1994 (0). All abbreviations in the figure are patient initials except R (right) and L (left).

revealed no significant patient group differences. Consideration of the means in Table 1 might suggest possible between-group differences on some of the semantic memory tests such as picture naming, word-picture matching, and category fluency. None of these were statistically significant, however, perhaps because of a large amount of within-group variability. The one exception was a significant effect of patient group on the pictures version of the Pyramid and Palmtrees Test of semantic association (PPT; Howard & Patterson, 1992).

A one-way ANOVA also revealed a highly significant main effect of patient group on RMF score, $F(3, 25) = 19.99$, $p < .001$. Post hoc comparisons confirmed that the predominantly right group was significantly impaired relative to the other patient groups and the healthy control participants. The performance of the bilateral group was also significantly impaired compared with the controls and the predominantly left group, but the predominantly left group performed within the control range. It seems extremely unlikely that these differences could be explained by disease severity, not only because of the pattern of MMSE scores described above but also because there was no significant correlation between scores on the MMSE and the RMF ($r = .327$, *ns*). The performance of the four groups on the RMF is shown in Figure 2.

To further investigate the laterality effect, we derived measures of atrophy in the right and left medial temporal lobes by averaging the full-scale atrophy rating scores for the parahippocampal gyrus and hippocampus in each hemisphere. Correlations between scores on the RMF and medial temporal lobe atrophy ratings were then compared statistically by using Williams's (1959) significance test for nonindependent correlations. This is a procedure that tests for a significant difference between the correlations of a criterion variable (e.g., RMF score) and two competing predictor variables (e.g., left and right medial temporal lobe atrophy ratings) that are themselves correlated.[1]

RMF score correlated much more highly with atrophy to the right medial temporal lobe ($r = -.910$, $p < .001$) than with atrophy to the left ($r = -.163$, *ns*), yielding a highly significant difference as measured by Williams's (1959) test, $t(10) = 3.64$, $p < .005$. A similar analysis was undertaken to compare the relative importance of damage to the right parahippocampal gyrus and the right hippocampus for face recognition memory. Both atrophy to the right parahippocampal gyrus ($r = -.943$, $p < .001$) and the right hippocampus ($r = -814$, $p < .005$) correlated highly with RMF score, but Williams's test revealed that the former had a significantly greater impact, $t(10) = 2.34$, $p < .05$, on performance.

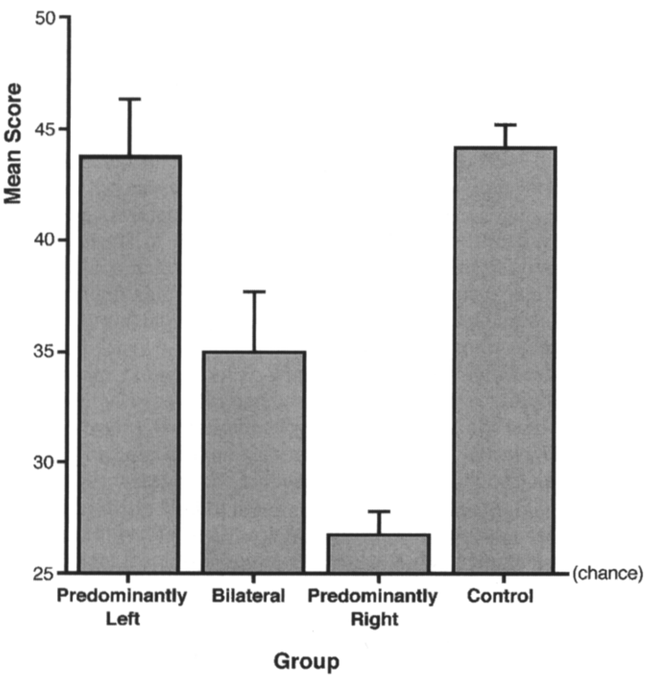

Figure 2. Performance on the Recognition Memory Test for Faces (Warrington, 1984) of patients with semantic dementia and control participants. The patients are grouped by pattern of temporal lobe atrophy: predominantly left, bilateral, and predominantly right.

Discussion

On the RMF (Warrington, 1984), the patients with semantic dementia and predominantly left-sided temporal lobe atrophy performed within the range of healthy control participants, while those with bilateral involvement or atrophy primarily affecting the right temporal lobe were significantly impaired, with the latter group showing the greater deficit. Additional analyses indicated that these group differences could not be explained by disease severity (as measured by the MMSE) or performance on tests of other cognitive domains (e.g., visuoperceptual ability), and that atrophy in the right hippocampus and parahippocampal gyrus correlated significantly more highly with performance on the RMF test than did the other temporal lobe areas measured.

The demonstration that patients with chiefly left temporal lobe atrophy can exhibit normal recognition memory for unfamiliar faces is important because, on the basis of previous literature (Evans et al., 1995; Warrington, 1975), one might have concluded that new episodic learning for faces is consistently affected in semantic dementia. The result of the present experiment allows us to hypothesize that the earlier studies detected impaired face recognition memory because the patients had pathological involvement of the right hemisphere. Although there is insufficient neuroanatomical data in Warrington's study of patients A.B. and E.M. to state much about the distribution of their pathology, our hypothesis can be confirmed in the case of V.H., the patient reported by Evans and colleagues, for whom we have atrophy rating data (see Figure 1).

The results of Experiment 1 also indicate that the right hippocampus and parahippocampal gyrus are critical for

[1] It should be noted that because these comparisons are between extent of atrophy and RMF score, we would expect correlations to be negative.

face recognition memory. The parahippocampal gyrus overlaps anatomically with the entorhinal cortex and includes the perirhinal cortex, an area thought to be critically involved in recognition memory (Aggleton & Brown, 1999; Murray & Mishkin, 1998; Simons et al., 1999). The present study demonstrated that although atrophy to both the right hippocampus and the right parahippocampal gyrus correlated highly with RMF score, the correlation of the parahippocampal gyrus was significantly higher. This provides support for the view that the hippocampus, although beneficial for recognition memory, is not as critically important as structures such as the perirhinal cortex (Aggleton & Brown, 1999; Baxendale, 1997; Murray & Mishkin, 1998).

Experiment 2 was designed to further explore the issue of recognition memory for faces in semantic dementia and to investigate the effects of manipulating both semantic knowledge and perceptual information in a recognition memory paradigm. Individual episodic face memory tasks, similar to the one used in Graham et al.'s (2000) study of recognition memory for objects, were constructed specifically for D.M. and S.L., 2 patients from the predominantly left group in Experiment 1. In each patient's test, half the test items (photographs of famous people) were selected on the basis of the patient's showing evidence of substantial semantic knowledge about the famous person; for the remaining half, the patient's knowledge of the celebrities was significantly degraded. Each patient's recognition memory for his or her "known" and "unknown" famous faces could then be assessed in conditions in which the faces were identical at study and test or in which different photographs were used in the two phases.

We predicted that D.M. and S.L. would show intact episodic memory for the faces of famous people about whom they had good conceptual knowledge, whether the photos at study and test were same or different, and also for faces of people about whom knowledge was degraded, so long as the same photographs were used at study and test. The patients' episodic memory for "unknown" famous people should, however, be impaired when different photographs of them are seen in the study and test phases. As we have noted previously (Graham et al., 2000), the terms *known* and *unknown* are placed in quotation marks to reflect the fact that semantic knowledge degrades progressively rather than being all-or-none.

Experiment 2

Method

Participants

Case report: D.M. D.M. (born in 1936) presented in 1995 with a history of difficulties with word-finding and comprehension and has been involved in various studies of semantic dementia conducted by our research group (Graham, Patterson, Pratt, & Hodges, 1999; Graham, Pratt, & Hodges, 1998; Graham et al., 2000; Hodges & Graham, 1998). Neuropsychological testing at the time of presentation (summarized in Table 2) confirmed D.M.'s semantic impairment. On tests of word production from the Hodges and Patterson semantic battery (Hodges & Patterson, 1995), such as picture naming and category fluency, he showed a marked deficit compared with performance of control participants. He was less impaired on tests of comprehension, scoring in the control range on the battery word-picture matching test and the picture version

Table 2
Summary of the Performance at Presentation of D.M., S.L., and 24 Healthy Control Participants on a Range of Neuropsychological Tests

Tests	D.M.	S.L.	Controls *M*	Controls *SD*
Semantic Memory				
Picture naming (48)	34	30	43.6	2.3
Word-picture matching (48)	46	44	47.4	1.1
Category fluency	77	43	113.9	12.3
PPT: pictures (52)	51	48	51.2	1.4
Synonym judgment (50)	27	30	47.6	2.1
Episodic Memory				
Rey figure: 45-min recall (36)	15.5	15.5	15.3	7.4
RMT: faces (50)	43.0	49.0	44.0	3.8
RMT: words (50)	36.0	41.0	47.0	2.8
Logical memory: 30-min delayed recall (24)	4.5	6.8	8.5	3.4
Visuoperceptual Ability				
Rey copy (36)	34	30	34.0	2.9
VOSP: Incomplete Letters (20)	19	20	19.2	0.8
VOSP: Object Decision (20)	17	20	16.9	2.3
VOSP: Dot Counting (10)		10	9.9	0.3
VOSP: Cube Analysis (10)	10	10	9.7	2.5
Working Memory				
Digit Span: forward	8	6	6.8	0.9
Digit Span: backward	7	3	4.7	1.2

Note. Maximum scores on tests are in parentheses. Control participants' data are from Hodges and Patterson (1995). PPT = Pyramid and Palmtrees Test; RMT = Recognition Memory Test; VOSP = Visual Object and Space Perception battery.

of the PPT (Howard & Patterson, 1992). On a more stringent test such as synonym judgment, however, he did show a significant deficit, and in the time since 1995, his performance has declined on other comprehension tasks from the semantic battery (Graham, Patterson, Pratt, & Hodges, 1999).

Like other reported cases of semantic dementia, D.M. showed no noticeable deficit on tests of other cognitive domains such as nonverbal episodic memory, scoring in the normal range on delayed recall of the Rey figure (Osterrieth, 1944) and on the RMF (Warrington, 1984), although he was impaired on the words version and on recall of the Logical Memory story (Wechsler, 1987). He performed normally on tests of visuospatial ability, such as copying the Rey figure and subtests of the Visual Object and Space Perception (VOSP) battery (Warrington & James, 1991), and was also unimpaired on tests of working memory such as Digit Span (Wechsler, 1981).

D.M.'s recognition and identification of famous names were tested by Hodges and Graham (1998), who reported that he was better at producing information about people who were currently famous compared with those famous from previous time periods. This reverse temporal step-function-the opposite of that found in amnesia-generalized to D.M.'s memory for famous faces and public events (Graham et al., 1998), adding to other evidence that patients with semantic dementia demonstrate significantly better retrieval of recent episodic memories compared with those from the more distant past (Graham & Hodges, 1997; Snowden et al., 1996). Assessment of coronal MRI scans for D.M. indicated significant atrophy confined mainly to the left temporal lobe, with relative sparing of the right temporal lobe, including preservation of the parahippocampal gyrus on the right and the hippocampus bilaterally (see Figure 1).

Case report: S.L. S.L. (born in 1948) was referred in January 1998 because of difficulties remembering the names of people and things, though she denied any comprehension problems. Her husband had noted a change in her personality after an episode of depression around the time of her mother's death in 1996. She had started to exhibit signs of rigidity, obsession, disinhibition, and impulsiveness, probably indicating some abnormality in frontal lobe function.

By the spring of 1998, S.L. began to complain that she kept "losing words" and became distressed at her increasing difficulty with remembering the names of friends. Neuropsychological testing (summarized in Table 2) indicated a significant degree of semantic impairment affecting word production, as measured by picture naming and category fluency (Hodges & Patterson, 1995) and, to a lesser extent, comprehension (synonym judgment). There was no noticeable deficit on tests of episodic memory, such as delayed recall of the Rey figure (Osterrieth, 1944) or the RMF (Warrington, 1984), though she was slightly impaired on the words version. Visuospatial ability (Rey figure copy and subtests from the VOSP; Warrington & James, 1991) and working memory (digit span) were also normal. Assessment of her MRI scans indicated severe atrophy of the temporal poles bilaterally and some involvement of the hippocampus, parahippocampal gyrus, and lateral temporal lobe on the left. There was relative preservation of other temporal lobe structures (see Figure 1).

Control participants. Seven healthy control participants from the MRC Cognition and Brain Sciences Unit volunteer panel also took part in the study. Three, matched to D.M. for age, sex, and education, were selected to act as controls in D.M.'s version of the task; the remaining 4, likewise matched to S.L., acted as controls in her version of the experiment.

Procedure

The experiment comprised two sections. In an initial pretest task, the patients' semantic knowledge of the person corresponding to each of 250 famous faces was assessed. From the patients' performance on this assessment, sets of "known" and "unknown" faces were selected for use in the main experiment. An individual episodic memory task was constructed for each patient in which recognition memory for the faces of "known" and "unknown" people could be investigated in conditions where the faces were perceptually identical (PI) at study and test, or where different photographs of the famous people were used in the two phases (the perceptually different, or PD, condition).

Initial pretest task. Black-and-white photographs of 250 famous people, scanned from picture books and magazines and downloaded from the Intemet, were used as stimuli in the famous people knowledge pretest task. The time period of fame of the celebrities varied from the 1930s to the present day. Each face was presented singly on a slide, and the patient was asked, without any time pressure, to try to name the face and to provide some identifying information about the person, such as his or her occupation or what the person was famous for.

On the basis of his or her performance on the pretest assessment, two sets of 40 photographs (a "known" and an "unknown" set) were selected for each patient for use in the main experiment. The "known" set contained photographs of famous faces that the patient had been able to name and/or produce substantial identifying information about. The "unknown" set contained photographs of famous people for whom the patient had been unable to produce either the name or any identifying information. For each patient, the two sets were matched as closely as possible in terms of time period of the celebrity's fame. For each of the 80 famous faces used in each patient's version of the test, another black-and-white photograph of the same celebrity was also located from the sources mentioned above. This photograph showed the celebrity in a pose different from that shown in the first set. For example, if the celebrity was looking straight at the camera in the first photograph, the second might show a three-quarters profile view.

Main experiment study phase. The main experiment was conducted at a later date, as soon as practicable after construction of the photograph sets based on the pretest results. In the study phase of the episodic memory task, 40 faces (20 from the "known" set and 20 from the "unknown" set) were each presented singly on A4 paper, and the participant was asked, without any time pressure, to name each of the famous people and to provide identifying information about them. The participant scored 1 in the naming part if she or he produced the full name of the famous person and 0.5 if she or he could produce only the first or last name. In a similar fashion, uniquely identifying information about the person (e.g., Neil Kinnock: "Labour man, lost election in 1992") scored 1, whereas correct but general, nonuniquely identifying information (e.g., Warren Beatty: "actor") scored 0.5.

Main experiment test phase. Fifteen minutes after the study phase (during which time a filler task not involving faces was performed), recognition memory for the 40 famous people was tested in PI and PD conditions. In the PI condition, the target photographs were identical to those seen in the study phase, whereas in the PD condition, the targets were different photographs of the people studied. In each condition, the target faces were randomly intermixed with foils that had not been seen in the study phase, half of which were the remaining famous people from the "known" set and half were from the "unknown" set. Each participant was tested on the episodic memory task on two occasions, approximately 1 month apart. In each session, half of the faces were presented in the PI condition, and half were presented in the PD condition, with the assignment of famous people to each condition and the order of presentation of the two conditions counterbalanced across test sessions. Each of the faces was presented singly on A4 paper, and the participant was asked to indicate whether or not she or he thought the person had been seen in the earlier study phase. It was explained that, in some cases, the test photograph would be different from the one seen previously.

Results

Study Phase

Because the patients and control participants were all administered the main experiment study phase on two occasions (with a different stimulus presentation order in each), they were credited with knowledge about a famous person only if they consistently named or produced information about them *both* times. Under this strict criterion, D.M. was, as expected, profoundly impaired at naming famous people from their pictures, but his performance was better on the "known" set (naming 5 out of 20 people) than the "unknown" set (of which he named none). His ability to produce identifying information about famous people from the "known" set (17 out of 20) was within 2 standard deviations of the matched controls, but he was able to produce consistent information about only 1 person from the "unknown" set. S.L. was similarly impaired at naming on her version of the study phase, producing the names of 5 out of 20 people from the "known" set and none from the "unknown" set. She was less impaired at describing the famous people, producing identifying information about all of the people in the "known" set and 6 out of 20 of those in the "unknown" set. These results confirm that the patients had considerable semantic knowledge about the people in their "known" sets but that their knowledge of the "unknown" celebrities was extremely poor.

Test Phase

The performance of D.M. and S.L. is illustrated in Figures 3A and 3B, respectively. The figures show the d' measures of discrimination for each of the sets of photographs in the test phase of the main experiment. Statistical comparisons were undertaken according to the procedure outlined by Macmillan and Creelman (1991), which entails calculating the confidence interval around the difference between two d' values. Looking at the patients' results in each of the conditions first, the difference between PI "known" and PI "unknown" photographs was not significant at the .05 level for either patient. For both D.M. and S.L., there was also no significant difference between PI "known" and PD "known" faces. There were, however, significant differences for each of the patients both between PI "unknown" and PD "unknown" photographs and between the PD "known" and PD "unknown" conditions (p values $< .05$).

The performance of each of the control participants is shown in Table 3. No significant differences were found between conditions for the control participants, either individually or as groups. The only exception to this was one of the controls matched to S.L. (Control 6), who showed a deficit on the PD "unknown" condition compared with her performance on the other conditions: Analysis of her responses in the study phase revealed that she was unfamiliar with some of the famous people used in the test and was

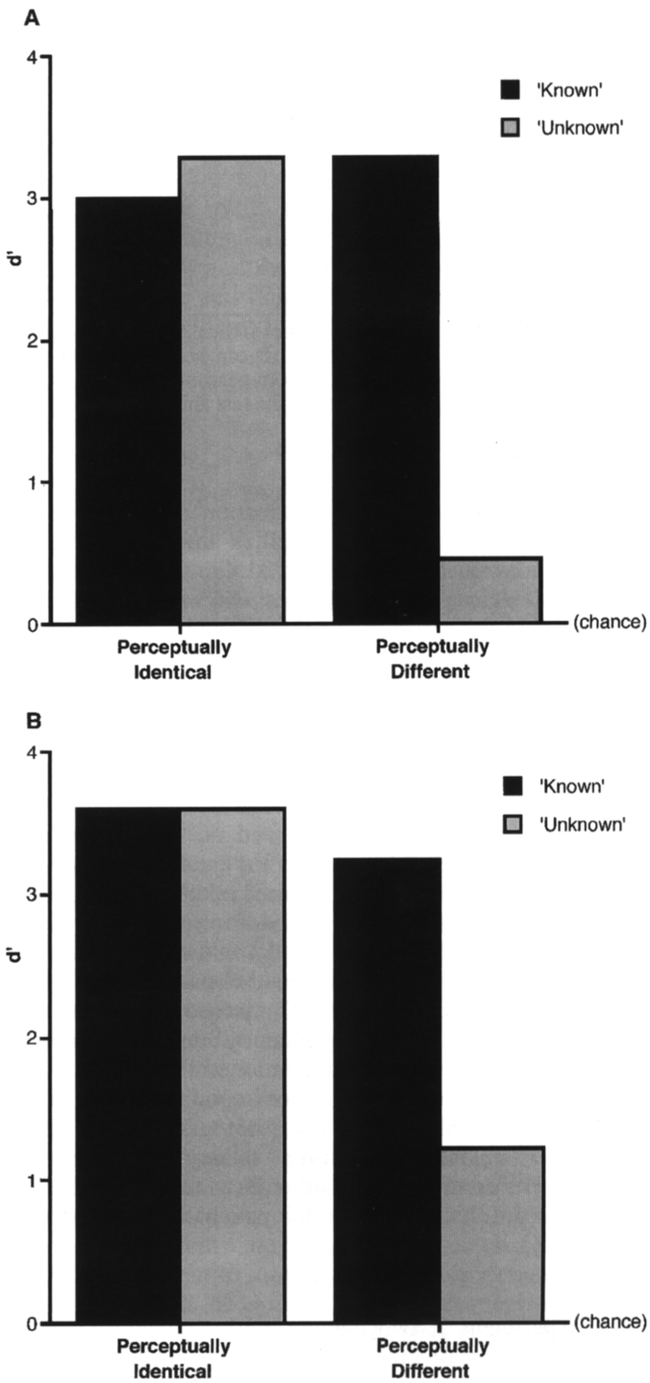

Figure 3. D.M.'s (A) and S.L.'s (B) performance on the perceptually identical and perceptually different conditions of the "known" and "unknown" famous faces episodic recognition memory test.

Table 3
The Performance of Each of the Matched Control Participants and Results of Comparisons With Patients D.M. and S.L. on the Four Conditions of the Recognition Memory Test

	Perceptually identical				Perceptually different			
	"Known"		"Unknown"		"Known"		"Unknown"	
Participant	*d'*	*p*	*d'*	*p*	*d'*	*p*	*d'*	*p*
Controls matched to D.M.								
Control 1	3.92	*ns*	3.92	*ns*	3.61	*ns*	2.35	<.05
Control 2	3.92	*ns*	3.92	*ns*	3.92	*ns*	2.32	<.01
Control 3	3.92	*ns*	3.92	*ns*	3.61	*ns*	2.49	<.005
Controls matched to S.L.								
Control 4	3.92	*ns*	3.92	*ns*	3.92	*ns*	2.68	<.05
Control 5	3.92	*ns*	3.92	*ns*	3.61	*ns*	2.93	<.05
Control 6	3.92	*ns*	3.92	*ns*	2.80	*ns*	1.06	*ns*
Control 7	3.92	*ns*	3.92	*ns*	3.24	*ns*	2.93	<.05

Note. The *p* values indicate level of significant difference between patient and control participant on each condition. It can be seen that both patients performed similarly to controls on all of the conditions apart from perceptually different "unknown." Control 6 was unfamiliar with many of the celebrities used in the test and thus performed unlike the other control participants (see text for more details).

able to consistently produce information about only 10 of those in S.L.'s "unknown" set. It is interesting that, of these 10 faces, she correctly selected 8 in the PD condition but was at chance on the celebrities who were unfamiliar to her. It would accord with our theory (and with previously reported data; Bruce, 1982) that a healthy individual who lacked semantic knowledge about a famous person would be unlikely to recognize that person in the PD condition.

Comparisons between the patients and their matched controls were conducted individually for each control participant. These results are displayed in Table 3, from which it can be seen that D.M. performed no differently from controls on the PI "known," PI "unknown," and PD "known" conditions but was impaired relative to each of the controls on the PD "unknown" condition. S.L. exhibited a similar pattern, performing normally on the PI "known," PI "unknown," and PD "known" conditions but showing an impairment on the PD "unknown" condition relative to 3 of the controls. S.L. was not significantly impaired compared with Control 6, the participant mentioned above who scored more poorly on the PD "unknown" condition than on the other conditions. S.L.'s deficit was not as severe as D.M.'s on the PD "unknown" condition, so any drop in performance by the control participant reduces the likelihood of a significant difference between the patient and her control.

Discussion

In Experiment 2, two patients with semantic dementia (D.M. and S.L.) affecting predominantly the left temporal lobe (see Figure 1) showed good episodic memory for faces of famous people when identical photographs of the celebrities were used at study and test, regardless of whether the patients could produce semantic information about them. When different photographs were used in the two phases, the patients were still able to detect the famous people seen previously if they retained a significant degree of semantic knowledge about them. Their episodic memory for famous people about whom they showed no evidence of knowledge was, however, markedly impaired when different photographs of the celebrities were used in the study and test phases.

The control participants performed close to ceiling when identical photographs were used at study and test (see Table 3). This makes it difficult to establish whether recognition memory in these conditions was truly "normal" in the patients tested in this paradigm, although preserved recognition memory has previously been documented in semantic dementia on tasks in which controls were not at ceiling (e.g., Graham et al., 1997; Simons et al., 1999). The issue of a control ceiling effect in the present experiment does not, however, diminish the importance of the theoretically interesting contrast within each patient between performance on the four recognition memory conditions. An additional point is that it is important to exclude the possibility that the patients might have had a high-level perceptual deficit that reduced their ability to perceive faces from different views. Accordingly, we tested both patients with the Benton Face Recognition Test (Benton, Hamsher, Vamey, & Spreen, 1983), a task that involves the matching of faces in different orientations and different lighting conditions. Both patients' age-corrected scores on the Benton test were in the normal range.

General Discussion

The results of these experiments suggest that recognition memory for faces can be preserved in semantic dementia: The patients with predominantly left temporal lobe pathology performed normally on Warrington's recognition memory test for unfamiliar faces (RMF; Warrington, 1984). In a more detailed investigation (Experiment 2), 2 of these patients, D.M. and S.L., achieved a high level of performance in episodic memory for famous faces when the same photographs of the person were used at study and test, even if they had been unable to produce any semantic information about the famous person shown. When different photographs of the person were used in the study and test phases, both patients had impaired recognition memory for the famous but now "unknown" faces. Taken together, the findings of Experiment 2 are inconsistent with Tulving's hypothesis about the hierarchical nature of episodic and semantic memory (Tulving, 1983, 1995; Tulving & Markowitsch, 1998) and provide further support for the proposal that, in certain circumstances, perceptual information can be sufficient to support successful recognition memory (Graham et al., 2000; Simons & Graham, 2000). Stated more generally, these results are consistent with the view that perceptual and semantic systems typically work together to support new episodic learning.

Is the Right Hemisphere Critical for Face Memory?

Experiment 1 demonstrated that patients whose atrophy was restricted mainly to the left temporal lobe showed normal performance on the RMF (Warrington, 1984), whereas those with right-sided or bilateral temporal lobe atrophy were impaired on this test. Additional analysis indicated that degree of atrophy of the right hippocampus and parahippocampal gyrus correlated highly with RMF score, with structural damage to the right parahippocampal gyrus correlating significantly higher.

If the RMF impairments documented in these patients could be explained by a deficit in perceptual processes for face analysis, rather than face memory per se, the patients might be expected to show impairment on standard tests of visual perception. As illustrated in Tables 1 and 2, however, all the patients tested performed within two standard deviations of controls (Hodges & Patterson, 1995) on tests like Rey figure copy (Osterrieth, 1944), Judgement of Line Orientation (Benton et al., 1983), Object Matching (Humphreys & Riddoch, 1984), and subtests of the VOSP battery (Warrington & James, 1991). Furthermore, the neuropsychological investigation of V.H., one of the patients with predominantly right temporal lobe atrophy also involved in the present study, yielded no evidence of a deficit on perceptual tasks involving faces (Evans et al., 1995). For example, V.H. consistently performed normally on the Benton Face Recognition Test (Benton et al., 1983) despite chance performance on the RMF, on two occasions separated by several months. This pattern is confirmed in published neuropsychological data (Lambon Ralph, Graham, Ellis, & Hodges, 1998) from other patients with predominantly right-sided atrophy involved in the present study, such as J.L. and B.M., who obtained normal performance on the Benton test but were approximately five standard deviations outside the control mean on the RMF.

The available evidence suggests that, in patients who present with predominantly left-sided atrophy, pathology spreads at later stages of the disease to involve bilateral temporal lobe structures, including. right-hemisphere regions implicated in recognition memory for faces. The patients in Experiment 1 with bilateral atrophy scored more poorly on a measure of disease severity (the MMSE; Folstein et al., 1975) than did patients with predominantly left-sided atrophy, suggesting that those in the former group were at more advanced stages of the disease.

The results of Experiment 1 provide additional support for the view that it is structures in the right hemisphere that are critical for face recognition memory (De Renzi, 1986; Farah, 1991; Warrington, 1984). Furthermore, the particularly high correlation between RMF score and the right parahippocampal gyrus supports the view that, although both the hippocampus (underlying recollection of contextual information) and the parahippocampal gyrus (an area that includes the perirhinal cortex, implicated in the detection of item familiarity) are involved in recognition memory, the parahippocampal gyrus is the more critical region (Aggleton & Brown, 1999; Baxendale, 1997; Murray & Mishkin, 1998).

Multiple Inputs to New Learning

In Experiment 2, as long as the same photographs were used at study and test, D.M. and S.L. had good recognition memory for faces. Furthermore, neither patient showed any significant impact on recognition memory scores as a result of either substantial retained semantic information or severely degraded knowledge for the celebrities whose faces were depicted. It was possible to demonstrate deleterious effects of impaired semantic knowledge on new episodic learning only when different photographs of the "unknown" famous person were used at study and test. Our interpretation of this result is based on the findings from studies of recognition memory for both familiar and unfamiliar faces (Bruce, 1982; Bruce, Carson, Burton, & Kelly, 1998) and for objects (Cooper, Schacter, Ballesteros, & Moore, 1992; Humphrey & Khan, 1992; Srinivas, 1995) in individuals without temporal lobe damage. Bruce (1982) examined the influence of perceptual processes by varying the angle or expression of familiar and unfamiliar faces between study and test. Unfamiliar faces that were changed between study and test were recognized less accurately than unchanged faces, but the perceptual manipulation had no effect when the faces were familiar to the participants.

From these results, Bruce (1982) postulated a framework for episodic recognition memory for faces in which different coding systems are used in the search for positive evidence sufficient to reach a threshold for recognition. She suggested that in the case of familiar faces, episodic memory can draw on information from sensory-perceptual and semantic systems. When an unfamiliar face is seen, it is primarily information from the sensory-perceptual systems that is available, which will be sufficient for successful recognition if that information is largely reinstated. When a face is changed between study and test, however, information from semantic knowledge becomes more critical: If the face is familiar, then such information may be sufficient, but if it is unfamiliar, recognition memory may fail.

We suggest, therefore, that the manipulation in the PD condition of the present study had the effect of reducing the value to the episodic decision process of the sensory-perceptual information available from seeing the target person in the earlier study phase. As a result, the decision as to whether a person had been seen previously became more reliant on the semantic knowledge activated by seeing both the original and the test photograph. As predicted, both D.M. and S.L. achieved a high level of success in recognizing perceptually different photographs as episodically familiar if they retained some semantic knowledge about the famous people, as measured by being able to name and/or produce information about them. Under circumstances in which semantic knowledge about a person was degraded, however, the patients were much less likely to succeed in selecting the PD photograph in the recognition memory task.

Tulving's serial parallel independent (SPI) model (Tulving, 1995; Tulving & Markowitsch, 1998) is based on the view that encoding of information is serial and that perceptual information about a viewed stimulus feeds only into the semantic system, which subsequently transmits information about the meaning of the item to episodic memory. The encoding of information into episodic memory is dependent, therefore, on output from the semantic system. The observation, both in the present study and in that by Graham et al. (2000), that the manipulation of semantic knowledge had no significant impact on performance in the PI condition is inconsistent with the SPI model. Instead, drawing on Bruce's (1982) framework, we have proposed that perceptual information typically works in conjunction with semantic knowledge to support new episodic learning and, moreover, that in the absence of a meaningful input from the semantic system, information from perceptual systems alone can be sufficient so long as such information extensively reinstates the earlier experience (Graham et al., 2000; Simons & Graham, 2000).

In summary, the results of Experiment 1 demonstrate that, when atrophy affects predominantly the left temporal lobe, patients with semantic dementia typically show normal recognition memory for faces. This intact ability is, however, highly sensitive to involvement of the right temporal lobe in the pathological process (especially structures like the perirhinal cortex), such that patients with predominantly right or bilateral atrophy are likely to be impaired. In Experiment 2, patients with semantic dementia and predominantly left temporal lobe atrophy had no significant problem recognizing identical photographs of faces as seen previously, even if their semantic knowledge about the people pictured was severely degraded. It was only when perceptually different photographs of the people were used in the study and test phases that an effect of semantic knowledge became evident. These results are inconsistent with a hierarchical model of long-term memory (e.g., Tulving, 1995) and support a model in which episodic memory typically draws upon information from multiple systems, both semantic and perceptual.

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