

Acquisition of post-morbid vocabulary and semantic facts in the absence of episodic memory

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Summary

Disagreement exists in the literature over whether it is possible for new semantic (factual) information to be learned in the absence of episodic (event) memory. We report the case of R.S., a 49-year-old amnesic man, who we found to have acquired information about famous people, public events and new vocabulary during the 13-year period since he became amnesic, despite having no

measurable anterograde episodic memory function and a profound loss of autobiographical memory. These data suggest that at least some severe amnesics are able to acquire new semantic knowledge, provided that critical temporal neocortical regions are spared. We discuss these findings in the context of recent connectionist models of memory.

Keywords: amnesia; temporal lobes; autobiographical memory; semantic memory

Introduction

Patients with the amnesic syndrome are unable to recall post-morbid events and demonstrate varying degrees of impairment at retrieval of pre-morbidly acquired autobiographical memories. In contrast, their fund of general knowledge is relatively preserved (Mayes, 1988; Baddeley, 1990). Various cognitive theories have been proposed to account for this pattern. One suggestion has been that amnesia represents a selective loss of episodic memory ability (Kinsbourne and Wood, 1975; Schacter and Tulving, 1982; Cermak, 1984). Episodic memory has been defined as the ability to store and recall personally experienced episodes, as opposed to semantic memory, which is concerned with culturally shared information, including language and facts about the world (Tulving, 1972, 1983). Accordingly, it might be hypothesized that amnesics should be capable of new semantic learning, although they would not be able to recall the learning episodes. Likewise, their retrograde amnesia should affect episodic but spare semantic memory.

A problem with this interpretation of amnesia is that almost all amnesics show at least some preservation of old pre-morbid episodic memories (although the extent of retrograde amnesia varies considerably) and a loss of knowledge of famous persons and events (which is clearly within the domain of semantic knowledge). These findings have led Squire and colleagues (Cohen and Squire, 1980; Cohen, 1984; Squire, 1987) to propose that amnesia represents a deficit in declarative memory (i.e. the capacity for conscious recollection of both facts and events). More recently,

computational neural network models of declarative memory have been developed which attempt to account for both the pattern and temporal profile of the psychological as well as the neuroanatomical data (McClelland *et al.*, 1993, 1995; Alvarez and Squire, 1994; Murre, 1996). In these models (which will be discussed more fully later) both episodes and facts are acquired by the same mechanism, involving the rapid indexing or linking of sensory traces in the hippocampus. Over time, with rehearsal or re-exposure, memories are instantiated in direct corticocortical links which are independent of the hippocampal formation. According to this view, amnesics should be as impaired at acquiring and recalling semantic information as they are at recalling experienced episodes. It remains possible, however, that some forms of explicit knowledge might be acquired, albeit slowly and in an impoverished form, in the absence of a functional hippocampal system.

The status of post-morbid semantic learning in amnesia is, therefore, of considerable theoretical importance. There is, however, a paucity of relevant experimental data, and many of these seem to conflict. Clinically, it is widely accepted that amnesics are impaired at acquiring factual information (Rozin, 1976), although Vargha-Khadem *et al.* (1997) have recently reported the cases of three amnesic children who are progressing reasonably well in school and showed average vocabulary skills despite pronounced episodic memory deficits. Gabrieli *et al.* (1983, 1988) investigated rote vocabulary learning in a small group of amnesics, and they

found no evidence of success despite extensive practice. In keeping with this, Dopkins *et al.* (1990) attempted to teach amnesics the term for a particular colour, but found that the amnesics overgeneralized, and did not appear to integrate the colour labels into their existing knowledge bases. Similarly, Grossman (1987) trained a group of Korsakoff's amnesics to associate a dark green pen with the label 'bice'. Although most of the patients learned to associate the word 'bice' with the pen, this knowledge did not generalize as it did in the control subjects. Verfaellie *et al.* (1995) studied knowledge of words that had entered the lexicon post-morbidly in a long-standing amnesic, and reported no evidence of vocabulary acquisition. Studies of the famous amnesic patient H.M. have shown 'meagre' post-morbid vocabulary acquisition (Gabrieli *et al.*, 1988).

In contrast, Glisky *et al.* (1986a, b), using standard anticipation-learning and vanishing-cues techniques (in which cueing is progressively reduced), managed to train amnesics to acquire a number of computer-related vocabulary terms. The vanishing-cues technique was developed in order to allow their subjects to make use of implicit memory to respond to fragment cues. They found learning with both methods, but much more in the vanishing-cues condition. This learning was, however, extremely arduous, and modifications of the definitions (which still preserved sense) resulted in a severe disruption of performance. This phenomenon has been referred to as the 'hyperspecificity' of amnesic semantic learning (Schacter, 1985). Hirst *et al.* (1988), however, reported the case of an amnesic woman (C.S.) whose progress in learning French was equal to that of her (non-amnesic) husband. These authors argue that C.S.'s language learning could not be considered to be hyperspecific, since she was able to generate unique sentences and to carry out translating tasks not present during tutoring. A limitation of the Hirst *et al.* (1988) study is that the patient had substantial pre-existing knowledge of Romance languages.

In further semantic acquisition studies, evidence has been found that amnesics retain some ability to acquire simple facts (Schacter *et al.*, 1984; Shimamura and Squire, 1987), show lasting implicit knowledge for ambiguous sentences (McAndrews *et al.*, 1987) and can learn to complete unpredictable sentences (Tulving *et al.*, 1991). Semantic learning, however, was arduous and inflexible in all of these cases. Van der Linden *et al.* (1994) taught two Korsakoff's amnesics concept names and definitions but, again, learning was slow, and only one subject showed significant flexibility in applying this knowledge.

On the basis of a study comparing perceptual and conceptual semantic priming in amnesics, Graf and Schacter (1985) concluded that implicit memory for new associations may occur. After a reanalysis and subsequent study, however, the same authors (Schacter and Graf, 1986) reported that this effect was found only in their milder amnesics and that it might possibly have been mediated by residual episodic memory functioning. Shimamura and Squire (1988, 1989)

also studied priming, and reported no evidence for facilitation as a result of conceptual cueing. Musen and Squire (1993), however, found that amnesics could acquire implicit memory for new associations with repeated presentations, although they were impaired at explicit (recognition) memory.

In summary, the above evidence suggests that some amnesics are able to acquire some semantic information, but it is not clear that all types of semantic material (in particular, vocabulary) may be learned, nor is it clear whether newly acquired semantic knowledge has the same properties as pre-existing knowledge. Of critical importance for this debate is the fact that almost all of the above studies have involved patients with a significant degree of residual episodic memory ability. Thus, Ostergaard and Squire (1990) have countered claims of dissociations between episodes and facts in amnesia, with the argument that the observed success on semantic tests could have been mediated by residual episodic memory.

In the present study, we investigated the status of post-morbidly acquired semantic knowledge over a broad range of domains in a profoundly amnesic patient with no detectable episodic memory ability. R.S. is unable to recall any specific episodes from his life, either pre- or post-morbidly, yet he demonstrates significant learning of both facts and vocabulary from the post-morbid period.

Case report

The subject of our study, R.S., is a 49-year-old right-handed man who is densely amnesic as a result of a subarachnoid haemorrhage suffered in early 1983, which rendered him unconscious for several weeks. Angiography revealed a posterior communicating artery aneurysm with bilateral posterior cerebral and left anterior cerebral artery spasm. Surgery was not performed. R.S. left formal education at the age of 15 years, and was formerly employed in the Communications Division of the Navy. He is married, with two children. He can remember no personally experienced episode from any period in his life, does not know the year or his age, and torments his wife every evening by continually asking where their daughter is (she was 12 years old at the time of his stroke, but is now 25 years old and has left home). R.S. is unable to answer open-ended questions, and his wife reports that he will never initiate an activity or conversation on his own. However, no evidence of confabulation has been observed; when R.S. does not know the answer to a question, he says so.

R.S.'s knowledge of the state of affairs in his own life seems not to have been updated since his stroke. He believes that he, and his wife and children are 13 years younger than they really are, and that his mother is still alive. He does not know what year or season it is and, when asked, states that he believes his memory to be 'about the same' as that of his neurologist.

MRI with coronal T₁ and axial T₂ slices in March 1995 showed infarction of left medial temporal lobe structures, with complete destruction of the left hippocampus,

parahippocampal gyrus, entorhinal and perirhinal cortex, but sparing of the amygdala and the temporal pole. The entorhinal cortex was therefore almost certainly involved. The status of the perirhinal cortex is less certain; the collateral sulcus on the left was no longer visible, implying destruction of the posterior perirhinal cortex. The more rostral portion of the perirhinal cortex on the medial surface of the temporal pole (areas 35 and 36) appeared intact (Corkin *et al.*, 1997). A much more circumscribed area of infarction was visible on the right, which involved the posterior part of the hippocampus, and there was partial atrophy of the remainder of the right hippocampus. In addition, poorly defined ischaemic change was seen in the superior aspect of the left thalamus and there was also another infarction with much clearer demarcation in the territory of the left anterior cerebral artery, involving the basal forebrain and medial left frontal lobe. Thus, R.S. has multifocal limbic damage involving the left hippocampal complex (possibly sparing part of the perirhinal cortex), posterior thalamus and left medial frontal lobe and posterior right hippocampus (see Figs 1 and 2). Of particular importance to the later discussion is the fact that R.S. shows preservation of the inferolateral temporal neocortex, a region that appears to be critical for general semantic knowledge (Patterson and Hodges, 1995).

Results

Neuropsychological assessment

The results of standard clinical neuropsychological testing are shown in Table 1. Although R.S. showed cognitive underfunctioning relative to his estimated pre-morbid level (National Adult Reading Test: NART 105), visuospatial skills appeared to still be in the normal range. Spontaneous speech was sparse but well articulated and syntactically correct without word-finding pauses or paraphasic errors. Performance on the Graded Naming Test (McKenna and Warrington, 1983) was also in the normal range. On the three-picture version of the Pyramids and Palm Trees Test, a test of semantic association (Howard and Patterson, 1992) he made seven errors, which is impaired relative to control subjects, and may indicate a mild disorder of associative semantic knowledge. On some tests of frontal function, R.S.'s performance was in the normal range. Bimanual co-ordination and a modified Wisconsin Card Sort Test were performed normally, and his score on the Cognitive Estimates Test (Shallice and Evans, 1978) was within 2 SD of the control mean. R.S. was, however, severely impaired on an initial letter-based verbal fluency (FAS) test, scoring in the first percentile.

R.S.'s auditory-verbal short-term memory performance was in the normal range (see Table 2). In contrast, he showed no learning on any test of delayed recall or recognition. He was unable to learn even the easy paired associates from the Wechsler Memory Scale—revised (Wechsler, 1987), and recognition testing was no more successful; his scores were

at chance levels on both the Words and Faces components of the Warrington Recognition Memory Test (Warrington, 1984). On the Logical Memory subtest of the Wechsler Memory Scale—revised, R.S. was able to remember only the last phrase of one story (presumably on the basis of working memory). When asked to recall the paragraphs and designs from the Wechsler Memory Scale—revised following a delay, he was unable to remember ever being exposed to them. Similarly, R.S. scored zero on all elements of the Rivermead Behavioural Memory Test (Wilson *et al.*, 1985), and did not achieve the cut-off for a scaled score of 1 on the Doors and People Test (Baddeley *et al.*, 1994). When the experimenter returned to the test room after leaving for a few minutes (following >3 h of testing) she was not recognized.

Given the above, it was very surprising that R.S. was able to name the current Prime Minister (John Major), and correctly state that he was a member of the Conservative party. We decided to explore R.S.'s autobiographical memory and semantic knowledge, with the aim of establishing the presence or absence of post-morbid knowledge acquisition.

Autobiographical memory and semantic knowledge

We systematically investigated the status of R.S.'s autobiographical memory and semantic knowledge in both the anterograde and retrograde domains. Autobiographical facts and events, knowledge of famous people (cued with both faces and names), public events and new vocabulary were assessed.

For the novel tests, groups of normal control subjects matched to R.S. on the basis of age and educational level were used. Individuals with a history of substance abuse, learning disability, neurological or psychiatric disease were excluded. Informed consent was obtained from all participants prior to testing.

Autobiographical memory

Autobiographical memory interview. This test of autobiographical memory (Kopelman *et al.*, 1989) requires the subject to generate information from three life periods: childhood, early adult life and recent life. For each time period, the subject is required to recall various personal semantic facts (e.g. names of school friends, teachers, occupations and addresses) as well as individual episodes (e.g. 'Describe an incident which occurred in the period before you went to school.').

R.S. scored zero for autobiographical episodes in all time periods and, although he was able to produce a few pieces of factual information, he scored in the definitely abnormal range for all three periods on the personal semantic component of the test (see Table 3).

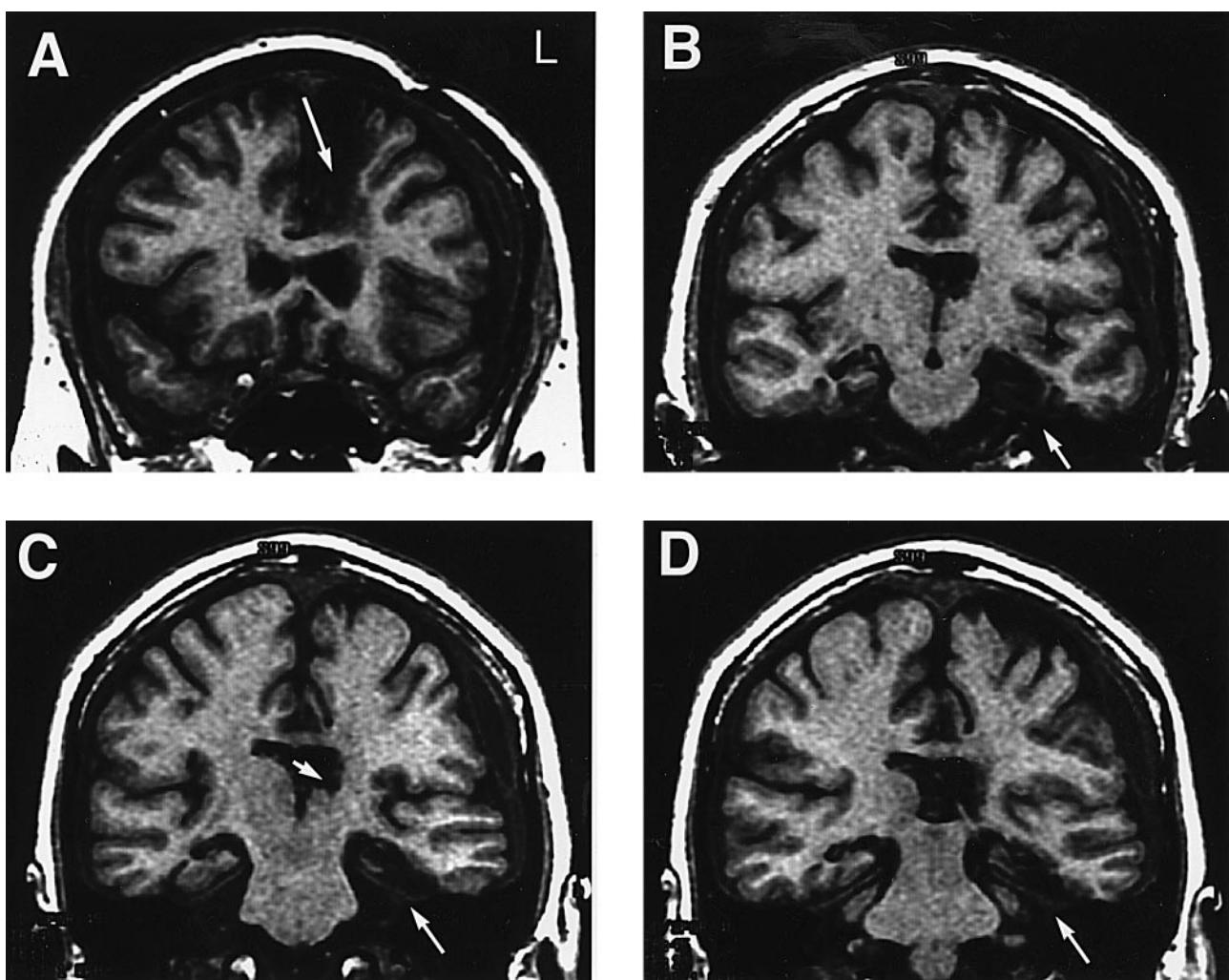


Fig. 1 Coronal T₁-weighted MRI images through the frontal and temporal lobes showing an area of ischaemic infarction of the medial left frontal lobe (arrow in A), destruction of the left hippocampus and parahippocampal gyrus including the entorhinal cortex and caudal perirhinal cortices (lower arrow in B, C and D), and a small area of low attenuation in the dorsolateral left thalamus (C). Note sparing of the inferolateral temporal cortex bilaterally.

Galton–Crovitz test of cued event recall. Cued recall of autobiographical events was further investigated using the Galton–Crovitz technique (Sagar *et al.*, 1988; Hodges and Ward, 1989). This test involves the presentation of 10 high-frequency nouns, and the subject's task is to produce a unique, personally experienced episode in response to each, and then to date each episode. Subjects are given up to 4 min to respond. For the first 2 min, only non-specific prompts are given (e.g. 'Can you be more specific?'). During the second 2-min period, concrete suggestions are allowed (e.g. 'Have you ever been in a boat?'). Responses are scored out of a possible three points, on the basis of spatiotemporal specificity and level of detail (Sagar *et al.*, 1988; Hodges and Ward, 1989). R.S. recalled no episodes in this task, even with extensive cueing. His score of one out of 30 illustrates the absoluteness of his autobiographical memory impairment. Hodges and Ward's (1989) control subjects scored 29.2 ± 1.4 (SD).

Knowledge of major autobiographical events.

Although R.S.'s performance on the above tests clearly indicated a severe episodic memory impairment, the possibility remained that he possessed some memory for personal episodes, but that this was not apparent due to the high retrieval demands of the autobiographical memory tests used. Therefore, we obtained information about a number of salient personal events from R.S.'s wife, and directly questioned him about these in detail. The events included his wedding, the births of his children, his entry into the Navy, etc. R.S. acknowledged that he was aware that these events had taken place, but appeared to have almost no knowledge of the circumstances surrounding them. For instance, when asked about an incident in which his son had been accidentally shot in the eye, he responded that he remembered that this had happened. However, he did not know how it had happened, where it had happened, who had taken his son to hospital, or even whether he himself had been present.

Thus, it is clear that R.S. is profoundly impaired at recall

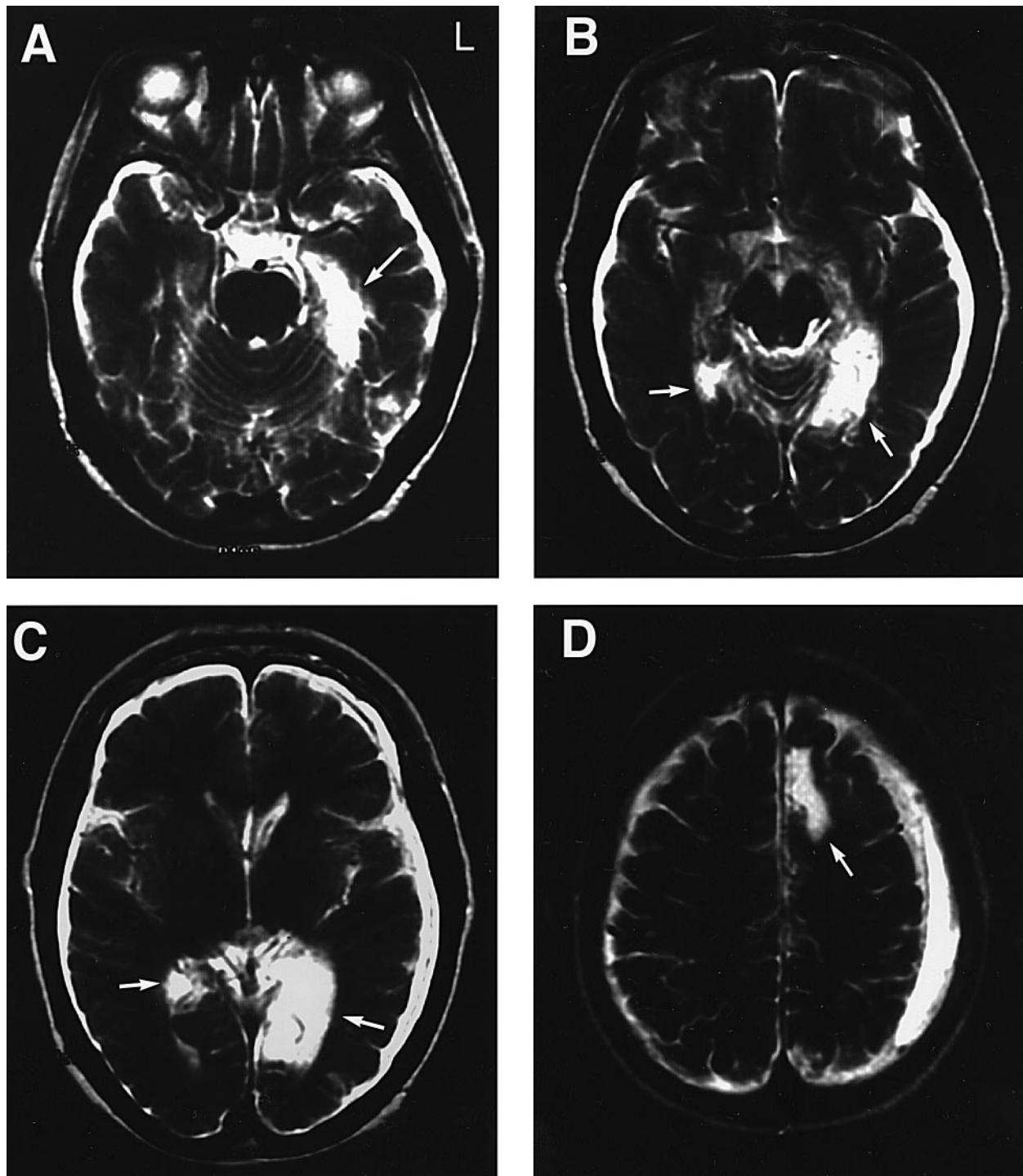


Fig. 2 Axially oriented T₂-weighted MRI images showing extensive damage to the left medial temporal lobe (A, B and C) with small areas of high signal intensity involving the posterior portion of the right hippocampal formation (B and C) and medial frontal lobe.

of autobiographical facts from the whole of his life, and absolutely no evidence of episodic memory functioning could be found.

Retrograde tests of semantic knowledge

R.S.'s pre-morbidly acquired semantic knowledge of famous people, public events and vocabulary was tested, in order to

permit comparison with performance on tests of post-morbidly encountered semantic information (see Table 4).

Famous Faces Test. R.S.'s knowledge of famous people was assessed with the Famous Faces Test of Greene and Hodges (1996). This test includes the photographs of 50 public figures who came to prominence between 1940 and the 1980s (10 per decade, e.g. Harold Macmillan, Louis

Table 1 Neuropsychological test results

Test	Score	Comments
General cognitive functioning		
NART	105	
Advanced Progressive Matrices	5/12	Dull (<10th percentile)
WAIS-R subtests (age scaled)		
Vocabulary	7	
Similarities	7	
Digit span	8	
Arithmetic	9	
Picture completion	7	
Picture arrangement	5	
Block design	8	
Verbal IQ	84	
Performance IQ	81	
Full scale IQ	82	
Visual/spatial processing		
Fragmented letters (VOSP)	20/20	Normal
Dot centre (VOSP)	17/20	Normal
Judgement of Line Orientation	20/30	Normal
Language functioning		
Spontaneous speech		Normal
Graded Naming Test	11/30	Scaled score 9
PPTT (verbal)	45/52	Controls make <3 errors
Frontal executive functioning		
Modified WCST	6 categories	Normal
Cognitive estimates	7 Controls	3.6 ± 1.9
Bimanual coordination		Normal
FAS fluency test	7	<1st percentile

NART = National Adult Reading Test; WAIS-R = Weschler Adult Intelligence Scale—revised; PPTT = Pyramids and Palm Tree Test; VOSP = Visual Object and Space Perception Battery; WCST = Wisconsin Card Sort Test.

Mountbatten and Diana Dors). Each target photograph is presented in an array with three similar distractor photographs of non-famous individuals. These arrays are presented singly, and the subject is asked first to point to the photograph of the famous individual (guessing if unsure), then to name the individual and, finally, to provide as much identifying information as possible. No specific cueing is given, although the subject may be asked if they can provide more information, or they may be probed for more details if their answer is ambiguous. Half marks are awarded where correct, but not uniquely identifying, information is provided. R.S.'s performance on the familiarity judgement portion of the test was entirely normal (45 out of 50 versus 43.0 ± 6.7 for control subjects). He was very poor relative to Greene and Hodges' control subjects at naming the faces (nine out of 50), but obtained higher scores when providing accurate information about the persons represented (18 out of 50; see Table 4). R.S.'s responses tended to be brief. For example, when presented with a picture of Sean Connery he was unable to provide a name, and when asked why the individual was famous he replied 'Films, I think'. When asked what roles the actor had played, R.S. responded 'James Bond'.

Famous Names Test. This test (Greene and Hodges, 1996) investigates knowledge of the famous people featured in the Famous Faces Test, accessed via their names. It was administered on a subsequent occasion to the Famous Faces Test. Stimuli consisted of the names of the previously described individuals, presented along with three similar distractor names. R.S. was required to choose the famous name, and then to provide uniquely identifying information about the individual. The cueing procedure was identical to that used in the Famous Faces Test. It can be seen in Table 4 that R.S. was mildly impaired relative to control performance on the familiarity component, but he scored only 25.5 out of 50 on the identification component. Again, his responses were very brief. When asked about the name Sean Connery, he replied '007'.

Famous Event Recognition Test. R.S.'s knowledge of famous events from the pre-morbid domain was assessed using the Famous Events Test of Hodges and Ward (1989). The test stimuli consist of the names of 100 news events; 50 true events from the 1930s to the 1970s (e.g. the Profumo affair and Watergate) were randomly mixed with 50 fictitious event names (e.g. the Goldberg affair and the Blackheath

Table 2 Anterograde memory test results

Test	Score	Comments
WMS-R		
Information/orientation	6	
Mental control	6	
Logical memory		
Immediate	2	(1st percentile)
Delayed	0	(1st percentile)
Visual reproduction		
Immediate	21	(7th percentile)
Delayed	0	(1st percentile)
Visual PAL		
I	4	
II	0	
Verbal PAL		
I	1	
II	0	
Figural memory	4	
Digit span		
Forward	7	(28th percentile)
Backward	4	(12th percentile)
Visual memory span		
Forward	8	(51st percentile)
Backward	6	(36th percentile)
Verbal memory index	<50	
Visual memory index	62	
Delayed recall index	<50	
Attention/concentration index	87	
General memory index	<50	
Rivermead Behavioural Memory Test	0 for all subtests	(Severely impaired)
Doors and People Test		
Names test		
Immediate verbal recall	0/12	
Delayed verbal recall	0/12	
Verbal recognition test A	4/12	(chance = 3)
Verbal recognition test B	3/12	(chance = 3)
Doors visual recognition test		
Test A	2/12	(chance = 3)
Test B	2/12	(chance = 3)
Shapes test		
Immediate visual recall	0/12	
Delayed visual recall	0/12	
Overall age-scaled score	<1	
Rey-Osterreith Complex figure		
Copy (max. 36)	29	
Delayed recall	0	
Warrington RMT		
Words (max. 50)	25	
Faces	24	

RMT = Recognition Memory Test; WMS-R = Wechsler Memory Scale—revised. PAL = Paired Associate Learning.

murders). R.S. was asked to judge whether each event name was authentic or fake. Although R.S. correctly endorsed a greater proportion of real events than Hodges and Ward's control subjects, his high number of false-positive responses brought his overall score (hits minus false alarms) down to a low level (see Table 4).

Pre-morbidly acquired vocabulary. Knowledge of vocabulary from the retrograde period was evaluated with the vocabulary subtest of the Weschler Adult Intelligence

Scale—revised. R.S.'s age-scaled score represents performance at a level 1 SD below normal (in the 16th percentile).

Thus, R.S.'s knowledge of semantic information from the pre-morbid period is clearly impaired relative to control subjects, but in comparison with his profound loss of autobiographical memory he performs surprisingly well on tasks of famous face and name familiarity. In addition, his ability to retrieve specific identifying information about famous faces and names reflects an unexpected degree

Table 3 Autobiographical memory performance

Test	Score	Comments
Autobiographical memory interview		
Episodes	0/27	Definitely abnormal
Childhood	0/9	Definitely abnormal
Early adult life	0/9	Definitely abnormal
Recent life	0/9	Definitely abnormal
Semantic facts	24/63	Definitely abnormal
Childhood	7/21	Definitely abnormal
Early adult life	10/21	Definitely abnormal
Recent life	7/21	Definitely abnormal
Galton-Crovitz cued recall	1/30	Controls 29.2 ± 1.4

Table 4 Tests of pre-morbidly acquired semantic knowledge

Test*	R.S.	Control subjects
Famous Faces Test		
Familiarity (50)	45	43.0 ± 6.7
Naming (50)	9	31.0 ± 9.2
Identification (50)	18	39.3 ± 8.8
Famous Names Test		
Familiarity (50)	43	49.7 ± 0.7
Identification (50)	25.5	49.1 ± 1.3
Famous Event Name Recognition		
Correct acceptances (%)	92	82.0 ± 14.9
Hits minus false alarms (%)	22	76.4 ± 13.3

*The number of items used for each test is given in brackets.

of preservation in comparison with his remote episodic memory.

Post-morbid tests of semantic knowledge

Tests of famous people, public events and vocabulary from the post-morbid period were constructed, in order to allow direct comparison with pre-morbidly acquired semantic knowledge.

Recent Famous Faces Test. This test used photographs of 38 famous individuals who became publicly known subsequent to R.S.'s stroke. These were each presented to R.S. in an array with three distractor photographs, and administration was identical to that of the previously described Famous Faces Test. R.S.'s performance was compared with that of eight normal control subjects (mean age 51.0 years, range 32–69 years; mean education 11.1 years, range 9–14 years).

Although R.S. is impaired (inevitably, given his limited interaction with the environment), on this test his familiarity score relative to control subjects (44.7%, see Table 5) is well above chance. He was able to provide some semantic information about six of these individuals; uniquely identifying two (John Major and, Mikhail Gorbachev), and giving correct information about a further four (Saddam Hussein, George Bush, Bill Clinton and Boris Yeltsin), giving

Table 5 Tests of post-morbidly acquired semantic knowledge

Test*	R.S.	Control subjects
Recent Famous Faces Test		
Familiarity (38)	17	27.3 ± 3.6
Naming (38)	2	13.5 ± 9.1
Identification (38)	4	19.2 ± 6.1
Recent Famous Names Test		
Familiarity (38)	25	33.6 ± 3.4
Identification (38)	7.5	29.8 ± 5.5
Recent Famous Event Name Recognition		
Correct acceptances (%)	85	90.0 ± 4.5
Hits minus false alarms (%)	30	64.2 ± 12.8
New Vocabulary Test (25)	15	22.8 ± 1.2

*The number of items used for each test is given in brackets.

him a score of four out of 38 (two full marks plus four half marks). In addition, R.S. was able to name two faces (George Bush and Mikhail Gorbachev). None of these individuals could have been known to R.S. prior to his stroke. Clearly, R.S. demonstrates some degree of new semantic learning on this test.

Recent Famous Names Test. The names of each of the above famous people were subsequently presented to R.S. Each name was presented in an array with three non-famous distractor names (e.g. Linford Tomlins, Linford Grey, Linford Waters and Linford Christie). Each set of four names consisted of the same first name combined with different surnames, and familiarity and identification were assessed as in the previous Famous Names Test. Results were compared with those of eight control subjects (mean age 53.6 years, range 32–69 years; mean education 11.0 years, range 9–14 years).

R.S. performed rather better than on the test of recent famous faces. He correctly recognized 66% of the names as familiar, and provided identifying information about seven individuals, plus accurate (but not uniquely identifying) information for a further individual (giving him an overall score of 7.5). As before, his sparse speech was reflected in his brief definitions (e.g. in response to 'Mikhail Gorbachev' he replied 'Political. Russia. Moving forwards'). Again, although R.S. does not perform at the level of control

subjects, his scores indicate a significant amount of anterograde semantic acquisition.

Recent Famous Event Name Recognition test. Post-morbidly acquired knowledge of events was tested with a set of 40 additional event names. Twenty were the names of actual events which occurred after R.S.'s stroke (e.g. 'the British beef scare' and 'the intruder in the Queen's bedroom'), and the remainder were fictitious distractors (e.g. 'the Corpstown march' and 'the invasion of Porto Novo'). This test was administered in the same fashion as the earlier Famous Events Test. Six control subjects were also tested (mean age 51.2 years, range 48–56 years; mean education 10.3 years, range 9–13 years).

As in the earlier Famous Events test, R.S. showed a strong tendency to make positive responses, which resulted in an impaired overall score relative to control subjects (see Table 5). However, his score on this test was significantly greater than chance (hits – false alarms = 30%), and he endorsed a significantly higher percentage of true than false events (χ^2 , $P < 0.05$). Therefore, R.S. demonstrated significant evidence of knowledge of public events from the anterograde domain. Although well below control level, his performance was actually better on this test than on the test of pre-morbid events.

New Vocabulary Test. In order to assess R.S.'s ability to acquire new vocabulary, we selected 25 words/terms which entered the British lexicon subsequent to his becoming amnesic from the Oxford Dictionary of New Words (Tulloch, 1991) and the Bloomsbury Dictionary of New Words (Green, 1991) (both these dictionaries include dates of entry into the British lexicon). We then constructed a (three-choice) multiple choice test, consisting of the correct definition of the word/term plus two plausible but false definitions (e.g. 'Does ME refer to (i) a South African political organization, (ii) a disc on which music is recorded, or (iii) a tiring post-viral illness?'). Eight control subjects were also given this test (mean age 51.1 years, range 32–69 years; mean education 11.3 years, range 9–14 years).

R.S.'s score of 15 out of 25 is well above the chance level of responding (χ^2 , $P < 0.01$). In addition, he was able to provide partially correct definitions of four words/terms prior to being given the multiple choices (e.g. for 'GCSE', the recently introduced English General Certificate of Secondary Education, he responded 'General course'). Thus, it seems that, as well as knowledge of public figures and events, R.S. has acquired new vocabulary in the post-morbid period.

R.S. demonstrated evidence of at least some degree of new semantic learning on every test administered. He showed surprisingly good performance on tests of famous face and name recognition, and evidence of some acquisition of semantic knowledge of famous people and events. In addition, he has clearly updated his general vocabulary.

Table 6 Tests of personal semantic knowledge

Test*	Score
Personal events test	
Pre-morbid	
Correct acceptances (15)	12
Hits minus false alarms	12
Post-morbid	
Correct acceptances (15)	10
Hits minus false alarms	0
Personally known individuals test	
Pre-morbid domain	
Familiarity score (30)	28
Correct acceptances (15)	13
Distractors rejected (15)	15
Identification (15)	13
Episodes (15)	0
Post-morbid domain	
Familiarity score (30)	15
Correct acceptances (15)	0
Distractors rejected (15)	15
Identification (15)	0
Episodes (15)	0

*The number of items used for each test is given in brackets.

Tests of personal semantic knowledge

Since it is often argued that most autobiographical memory tests place higher demands on strategic retrieval processes than do tests of public knowledge, we next tested R.S.'s knowledge of people and events from his own life using tasks with minimal retrieval demands. We were particularly interested to see whether R.S. was able to discriminate true post-stroke events from distractor items.

Personal Events Test. This test was constructed and administered in a manner similar to the Famous Events Test. Actual autobiographical events (e.g. 'You won an award for a painting of a farmyard scene.' and 'Your son cracked a bone in his wrist.') were intermixed with an equal number of fictitious distractors (e.g. 'You had to have the roof retiled.' and 'You went on holiday to Hungary.'). R.S. was auditorily presented with each event and asked to judge whether it was authentic or false. The test was composed of two subtests: 30 items from the pre-morbid period and 30 items from the post-morbid period. Autobiographical information was obtained through interviews with R.S.'s relatives and carers.

R.S.'s performance on the pre-morbid section of the test was quite good (see Table 6). He correctly endorsed 80% of the correct events, and correctly rejected 100% of the distractors. In contrast, he showed no evidence at all of being able to distinguish between true and false post-morbid events (hits – false alarms = 0%).

Personally known individuals test. This test was designed to test R.S.'s knowledge of people known either before or since his stroke. It was composed of 60 names, 30 of which were individuals known to R.S. and 30 of which were distractors. Half of the target names were from the pre-

morbid period (e.g. a co-worker from the Navy and a neighbour), and half were from the post-morbid period (e.g. R.S.'s key worker from the day centre that he attends and his son's wife). These were auditorily presented to R.S., and he was asked 'Is this the name of someone you know?'. If he answered affirmatively, he was asked first how he knew them and secondly to attempt to recall an episode involving the person.

Again, R.S.'s performance in the pre-morbid domain was very good. He endorsed 13 out of 15 known individuals, and, in addition, correctly identified each of them (although he could recall no episodes involving any individual). He correctly rejected 100% of the distractor names. However, R.S. endorsed none of the 15 names of individuals known in the period since his stroke.

Thus, R.S. showed no knowledge of episodes from the post-morbid period, even when only familiarity judgements were required. Similarly, R.S. did not recognize the names of individuals met during the post-morbid period, although it is obviously not possible to know how often he would have heard these people referred to by their full names.

Discussion

We argue that our patient, R.S., has provided irrefutable evidence that new semantic information may be acquired in the absence of any significant anterograde episodic memory. R.S. demonstrated post-morbid semantic acquisition on all of our tests of public knowledge, despite having no detectable episodic memory. This evidence is made even more compelling by the fact that R.S.'s present limited lifestyle means that his exposure to new information about the world must be much reduced relative to that of most normal individuals.

There are only a few cases in the literature of a patient with an autobiographical memory deficit as extensive as that of R.S. For example, K.C. (Tulving *et al.*, 1988) is similar to R.S. in that he is totally unable to access any personally experienced event information from any period of his life. As Tulving *et al.* (1988) have pointed out, most previously reported amnesics whose cases have been described in detail have been able to provide at least some information about autobiographical events from some time in the past (e.g. Andrews *et al.*, 1982; Cermak and O'Connor, 1983; Zola-Morgan *et al.*, 1983; Damasio *et al.*, 1985; Butters and Cermak, 1986; Goldberg and Bilder, 1987; Wilson and Baddeley, 1988; McCarthy and Warrington, 1992). R.S. is as amnesic as K.C. on standard tests of anterograde episodic learning.

R.S.'s performance on our tests clearly indicates acquisition of new information and associations rather than mere transitory priming of old knowledge. This is consistent with the findings of Butters *et al.* (1993) in indicating that amnesics are capable of acquiring new flexible semantic information (although this may require extensive practice). R.S.'s acquisition of new words is especially interesting, in light

of previous studies that have either been unsuccessful in demonstrating vocabulary learning in amnesics or have shown that knowledge of words could be acquired, but tended to be hyperspecific and to lack generalization. Glisky *et al.* (1986 *a, b*) pointed out two factors which they felt might have led to better learning of new vocabulary in their study than that observed by Gabrieli *et al.* (1988). The first was that Glisky *et al.* made use of the vanishing cues method, and the second the fact that their study involved the learning of new associations to words which were already known to the patient (e.g. loop and save) rather than unknown low frequency words.

In their discussion of new learning in K.C., Tulving *et al.* (1991) also emphasize the role of pre-existing knowledge in determining what information amnesics are able to acquire. They conclude that amnesic semantic learning is heavily influenced by the 'meaningfulness' of the information to be learned, i.e. by the degree to which it relates to, and is consistent with, existing concepts. In addition, they state that interference has highly detrimental effects on amnesic learning. Tulving *et al.* point out that the training procedure used in the Gabrieli *et al.* (1988) study resulted in the production of a large number of incorrect responses during training, and that this interference rendered the technique ineffective.

In the present case, R.S. may have shown significantly better and more flexible learning than would be expected on the basis of the amnesia literature simply as a result of the ecological validity of his 'training' (which took place through natural interaction with the environment). R.S. was not forced into making errors during learning, as in the Gabrieli *et al.* (1983, 1988) studies, reducing the effect of interference from competing responses. Glisky *et al.* (1986*a, b*) and Hirst *et al.* (1988) both point out the advantages shown in amnesic vocabulary acquisition when either the word or the definitional concept is pre-existing. R.S., however, was able to acquire new terms and novel concepts concurrently, demonstrating that it is possible, although this may be more difficult for amnesics than the acquisition of new words and concepts singly. Tulving's observations on 'meaningfulness' may also be relevant here. Although it is difficult to quantify the meaningfulness of our stimuli, it would seem likely that terms which have recently entered mainstream culture and their associated concepts would have greater meaningfulness to an individual than would the arcane words employed by Gabrieli *et al.* (e.g. anchorite and manumit) or the computer-related vocabulary used in the studies of Glisky *et al.* (1986*a, b*).

This leads to the question of why no evidence of new vocabulary acquisition has been reported in the two previous studies in which natural acquisition has been assessed in long-standing amnesia (Gabrieli *et al.*, 1988; Verfaellie *et al.*, 1995). A likely possibility is that different patterns of neurological damage could account for the disparate results of these studies. R.S.'s left temporal damage affected mostly medial temporal structures, sparing lateral temporal cortex.

Verfaellie's patient suffered from herpes simplex encephalitis, which often destroys the inferolateral temporal cortex, a region known to be critical for semantic memory (Hodges *et al.*, 1992, 1994). The long-term amnesic, H.M., who was the subject in the study of Gabrieli *et al.* (1988), had medial rather than lateral temporal lobe damage, and did in fact demonstrate a degree of knowledge of famous names and new vocabulary, although this was a smaller effect than that seen in R.S. Gabrieli *et al.* (1988) mention that in the past few years H.M. has developed mild language impairment. This may have affected his semantic encoding, and could account for H.M.'s less marked (though not non-existent) post-morbid vocabulary knowledge.

A similar type of explanation may account for R.S.'s ability to acquire information concerning public figures. The three cases in the literature with selective deficits in person-specific knowledge have all involved damage to right lateral temporal cortex (Ellis *et al.*, 1989; Hanley *et al.*, 1989; Evans *et al.*, 1995). Preservation of right lateral cortical structures may, therefore, have been critical to R.S.'s preserved knowledge of famous people and public events from the pre-morbid period, and to his ability to acquire new information of this kind. For a fuller discussion of the material specific roles of left and right temporal lobes in semantic knowledge see Hodges and Graham (1998).

We should stress that we are not claiming that R.S.'s semantic knowledge from the post-morbid period is normal. He performs surprisingly well on tests of familiarity judgement (recognition), but shows only a small amount of learning on tests of identification and naming. The point which we would like to emphasize is that even the little knowledge acquisition which he does demonstrate is striking, in the context of his profound amnesia.

We now attempt to account for our findings in terms of cognitive accounts of the amnesic syndrome. As mentioned previously, one proposal has been that episodic and semantic memory may be dissociated in amnesia (Kinsbourne and Wood, 1975; Parkin, 1982; Cermak, 1984; Vargha-Khadem *et al.*, 1997). One version of this theory (Tulving *et al.*, 1991) states that the episodic memory system is embedded within the semantic system, and that damage to the semantic system leads to impairment of episodic acquisition and retrieval, whereas impairment of the episodic system does not necessarily have any deleterious effect on semantic memory. Tulving *et al.* (1991) argue that while, in some amnesic patients, semantic memory performance is worse than that of normal individuals as a result of damage to the semantic memory system itself, in many cases the observed discrepancy between amnesics and control subjects has reflected the ability of the normal individuals to use intact episodic memory to boost performance. This hypothesis, while difficult to disprove, seems unlikely. The present case, together with the findings of previous studies, proves that some semantic memory can be acquired in the absence of detectable episodic memory. We are not, however, claiming that R.S.'s semantic acquisition is normal.

An opposing school of thought proposes that episodic and semantic memory are both components of declarative memory, and that, as such, they are equally impaired in amnesia (Zola-Morgan *et al.*, 1983; Cohen, 1984; Cermak *et al.*, 1985; Squire, 1986; Squire *et al.*, 1993). Squire and colleagues (Ostergaard and Squire, 1990; Squire *et al.*, 1993) have pointed out that, in most reported cases of new semantic learning in amnesia, some episodic memory function has been spared. Since episodic memory is by definition unique to time and place, while learning opportunities for semantic memory may be repeated, it has been argued that semantic memory will always appear to be relatively better than episodic.

It has also been suggested that frontal lobe damage may affect episodic memory disproportionately (Squire *et al.*, 1993). In addition to bilateral hippocampal infarction (complete on the left, involving entorhinal cortex, and partial on the right) R.S. has sustained damage to the left thalamus, left basal forebrain and frontal lobe. Squire *et al.* (1993) have proposed that the case of K.C. (Tulving *et al.*, 1988, 1991; Hayman *et al.*, 1993) can be explained as a deficit in declarative memory, with additional source amnesia due to frontal lobe pathology. It could be argued that R.S.'s cognitive profile is the result of frontal damage superimposed upon a partially damaged hippocampal system which is still capable of mediating some learning about both facts and events. However, on tests of anterograde memory, R.S.'s performance was at chance level on recognition as well as recall tests, which makes this explanation highly unlikely.

Recent computational models of the interaction of hippocampal and neocortical systems in memory have attempted to account for extant data pertaining to episodic and semantic knowledge in amnesia (see Evans *et al.*, 1996; Graham and Hodges, 1997). These models, although different in detail, all propose that, during learning of an event, rapidly modifiable synapses in the hippocampus receive convergent input from neocortical association areas, and form a sparse, distributed representation (Rolls, 1990; Alvarez and Squire, 1994; Treves and Rolls, 1994; McClelland *et al.*, 1995; Murre, 1996). This region is thought to operate as an auto-associative neural network which mediates recall of the stored event on the basis of a partial cue.

When presented with a part of the stored pattern of neural firing coding for the event, the hippocampal network completes the pattern through autoassociation, reproducing the specific pattern of neural activity which was present at encoding. This results in the reinstatement (through the back projection system to various regions of neocortex) of the pattern of cortical firing which occurred during learning, corresponding to conscious recall of the episode. This reactivation of the neocortical representation may occur through active rehearsal, repeated experiences or randomly during sleep. Eventually, the slowly adapting cortical synapses become interconnected independently of the hippocampus, and retrieval can proceed without the medial temporal system (the memory is consolidated).

McClelland *et al.* (1993) were the first to develop an explicit computational model of the relationship between the hippocampus and neocortex in memory. On this account, a fast learning process is required, since it is necessary to record rapidly occurring events in the world. Too rapid learning in the neocortical system would result in catastrophic interference with previously stored patterns. Instead, fast learning takes place in the hippocampus, which then gradually teaches the information to the neocortex through reinstatement. Thus, damage to the hippocampal system will result in loss of memories which have not been fully consolidated, and this translates into temporally graded retrograde amnesia.

According to McClelland *et al.* (1993), the same process normally underlies the acquisition of episodes and facts, since semantic information is encountered in particular contexts. With repeated reinstatements, gradual changes in neocortical connection weights will result in factual information being integrated into neocortical representations. If information about time and place of occurrence is reinstated often enough, this information will also become represented in neocortex, and will be capable of mediating performance on an episodic memory task.

In the absence of a functioning hippocampal system, it is theoretically possible for the neocortex to learn (albeit slowly) in isolation, through repeated exposure to the information leading to small changes in neocortical connection weights with each encounter. The above models may also provide an explanation for the observation that semantic learning in amnesic patients is greatly reduced under conditions in which interference exists (Tulving *et al.*, 1991). Medial temporal damage means that amnesics such as R.S. may be without the ability to make use of sparse distributed hippocampal representations to aid them in distinguishing between situations which differ only slightly.

R.S.'s episodic memory deficit is disproportionately severe relative to his semantic memory deficit. One interpretation for this is his combination of medial temporal lobe destruction with superimposed frontal pathology. An alternative explanation, one that we favour, is that in the absence of a functional medial temporal system he has retained the ability to slowly learn vocabulary and semantic facts through repeated exposure to spared temporal cortical areas (see Kapur 1994; Vargha-Khadem *et al.*, 1997). Since this learning would proceed without the benefit of the hippocampally mediated multimodal binding which a normal individual would bring to bear on the problem, it might allow R.S. to be relatively more successful on tasks such as judging the familiarity of famous faces and names than on tests of autobiographical memory, which are typically considered to be more heavily dependent on integrated multimodal learning. In this situation, it may be of critical importance that the neocortical regions which previous studies have implicated in the acquisition and storage of specific kinds of semantic knowledge (the left and right inferolateral temporal neocortices for general and person-specific information,

respectively) are spared in R.S. (Evans *et al.*, 1995; Hodges *et al.*, 1994; Hodges and Graham, 1998). A similar mechanism was proposed by Vargha-Khadem *et al.* (1997) to explain the relatively normal acquisition of semantic knowledge by three patients with severe episodic memory deficits resulting from anoxia in early life, and in the patient reported by Kapur (1994), who had suffered fairly pure mammillary body damage. The former authors stress the role of the perirhinal and entorhinal cortices in the formation of context-free semantic memories. It is difficult to be certain about the status of these structures in our patient, but according to current views of their location in man (see Corkin *et al.*, 1997) it seems that the entorhinal cortex on the left was completely destroyed, as was the caudal part of the perirhinal cortex contained within the banks of the collateral sulcus. However, the more rostral portion may have been spared. This may explain the relatively limited semantic acquisition shown by R.S. compared with the three patients of Vargha-Khadem *et al.* (1997). Another critical feature may be the age at which damage to these systems occurs.

One point which remains unclear is why, given his acquisition of a certain amount of public knowledge, R.S. has been unable to acquire even the most salient personal facts, such as the fact that his daughter has grown up and left home, or that his mother has died. It may be that R.S.'s frontal damage has differentially affected his recall of autobiographical information, as has been suggested by a number of authors (Janowsky *et al.*, 1989; Della Sala *et al.*, 1993; Hodges and McCarthy, 1993; Squire *et al.*, 1993). Alternatively, R.S.'s relative weakness with personally relevant information may reflect his inability to use the hippocampal system to reinstate autobiographical memories during sleep and conscious reminiscence. Since R.S. is not able to perform these procedures, his learning may be low in autobiographical content relative to normal individuals. The total number of environmental exposures to new facts may therefore become abnormally salient. Although it initially appears paradoxical that R.S. knows that Reagan is no longer President of the US, but not that his mother has died, it is probable that his total number of exposures to the first fact has been greater than to the second.

In summary, we have provided strong evidence that it is possible for an amnesic with no detectable episodic memory to acquire new explicitly accessible semantic information, including knowledge of famous people, public events and vocabulary, and that this is not necessarily hyperspecific in nature. Future studies will be required to investigate the characteristics of newly acquired knowledge in other amnesic patients. It may be that, just as our patient differs from those previously studied by Gabrieli *et al.* (1988) and Verfaellie *et al.* (1995) in terms of new vocabulary learning, careful testing will reveal further dissociations in the kinds of semantic information that may be acquired by amnesics, depending upon the precise pattern of their neuroanatomical damage.

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