

# Visual imagery deficits, impaired strategic retrieval, or memory loss: disentangling the nature of an amnesic person's autobiographical memory deficit

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## Abstract

Conclusions about the duration of hippocampal contributions to our autobiographical record of personal episodes have come under intense scrutiny in recent years. Interpretation is complicated by such factors as extent and site of lesions as well as test sensitivity. We describe the case of an amnesic person, K.C., with large, bilateral hippocampal lesions who figured prominently in the development of theories of remote memory due to his severely impoverished autobiographical memory extending across his entire lifetime. However, the presence of lesions in higher-order visual cortex raises the possibility that K.C.'s retrograde autobiographical amnesia is mediated by loss of long-term visual images, whereas widespread frontal lesions suggest that his impairment may relate to deficits in strategic retrieval rather than storage. Normal performance on an extensive battery of visual imagery tests refutes the imagery loss interpretation. To test for deficits in strategic retrieval, we used a more formal autobiographical memory test requiring generation of personal events under varying levels of retrieval support. However, even with rigorous contextual prompting, K.C. produced few pre-injury recollections; all were schematic, lacking the richness of detail produced by control participants, raising doubt that his deficit is one of retrieval. Findings are discussed in the context of theories concerning the duration of hippocampal-neocortical interactions in supporting autobiographical re-experiencing. The approach we used to investigate the effects of different lesions on memory provides a framework for dealing with other patients who present with an interesting functional deficit whose neuroanatomical source is difficult to specify due to widespread lesions.

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## 1. Introduction

Our lives are shaped by the numerous unique events that we experience in our lifetime and our reliving of those events in memory. Memory for episodic, autobiographical details depends on the ability to recover information concerning unique events and thus differs from memory for the more semantic, context-independent gist or core extracted from repeated events (Tulving, 1972, 1983). Recent findings from functional neuroimaging suggest that the distinction between autobiographical and semantic memory may be reflected in the way in which these two types of information are organized in the brain for long-term storage (Graham, Lee, Brett, & Patterson, 2003a; Conway, Pleydell-Pearce,

Whitecross, & Sharpe, 2002; Levine et al., in press; Maguire, 2001). Moreover, reports of amnesic patients with substantial hippocampal damage show that premorbid memories of personal episodes and semantic facts are affected disproportionately, such that memory loss is severe and often extends across all time periods for episodes (Cipolotti et al., 2001; Fujii, Moscovitch, & Nadel, 2000; Piolino et al., 2003; but see Bayley, Hopkins, & Squire, 2003) but applies only to the most recent time periods for facts (Fujii et al., 2000; Manns, Hopkins, & Squire, 2003). In this paper, we examine whether deficits in visual imagery associated with posterior neocortical damage, or in strategic retrieval associated with prefrontal cortex damage, can account for the severe, retrograde autobiographical amnesia in patient K.C., who has extensive bilateral hippocampal lesions.

The amnesic patient K.C., though problematic in some ways (see below), provides a particularly striking example of the dissociation between episodic and semantic memory.

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Qualitative assessment of K.C., who suffered widespread brain damage that included almost complete hippocampal loss bilaterally following a closed-head injury twenty years ago, revealed remote memory loss that was minimal in duration for factual information but relatively complete for personal episodes (Tulving, Schacter, McLachlan, & Moscovitch, 1988; Rosenbaum et al., 2000). Consistent with the extent of his damage, he exhibited a severe anterograde and retrograde amnesia for autobiographical episodes associated with visually presented family photographs (Westmacott, Leach, Freedman, & Moscovitch, 2001; for an earlier description of this impairment, see Tulving et al., 1988). There was no sign that the photographs triggered any feeling of re-experiencing or emotional response. K.C. was unable to place events in the photographs within a temporal-spatial context or relate them to any life experiences beyond that which was obvious to any individual seeing the photographs for the first time. Even after extensive prompting, he could not recreate an episode from any part of his life. This was in sharp contrast to his relatively preserved conceptual autobiographical knowledge and world knowledge, as indicated by his ability to identify the people within family photographs, as well as famous names and places, and to define words from time periods across his pre-morbid life span except for the 5–10 years before his accident. Similar to this pattern of personal and general semantic preservation but autobiographical episodic impairment, K.C. appears to have retained a schematic cognitive map sufficient for navigation in an environment experienced since he was 9 years old, but has lost more detailed topographical features of that environment, such as the appearance of salient houses (Rosenbaum et al., 2000).

Accounts such as this suggest a special, continuous contribution of the hippocampus to the retrieval of autobiographical memories across the entire life span. Nadel and Moscovitch (1997, 2001) proposed that autobiographical memories, whether old or newly formed, are supported by an ensemble of hippocampal-neocortical interactions, such that the hippocampal information serves as a pointer to information held in neocortical regions specialized in the processing and storage of the particular sensory, emotive, and contextual details that define an episode. The reinstatement of a personal episode in all of its details continues to depend on such cohesively bound neocortical-hippocampal complex traces for as long as that memory exists. According to this view, complete damage to the hippocampus would lead to a retrograde amnesia that encompasses an entire lifetime of personal incidents, whereas partial damage would lead to a temporally graded loss.

Focal lesions to neocortex should likewise give rise to a severe impairment in recall of autobiographical incidents in the absence of a disproportionate sparing of earlier memories (Conway & Fthenaki, 2000; Dall’Ora, Della Sala, & Spinnler, 1989), but the loss may be specific to the type of information that the damaged neocortical component was once specialized to represent (Moscovitch & Nadel, 1999). In-

deed, extensive and flat gradients in remote autobiographical memory loss have been documented in patients with damage to posterior regions of neocortex involved in the maintenance or access of visual material (e.g., O’Connor, Butters, Miliotis, Eslinger, & Cermak, 1992; Ogden, 1993). In line with several theoretical frameworks (e.g., Conway, 1992, 1996; Ogden, 1993), Rubin and Greenberg (1998) classified such patients as suffering from “visual memory-deficit amnesia” according to Farah’s (1984) scheme that the patients demonstrate loss of stored visual information in memory in addition to visual associative agnosia (see also Greenberg & Rubin, 2003). Their analysis suggested that the re-experiencing of a personal episode relies most heavily on the ability to conjure up in imagery detailed visual features present during the original event (Brewer & Pani, 1996). They further proposed that if generated successfully, long-term visual representations proceed to reactivate non-visual percepts, conceptual knowledge, and emotions related to the event as they are placed within a spatial and temporal context. It follows that if the neocortical visual storage component of the ensemble described by MTT is compromised, access to the remaining details that characterize the event is denied, and autobiographical memory loss is likely to occur. Recently, Graham and Hodges (e.g., Graham & Hodges, 1997; Hodges & Graham, 2001) proposed a similar explanation to account for the amnesia associated with many cases of semantic dementia.

This alternative account of retrograde amnesia in patient K.C. is plausible in view of the fact that his lesion encroaches on sites in posterior neocortex identified by Rubin and Greenberg (1998). Such an account was considered unlikely because K.C. is not agnostic and because of recent reports that his recognition of people and landmarks that were familiar pre-morbidly was preserved as was his visual imagery for the spatial arrangement of those landmarks (Rosenbaum et al., 2000; Westmacott et al., 2001). Nonetheless, because only imagery of landmarks and their arrangement was tested, it is conceivable that more rigorous investigation would reveal a deficit in visual imagery in the absence of a corresponding deficit in visual perception (e.g., Behrmann, Moscovitch, & Winocur, 1994; O’Craven & Kanwisher, 2000), which may contribute to K.C.’s autobiographical memory loss (Rubin & Greenberg, 1998).

To evaluate this hypothesis, a series of tests that normally require visual imagery to solve were adapted to assess K.C.’s ability to make judgments about the visual appearance and spatial properties of objects from memory. If he proves capable of accessing visual images from long-term memory, we would then be interested in his capacity to construct and identify novel items through mental rotation and integration of known images. We believe that such a demonstration would indicate beyond reasonable doubt that K.C.’s retrograde autobiographical amnesia is not attributable to functional loss in posterior visual neocortex, which is needed to conjure images in general. It would be necessary to rule out

this general deficit before considering the possibility that a more specific deficit exists in imagery related directly to autobiographical memory, an idea advanced by Conway (for an updated version, see Conway, 2001).

Although damage to higher-level visual neocortex related to event circumstances would lead to disruption in autobiographical memory at the level of storage, this is but one component in most models of autobiographical memory systems; breakdown in access or retrieval relating to frontal lobe pathology should prove equally detrimental. The frontal lobes act as an intelligent central system that works with stored memories and operates on them, performing such retrieval functions as initiating, guiding, and organizing a memory search in addition to monitoring its recovered content (Moscovitch, 1992; Moscovitch & Winocur, 1992, 2002). Unlike semantic facts, which are less detailed, more differentiated, and often rehearsed, the multifaceted nature of autobiographical episodes demands the active, simultaneous re-creation of elements similar to those that were present during the initial experience and often in the absence of sufficiently detailed and readily available cues. Indeed, patient and neuroimaging studies together have indicated that the frontal lobes may be necessary for accessing all autobiographical memories, regardless of the age of the memory (Kopelman, 1991; Levine et al., 1998; Ryan et al., 2001; but see Maguire, Henson, Mummery, & Frith, 2001). It is possible, therefore, that K.C.'s autobiographical memory deficit does not reflect loss of stored representations of personal incidents but, instead, reflects executive dysfunction manifest as an inability to initiate strategies elaborate enough for the retrieval of intact, detailed information. If K.C.'s deficit is primarily one of generating details and organizing them into a coherent memory, contextual prompting should facilitate recovery of personal episodic details that are preserved in long-term storage. Moreover, memory loss should not be observed on tests of recognition.

In order to gain a better sense of whether K.C.'s loss of autobiographical details is symptomatic of a more general impairment stemming from concomitant damage to his frontal lobes rather than of memory storage per se, we administered a newly developed and highly structured Autobiographical Interview (Moscovitch, Yaschyshyn, Ziegler, & Nadel, 2000; Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). In this test, the traditional three-point scoring method of the Crovitz cue-word technique (Crovitz & Schiffman, 1974) and Autobiographical Memory Interview (Kopelman, Wilson, & Baddeley, 1989, 1990), on both of which K.C. is impaired, is replaced with a method of counting and classifying details elicited in free- and cued-recall conditions. Not only does this test prove more sensitive in capturing severely deficient detail generation in amnesic patients who score normally on more traditional tests of autobiographical memory (Moscovitch et al., 2000), but it also allows for evaluation of the effects of retrieval support on episodic and on semantic memory.

## 2. Participants

### 2.1. Patient K.C.

K.C. is a 50-year-old, right-handed man with 15 years of formal education who suffered irreversible amnesia as a consequence of a traumatic brain injury from a motorcycle accident in 1981.

#### 2.1.1. Neuroimaging

Magnetic resonance imaging (MRI) and computerized tomography (CT) illustrating the specific loci of brain damage suffered by K.C. have been documented elsewhere (e.g. Rosenbaum et al., 2000; Tulving et al., 1988; Tulving, Hayman, & MacDonald, 1991). MRI performed in 1996 revealed a pattern of diffuse brain damage that includes almost complete devastation to his hippocampus on the right ( $Z = -9.8$ ) and left ( $Z = -7.8$ ; see Fig. 1) and clear signs of atrophy to his parahippocampal gyrus on the right ( $Z = -4.8$ ) and left ( $Z = -19.1$ ). Also of note is a large lesion in left occipital-temporal cortex, which extends slightly into retrosplenial cortex, as well as lesions to medial occipital-temporal-parietal, medial occipital, and left frontal-parietal regions (Fig. 2). Other limbic structures such as the mammillary bodies, the septal area, and the fornices are also noticeably atrophic.

#### 2.1.2. Neuropsychological profile

The results of extensive neuropsychological testing in 1996 have been described in detail elsewhere (e.g., Rosenbaum et al., 2000; Westmacott et al., 2001), and are summarized only briefly here (presented in Table 1). Of note, slight declines in performance from earlier assessments were noted on the WAIS-R in the 1996 assessment (Full Scale IQ of 88, Verbal IQ of 96, Performance IQ of 79) but were not observed on the Wechsler Abbreviated Scale of Intelligence (WASI) in a recent 2003 assessment (Full Scale, Verbal, and Performance IQ of 99). Despite his intellectual ability, K.C. exhibited profound impairment on standardized tests of anterograde memory, and this is reflected in his inability to recognize the examiner after more than 40 lengthy testing sessions. On the WMS-R, he received scores of 61, 67, and 69 on the General, Verbal, and Visual memory scales, respectively. His performance was within the 5th percentile on logical memory I and 13th percentile on visual reproduction I, and he received a score of zero in the delayed conditions of these subscales as well as on delayed memory for the Rey–Osterrieth complex figure. He also performed at chance levels on the Warrington Recognition Memory Test, recognizing only 26 of 50 items on the words and faces subscales. Memory performance in the immediate and delayed conditions of the California Verbal Learning Test (CVLT) was likewise impaired (acquisition:  $T = 12$ , short delay recall:  $Z = -4$ , long delay recall:  $Z = -4$ , and recognition discriminability:  $Z = -3$ ). Performance was also impaired on the Autobiographical Memory

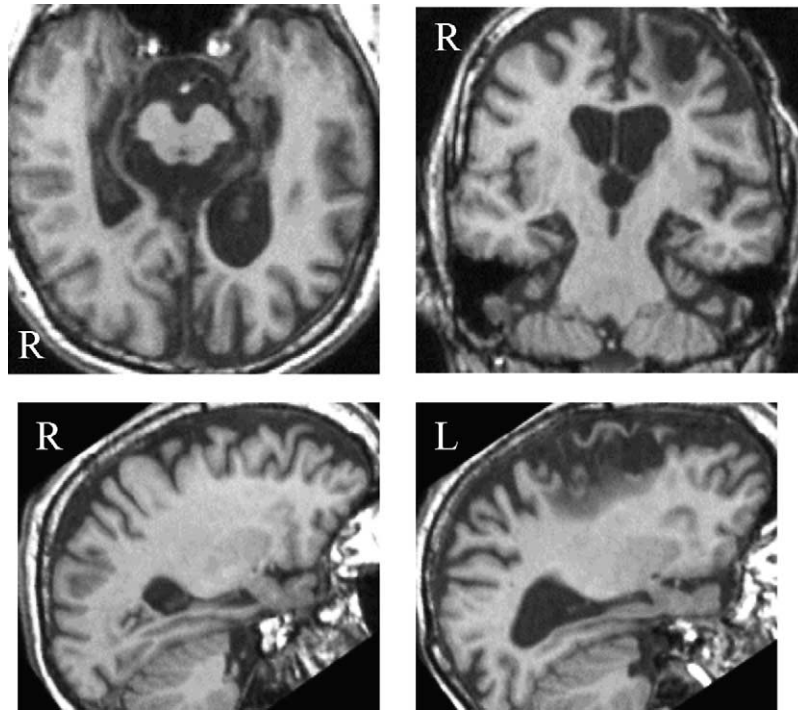


Fig. 1. Magnetic resonance imaging slices showing patient K.C.'s bilateral hippocampal damage in axial (top row, left), coronal (top row, right), and sagittal (bottom row) views.

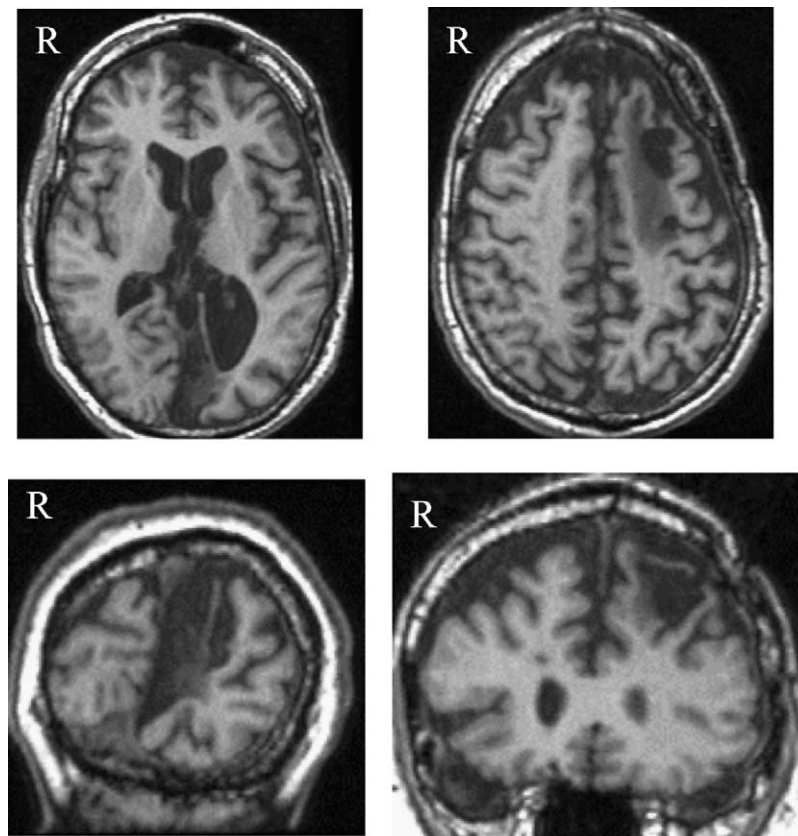


Fig. 2. Magnetic resonance imaging slices showing patient K.C.'s extensive lesions to medial occipital (left column) and frontal (right column) regions in axial (top row) and coronal (bottom row) views.

Interview (AMI; Kopelman et al., 1990), a standardized test of memory for autobiographical incidents (unique episodes) and personal semantic information (facts pertaining to the person's past) from across the person's life. Retrograde and anterograde memory for unique episodes fell within the 'definitely abnormal' range for all time periods tested, namely childhood (2/9), early adult life (3/9), and recent years (1/9). On the personal semantics subsection of the AMI, with the exception of the childhood period, which was classified as 'acceptable' (16/21), performance for the later time periods was again within the 'definitely abnormal' range (early adult life, 13.5/21; recent years, 8/21).

Table 1  
Neuropsychological profile of patient K.C.

Neuropsychological Test	Score
WAIS-R (standard score)	
FSIQ	88 (99) <sup>a</sup>
VIQ	96 (99)
PIQ	79 (99)
AM-NART (standard score)	102
WAIS-R Vocab (scaled score)	9
Boston Naming Test (/60)	57
Semantic fluency <sup>b</sup> (scaled score)	10
WMS-R	
General memory (standard score)	61
Verbal memory (standard score)	67
Visual memory (standard score)	69
LP I (%ile)	5th
LP II (%ile)	<1st
VR I (%ile)	13th
VR II (%ile)	<1st
WRMT (/50)	
Words	26
Faces	25
CVLT	
Acquisition ( <i>T</i> -score)	12
Short delay free ( <i>Z</i> -score)	-4
Long delay free ( <i>Z</i> -score)	-4
Recognition discriminability ( <i>Z</i> -score)	-3
ROCF (/36)	
Copy	36
Immediate recall	4
Delayed recall	0
AMI Autobiographical (/9)	
Childhood	2
Early adult life	3
Recent life	1
AMI Personal Semantics (/21)	
Childhood	16
Early adult life	13.5
Recent life	8
Judgement of Line Orientation (/30)	23
WAIS-R block design (scaled score)	9
Benton Visual Discrimination Test (%ile)	>95th
Benton Face Recognition Test (%ile)	1st
Letter fluency <sup>c</sup> (scaled score)	6
WAIS-R digit span (scaled score)	12
Trail Making Test ( <i>Z</i> -score)	
Part A	-11.7
Part B	-12.8

Table 1 (Continued)

Neuropsychological Test	Score
WAIS-R similarities (scaled score)	11
WAIS-R matrix reasoning (scaled score)	11
WCST	
Categories (/6)	6
Persev. Resp. ( <i>Z</i> -score)	-0.9
Concept Generation Test	
Groupings	4 (unimpaired)

WAIS-R, Wechsler Adult Intelligence Scale – Revised; AM-NART, American National Adult Reading Test; WMS-R, Wechsler Memory Scale – Revised; LP, Logical Passages; VR, Visual Reproduction; CVLT, California Verbal Learning Test; ROCF, Rey Osterrieth Complex Figure; AMI, Autobiographical Memory Interview; WCST, Wisconsin Card Sorting Test.

<sup>a</sup> Number in parentheses represents standard score on the Wechsler Abbreviated Scale of Intelligence (WASI) from a 2003 re-assessment of general intellectual function.

<sup>b</sup> Score is based on the number of animal names produced in 1 min.

<sup>c</sup> Score is based on the total number of words produced for the letters F, A and S when given 1 min for each.

Of particular relevance, despite his impaired autobiographical memory, K.C.'s ability to match lines of identical orientations on the Judgment of Line Orientation test is normal (23/30; within normal range) as is his ability to discriminate designs on the Benton Visual Discrimination Test (27/32; above 95th percentile). Identification of line drawings of common objects on the Boston Naming Test was well within normal limits (57/60), and his copy of the Rey–Osterrieth complex figure received a perfect score. Nonetheless, K.C.'s performance on the Benton–Van Allen Face Recognition Test was extremely impaired (31/54), placing him within the first percentile. Difficulties were also apparent on the Farnsworth–Munsell 100-hue and dichotomous test for colour vision, which requires the placement of hues in order of progression. Anecdotally, however, there is no evidence of prosopagnosia nor is there any indication of visual object or colour agnosia, which is especially clear in K.C.'s intact descriptions and perceptual matching of premorbidly familiar people, places, and objects presented in photographs.

With respect to tests of executive function, K.C. performs well on verbal and nonverbal tests of abstract reasoning (WASI similarities and matrix reasoning subtests) and on tests of concept formation and mental flexibility (Wisconsin Card Sorting Test, Concept Generation Test). K.C.'s completion times for the two parts of the Trail Making Test, another test of executive function, clearly falls outside of the normal range of performance. However, this is likely due to peripheral motor impairments that he exhibits, as indicated by a ratio between the completion times for trails A and B that is comparable to what has been reported for healthy age-matched controls (0.43; Stuss, Stethem, & Poirier, 1987). Finally, working memory performance is within normal limits on both forward and backward digit span tests of the WAIS-R.

## 2.2. Control participants

Comparisons in performance on the Visual Imagery and Autobiographical Interview Experiments were made with two separate groups of 12 right-handed adults (group 1: one-third male; group 2: one-half male) without a history of neurological or psychiatric illness, free from medication known to affect cognitive functioning, and matched in terms of age (group 1:  $M = 52.8$ ,  $S.D. = 6.13$ ; group 2:  $M = 52.7$ ,  $S.D. = 4.07$ ) and education (group 1:  $M = 17.1$ ,  $S.D. = 3.12$ ; group 2:  $M = 15.6$ ,  $S.D. = 1.97$ ). Results were analyzed with a recently described modified *t*-test method that treats an individual patient as a sample, thereby permitting comparison of the patient's test score against norms derived from control samples of small to moderate size (Crawford & Howell, 1998; Crawford & Garthwaite, 2002). K.C. and the controls gave informed, written consent to be involved in the study, which was approved by the Baycrest Centre for Geriatric Care and the University of Toronto ethics committees.

## 3. Experiment 1: Visual imagery of object identity and spatial location

As mentioned, earlier work had revealed that K.C. is able to use spatial imagery of a remotely formed cognitive map of his neighborhood to produce an accurate drawing of the arrangement of streets and landmarks, perform accurate proximity, distance, sequencing, and heading judgments based on the positions of those landmarks, and manipulate that information through mental simulation of a detour when faced with an unusable route (Rosenbaum et al., 2000). Similarly, as an illustration of intact procedural learning, K.C. may have utilized visual motor imagery when describing the steps necessary to change a flat tire on a car, though reliance on implicitly encoded propositional information may have equally sufficed (Tulving et al., 1988).

To establish more definitively whether visual imagery loss serves as the possible source of K.C.'s inability to recover personal event details, it is necessary to examine more carefully his ability to evoke visual images from long-term storage, particularly with respect to the physical appearance of objects. Further demonstration that K.C. is capable not only of 'seeing' in the absence of sensory stimulation, but also of segmenting, combining, and rotating in mind known images would provide overwhelming evidence of an intact visual imagery store in spite of impaired autobiographical memory. Accordingly, we assessed K.C.'s ability to generate and manipulate images on a variety of tests known to be sensitive to visual imagery loss (see Behrmann et al., 1994).

### 3.1. Tests of imagery for object shape

There are reports of patients with lesions to ventral stream occipital-temporal cortex who are selectively impaired at

imagery the appearance of visual features of known objects (e.g., Farah, Hammond, Levine, & Calvanio, 1988). We wished to determine whether K.C. would show similar impairment on a variety of tests that gauge imagery for these qualities. To this end, we first assessed participants' ability to image and make decisions about the shapes of letters in the alphabet and of animals.

#### 3.1.1. Letter shape test

**3.1.1.1. Procedure.** According to the procedures described by Farah, Gazzaniga, Holtzman, and Kosslyn (1985) and Kosslyn, Holtzman, Farah, and Gazzaniga (1985), each letter was presented auditorily one at a time in random order. In the first part of the task, the participants were asked to imagine the uppercase form of each letter and decide whether it has a curved part or only straight lines (e.g., D versus M). In the second part, they were to imagine the lowercase form of each letter and judge whether it has parts extending above or below its main body or not (e.g., b or p versus a or m).

**3.1.1.2. Results.** Upon inspection of letters in imagery, as controls ( $M = 98\%$ ,  $S.D. = 3.62$ ), K.C. showed intact knowledge of the shape of 96% of the uppercase letters,  $t(11) = -0.53$ , ns, and performed slightly worse, though still within the normal range, when making decisions about lowercase forms (controls:  $M = 94.3\%$ ,  $S.D. = 4.96$ ; K.C.: 85%;  $t(11) = -1.8$ ,  $P = 0.1$ ).

#### 3.1.2. Animal parts test

**3.1.2.1. Procedure.** A set of 20 animals that are not characterized by the size and shape of their tails (e.g., Farah et al., 1988) and a separate set of twenty animals that are not typically identified by their ears were selected (e.g., Kosslyn et al., 1985). Animal names were presented aloud, one at a time, and the participants were to judge in imagery whether the animal has a long or short tail relative to its overall body length for the first set or decide whether the animal has floppy or upright ears for the second set.

**3.1.2.2. Results.** Performance on the tail and ear judgment tasks indicated preserved knowledge of the visual appearance of animal body parts in K.C. On the animal tails task, K.C. obtained a score of 90% (controls:  $M = 89.2\%$ ,  $S.D. = 5.97$ ;  $t(11) = 0.13$ , ns), whereas on the animal ears task, controls made correct judgments for 86.7% of the animals on average ( $S.D. = 6.51$ ) and K.C. made correct judgments for 80% of the animals,  $t(11) = -0.99$ , ns.

### 3.2. Test of imagery for object size

We next wished to investigate imagery for the appearance of a different class of visual attribute that involves

relative comparisons of two objects imaged simultaneously. This was accomplished with a size comparison test.

### 3.2.1. Procedure

A set of 16 object pairs similar to those administered by Farah et al. (1988) was used. For each trial, a pair of similarly sized objects (e.g., thimble and eraser) was read aloud, and participants were to decide which of the two objects was larger.

### 3.2.2. Results

K.C. was able to make size comparisons in imagery without error and did not differ significantly from controls,  $M = 96.5\%$ ,  $S.D. = 4.76$ ;  $t(11) = 0.71$  and  $-0.5$ , respectively.

## 3.3. Test of imagery for object colour

As described above, previous neuropsychological testing has revealed that K.C. displays poor colour vision. To establish whether or not he exhibits a corresponding loss of colour memory, a colour imagery task similar to that described by Farah et al. (1988) was administered.

### 3.3.1. Procedure

A set of 32 objects was created with the provision that the colour name of each object is not a common verbal associate (e.g., sky is blue; Beauvois, 1982). Upon hearing the name of an object, participants were to provide the colour most associated with it.

### 3.3.2. Results

K.C. performed similarly to controls on this task ( $M = 90.3\%$ ,  $S.D. = 6.79$ ) and provided the correct colour for 84% of the objects,  $t(11) = -0.89$ , ns.

## 3.4. Tests of spatial imagery

In the previous set of tasks, we obtained evidence that K.C., like controls, was unimpaired on visual imagery tests that measure the appearance of objects in terms of their shape, size, and colour. Given an intact “what” system of visual imagery, we wished to assess the integrity of K.C.’s “where” system and whether different aspects of spatial imagery might be dissociated (see Levine, Warach, & Farah, 1985).

### 3.4.1. Mental clock test

The mental clock test served as the first measure of spatial imagery and followed a procedure similar to that described initially by Paivio (1978) and by Craik and Dirks (1992).

**3.4.1.1. Procedure.** In response to different times of the day, participants were asked to image a clock face and decide whether the two hands, when representing these times, were

at an angle of greater or less than  $90^\circ$  (e.g., 1:35 and 6:20, respectively).

**3.4.1.2. Results.** K.C. made accurate decisions regarding the imagined spatial positions of hands on a clock for 96% of the 24 trials, which was similar to how controls performed,  $M = 94.5\%$ ,  $S.D. = 6.08$ ;  $t(11) = 0.24$ , ns.

### 3.4.2. Brooks letter test

K.C. was clearly successful at judging the spatial distance subtended by the hands of a clock by forming a mental snapshot of the object. In order to extend these results to a more dynamic measure of spatial imagery, we administered a test that permits mental navigation of a route that, unlike the battery of remote spatial memory tests administered by Rosenbaum et al. (2000), had never been ‘traveled’ along.

**3.4.2.1. Procedure.** Participants were instructed to imagine a large block-capital ‘E’ and then an ‘F’ as though positioned on the floor. For each letter, they were to imagine walking along its border in a clockwise direction, beginning at the lower left-hand corner, and to describe the order of right- and left-hand turns that would be made (20 turns in total; Brooks, 1968).

**3.4.2.2. Results.** Performance on this spatial imagery task was preserved in K.C., with only one error produced (controls:  $M = 94\%$ ,  $S.D. = 6.44$ ;  $t(11) = 0.19$ , ns).

## 3.5. Verification of high- and low-imagery sentences

The sentence verification test devised by Eddy and Glass (1981) was administered next to permit the assessment of imagery for both object appearance and spatial location on a number of dimensions within the same measure. This test also has the advantage of controlling for overall sentence complexity through the presentation of closely equated sentences that do not require imagery for verification.

### 3.5.1. Procedure

An equal number of true and false versions of each of 16 high imagery sentences (e.g., “The accelerator on a car is the right pedal.”) and 16 low imagery sentences (e.g., “The introduction precedes the story.”) matched in terms of difficulty were randomly intermixed and presented one at a time to participants for verification.

### 3.5.2. Results

K.C.’s performance was perfect for the low imagery sentences and near control levels for the high imagery sentences (controls:  $M = 92.3\%$ ,  $S.D. = 6.12$ ; K.C.: 88%,  $t(11) = -0.67$ , ns), indicating relatively in-depth knowledge of visual characteristics of objects such as shape, size, colour, and spatial properties.

### 3.6. Identification of recreated images

In view of K.C.'s intact imagery for the identity and spatial location of previously perceived objects, we were interested in assessing his ability to modify and combine stored percepts in novel ways. Accordingly, the 12 items from the image generation tests created by Finke, Pinker, and Farah (1989) and the 24 items created by Moscovitch (Behrmann et al., 1994) were administered.

#### 3.6.1. Procedure

K.C. and controls were asked to envisage with their eyes closed a specified letter, number, or symbol, and, as indicated by a set of instructions read aloud, transform the image into an object (e.g., "Imagine the letter B. Rotate it 90° to the left. Put a triangle directly below it having the same width and pointing down. Remove the horizontal line." Solution: "ice-cream cone") or letter (e.g., "Take the letter F. Drop the top line. Add a vertical line to the right of the figure." Solution: "H"). Once completed, the participants were to identify verbally or draw the recreated image.

#### 3.6.2. Results

K.C. was able to manipulate visual images that were successfully recovered from long-term visual memory into new letters or objects. On the object generation task, K.C. identified verbally 79% of the items, indicating that he perceived and recognized the internal images that he had created for most items (controls:  $M = 82.3\%$ ,  $S.D. = 4.27$ ,  $t(11) = -0.73$ , ns), and he drew correctly an item that he was unable to identify. His inability to draw two items seemed to be caused by a failure to keep in mind earlier commands within the trials and likely reflects his anterograde amnesia. On the letter generation task, K.C. received an identification score of 79% but was unable to draw correctly those items that he had failed to identify (controls:  $M = 87.6\%$ ,  $S.D. = 5$ ,  $t(11) = -1.65$ , ns).

### 3.7. Comment

A recurring issue of debate in the literature has been whether the absence of a gradient in autobiographical memory observed in a number of patients, most with an extensive lesion profile, is the result of damage to the medial temporal lobe or whether it is caused by additional lesions to neocortex (e.g., Manns & Squire, 2002). Given that the extent of K.C.'s neural damage includes lesions to higher-order visual cortex, it may be argued that his retrograde amnesia for a lifetime of personal incidents may stem from a loss of visual images crucial to autobiographical memory, rather than from deficient storage or retention mediated by the hippocampus. However, the pattern of results in Experiment 1 (Section 3) indicates that he is capable of inspecting in the mind's eye objects stored in long-term visual memory for accurate judgements of shape, size, and colour as well as the spatial relations contained within these visual represen-

tations. His ability not only to hold in mind these qualities but to disassemble, reorganize, and rotate them for the creation of new images is strong evidence of a functional imagery system that allows for the integration of visual identity with spatial location. This system is necessary, but clearly not sufficient, for autobiographical memory retrieval.

## 4. Experiment 2: Autobiographical Interview

Having established that K.C. can access and make use of long-term visual representations and that his autobiographical memory deficit is not accompanied by one in visual imagery, we were interested in knowing if his deficit is specific to memory storage or reflects a deficit in executive function needed to access or to generate details. We therefore administered the recently developed Autobiographical Interview (Moscovitch et al., 2000; Levine et al., 2002) to characterize in a more structured way K.C.'s ability to retrieve autobiographical memories established at different times in his life under different levels of retrieval support. Relative to other measures of autobiographical memory, this test features a highly sensitive and reliable scoring procedure for categorizing and quantifying autobiographical details as episodic or non-episodic in nature. Moreover, the cueing procedure that is part of the test helps to overcome deficits in executive function that may lead to poor memory performance in adults with reduced frontal function (Levine et al., 2002).

### 4.1. Procedure

Participants were asked to provide a detailed description of a significant one-time episode that was personally experienced at a specific time and place from each of five life periods (i.e., childhood, adolescence, early adult life, middle adult life, and recent life) and under different levels of cueing (i.e., free recall, general probing, and specific probing) to examine any facilitative effects of retrieval support. In cases where a specific event was not generated independently, an extensive list of event topics was presented to assist in event retrieval. Descriptions were recorded and transcribed. Following administration, event descriptions were segmented into details, which are informational bits relating to a one-time occurrence, observation, or thought that are often expressed as a grammatical clause. Each detail was then classified according to the procedure outlined in Levine et al. (2002). Briefly, details were defined as "internal" or episodic and assigned to one of five categories (event, place, time, perceptual, and emotion/thought) if they related directly to the main event described, were specific to time and place, and conveyed a sense of episodic re-experiencing. Otherwise, details were considered "external," consisting of autobiographical events tangential or unrelated to the main event, semantic facts, repetitions, or other metacognitive statements or editorializing. The sum of details in each category was calculated in a cumulative manner for each level of

cueing. Quantitative ratings were accompanied by qualitative ratings assigned to each of the internal detail categories, with the possibility of attaining a maximum of 3 points for each category except for episodic richness, which was extended to 6 points to better capture participants' sense of re-experiencing (i.e., overall maximum = 18 points). Three extensively trained scorers who had achieved high interrater reliability (see Levine et al., 2002) and who were blind to group were assigned memories at random for scoring. K.C.'s memories were scored by two separate raters, with discrepancies (which were minor) resolved by discussion.

#### 4.2. Results

Details from the five life periods were first combined to form a single score for each of the internal, external, and ratings categories to examine whether K.C. and the control participants differed significantly with respect to internal and external detail generation. Because the general probing condition added little, if anything, to the number of details elicited in the free recall condition, the two conditions were collapsed into a low retrieval support condition (i.e., recall) and were analyzed separately from a condition of high retrieval support (i.e., specific probe; Levine et al., 2002). The quantitative and qualitative composite scores for each level of retrieval support were then separated into their respective feature categories for the second analysis to identify any differences in the type of details generated, and into life periods for the final analysis to determine any effects of age of memory.

##### 4.2.1. Composite measures of autobiographical retrieval

The total number of details collapsed across all five life periods for K.C. compared to controls was analyzed separately for the internal and external detail categories and for the ratings composite scores (presented in Fig. 3). K.C. was able to generate events only when provided with the event

list and only in response to specific probing. Under conditions of low retrieval support, his recall was severely impoverished (internal details:  $t(11) = -3.104$ ,  $P < 0.01$ ; external details:  $t(11) = -1.93$ ,  $P < 0.05$ ; ratings:  $t(11) = -6.15$ ,  $P < 0.001$ ). Despite the extensive retrieval support provided in the specific probe condition, however, any descriptions of personally experienced events that he did manage to provide were vague and extremely sparse in detail (internal details:  $t(11) = -4.73$ ,  $P < 0.001$ ; external details:  $t(11) = -2.22$ ,  $P < 0.05$ ), and this was most pronounced for the ratings composites ( $t(11) = -11.96$ ,  $P < 0.001$ ).

##### 4.2.2. Analysis of specific autobiographical retrieval categories

The number of details produced by K.C. and controls for individual categories of autobiographical recall and specific probing is presented in Fig. 4. K.C. was impaired relative to control participants on all categories of internal event details tested, producing significantly fewer event ( $t(11) = -2.83$ ,  $P < 0.01$ ), place ( $t(11) = -2.83$ ,  $P < 0.01$ ), time ( $t(11) = -2.25$ ,  $P < 0.05$ ), perceptual ( $t(11) = -2.94$ ,  $P < 0.01$ ), and thought/emotion ( $t(11) = -2.57$ ,  $P < 0.01$ ) details when given specific probes. K.C.'s scores for individual ratings categories were much like those obtained for the internal categories analysis. In line with the previous analyses, ratings for time ( $t(11) = -2.15$ ,  $P < 0.05$ ), place ( $t(11) = -7.45$ ,  $P < 0.001$ ), perception ( $t(11) = -7.64$ ,  $P < 0.001$ ), and thought/emotion ( $t(11) = -9.12$ ,  $P < 0.001$ ), were lower than those of controls, a pattern that contributed to a deficient overall sense of re-experiencing (episodic richness:  $t(11) = -14.25$ ,  $P < 0.001$ ) in the specific probe condition. Analysis of the external detail categories indicated that K.C.'s low external composite score following specific probing was driven primarily by a reduced tendency to produce metacognitive or editorial statements (other:  $t(11) = -2.11$ ,  $P < 0.05$ ), and to a limited extent, details that were semantic in nature,  $t(11) = -1.49$ ,  $P < 0.08$ . Recall of details

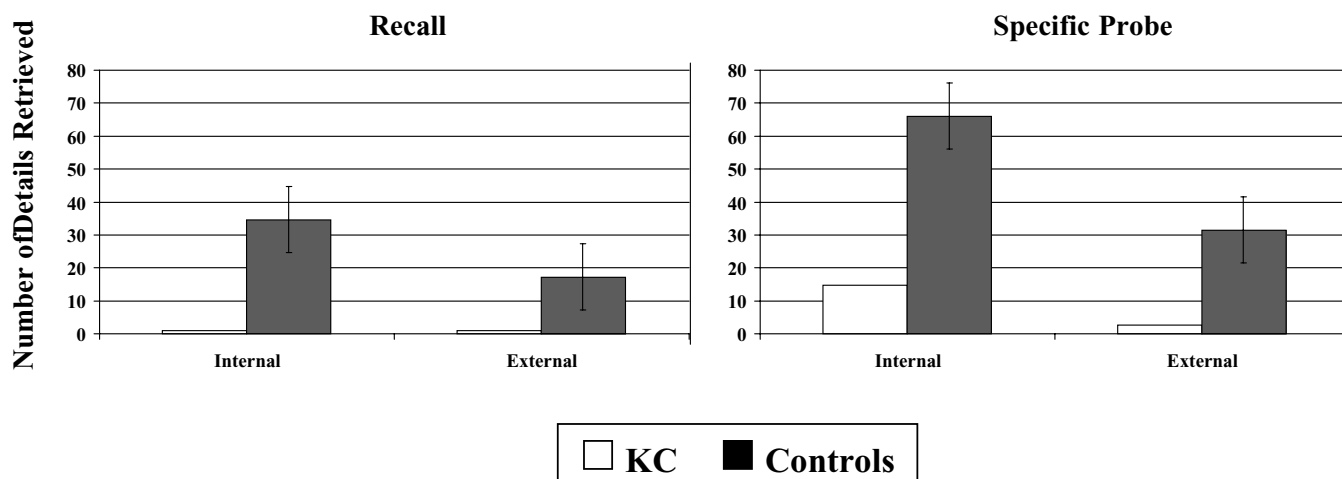


Fig. 3. Total number of internal and external details given by patient K.C. and control participants for all life events during recall (left) and after specific probing (right).

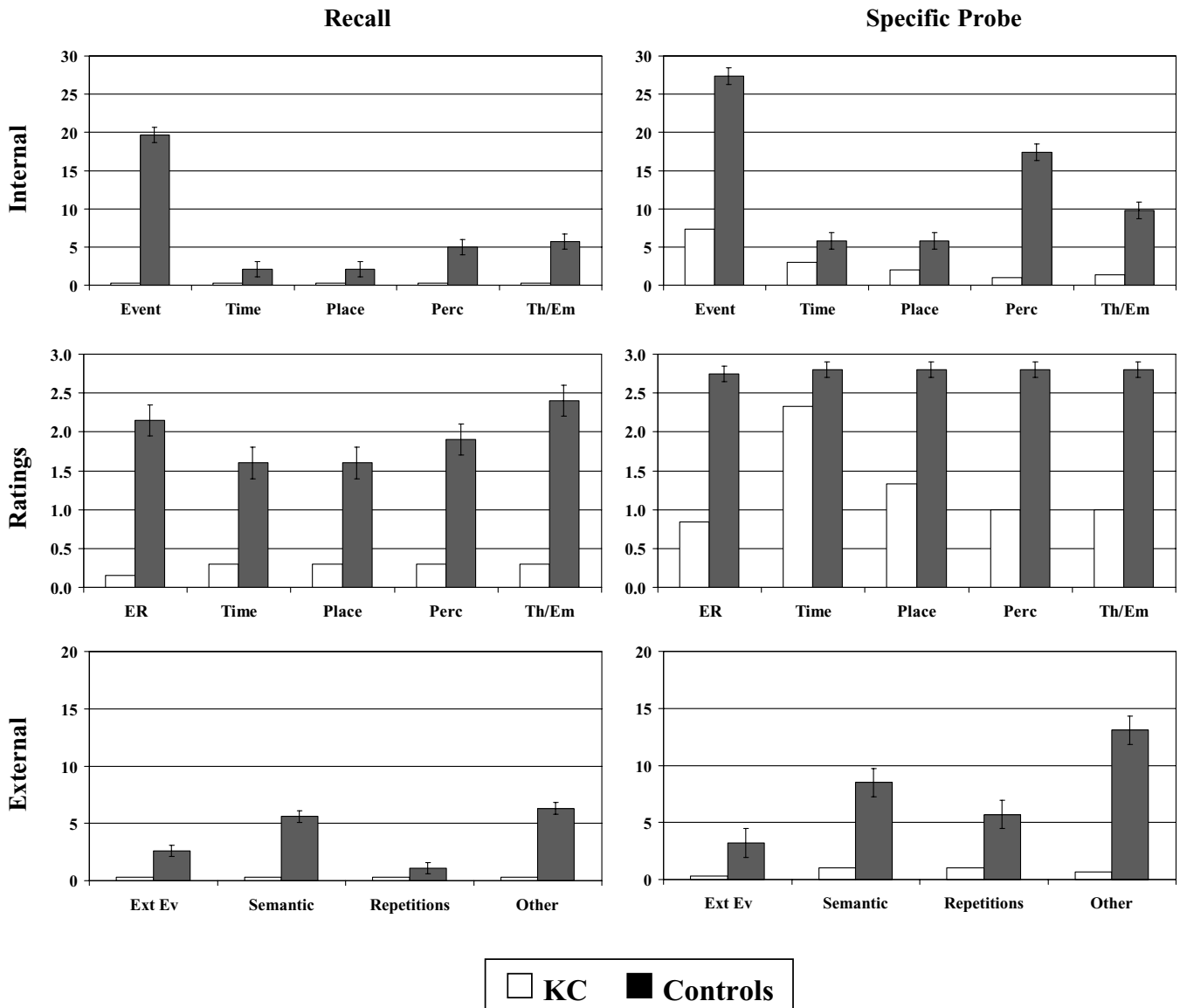


Fig. 4. Total number of details given by K.C. and control participants per event in different internal detail categories (top row), total scores per event in different rating categories (middle row), and total number of details given per event in different external detail categories (bottom row) during recall (left column) and after specific probing (right column). Asterisks indicate significant differences between K.C. and controls. Perc = perceptual; Th/Em = thought/emotion; ER = episodic richness; Ext Ev = external event; Sem = semantic; Rep = repetitions.

external to the central event and number of repetitions did not differ between K.C. and the control participants,  $t(11) = -1.07$  and  $-1.23$ , ns, respectively.

#### 4.2.3. Life period analysis of autobiographical retrieval

A finer examination of detail composites and ratings within each life period was conducted. Examination of Fig. 5 reveals a slight improvement in K.C.'s performance with specific probing that is explained by detail generation only for the pre-morbid life periods. Even in these periods, however, performance fell significantly below that of controls for internal/episodic details (period 1:  $t(11) = -2.67$ ,  $P < 0.01$ ; period 2:  $t(11) = -2.21$ ,  $P < 0.05$ ; period 3:  $t(11) = -3.05$ ,  $P < 0.01$ ) and for the ratings composite (period

1:  $t(11) = -4.62$ ,  $P < 0.001$ ; period 2:  $t(11) = -3.94$ ,  $P < 0.001$ ; period 3:  $t(11) = -11.12$ ,  $P < 0.001$ ). K.C.'s recall of external details for period 2 significantly differed from that of controls ( $t(11) = -1.84$ ,  $P < 0.05$ ) and approached significance for periods 1 and 3 ( $t(11) = -1.53$ ,  $P < 0.07$  and  $t(11) = -1.71$ ,  $P < 0.06$ , respectively). Interestingly, those events included in the analyses that K.C. did retrieve were the very same ones that he and his family members had recounted in previous studies upon informal interview and in response to viewing photographs, and at least one event was, in fact, experienced on more than one occasion (i.e., trip to Mardi Gras). This raises the possibility that any events that K.C. retrieved were ones that are rehearsed most frequently, an exclusionary criterion when defining a

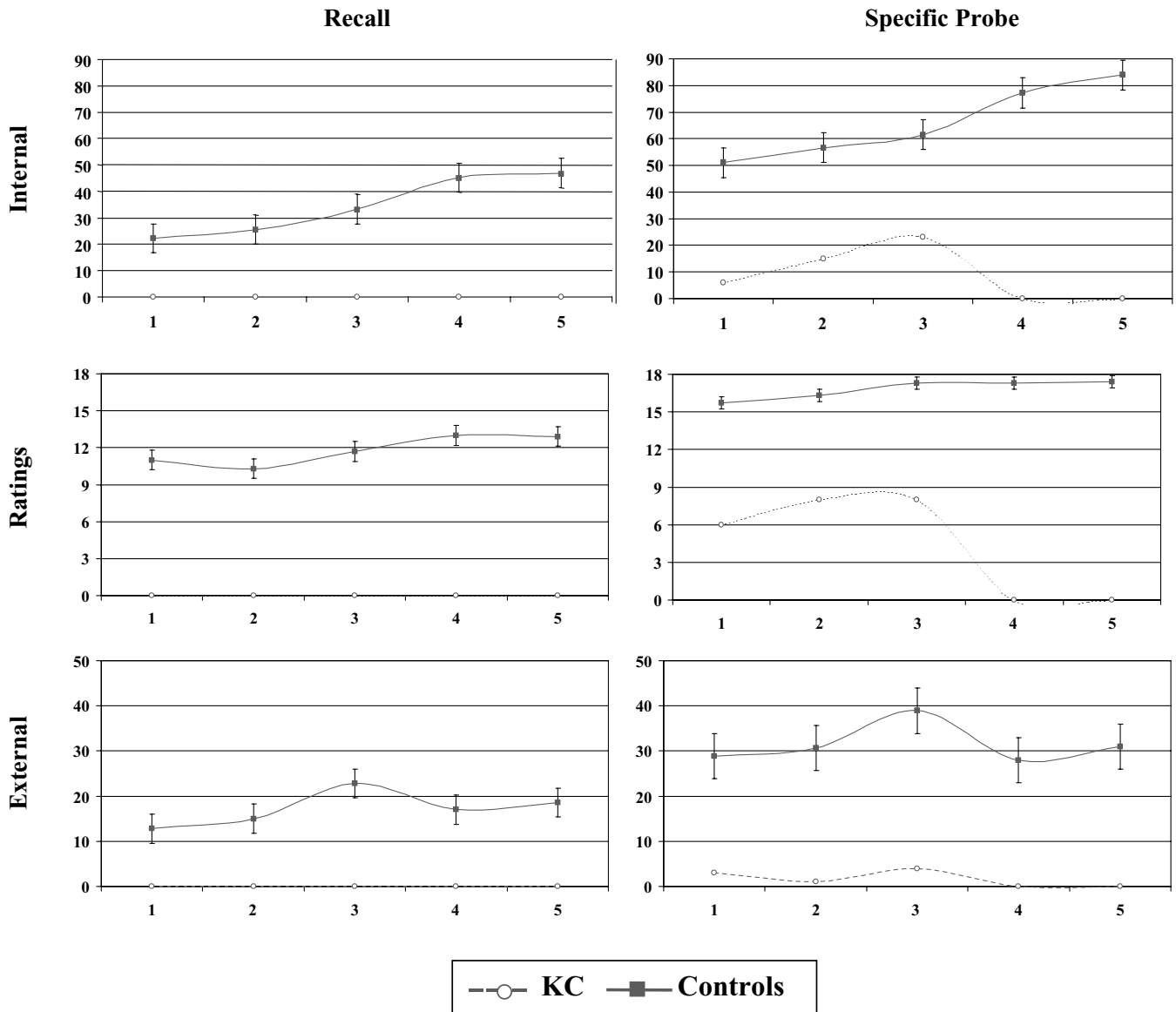


Fig. 5. Total number of details retrieved by K.C. and control participants for internal (top row), ratings (middle row), and external (bottom row) categories across five life periods for recall (left column) and after specific probing (right column). Asterisks indicate significant differences between K.C. and controls.

personal experience as unique and non-replicable (Tulving, 1983). In any case, inspection of these memories reveals that K.C. provided conservative ‘guesses’ that lacked experiential character and instead seemed most logical in the context of the event, as though he was describing what another person experiencing that same event would most likely see or feel. Moreover, consistent with his previously well-defined anterograde amnesia, K.C. was unable to retrieve any event or personal fact from the two most recent time periods tested. It is here that specific probing was unable to promote retrieval of even a single detail for any category, with significant differences for the internal category (period 4:  $t(11) = -3.28$ ,  $P < 0.004$ ; period 5:  $t(11) = -3.63$ ,  $P < 0.002$ ) and ratings composite (period 4:  $t(11) = -24.71$ ,  $P < 0.001$ ; period 5:  $t(11) = -20.43$ ,  $P < 0.001$ ) and a

trend towards significance for the external category (period 4:  $t(11) = -1.73$ ,  $P < 0.06$ ; period 5:  $t(11) = -1.65$ ,  $P < 0.06$ ) when performance was compared to that of controls.

#### 4.3. Comment

Taken together, the results indicate a severe anterograde amnesia for internal details in K.C. on the Autobiographical Interview, thereby reproducing a pattern of deficit that was previously identified in K.C. using alternate measures of autobiographical memory. Specifically, K.C. was unable to recall a single detail under conditions of low retrieval support. When given specific retrieval cues, his overall level of detail generation improved only slightly but was still far below the level of control participants. This was true

of all event features, whether temporal, spatial, perceptual, or reflective/emotional in nature. External details for these time periods were also deficient with respect to semantic and metacognitive/editorial statements, significantly so for an event from his adolescence. In fact, any details from the period spanning childhood to early adulthood which K.C. did recall were of events identical to those recalled in earlier investigations and, in one case, an event that occurred repeatedly before K.C.'s brain injury. This observation is in line with Tulving et al.'s (1988) original contention that any early life events recalled by K.C. reflect personal semantic knowledge that is recalled in the absence of the autobiographical re-experiencing or mental time travel thought to be characteristic of autobiographical memory.

## 5. Discussion

The current study addressed whether the finding in patient K.C. of extensive, ungraded remote memory loss specific to autobiographical episodes is related to malfunctioning of posterior neocortex, needed to store or retrieve long-term visual images, or to malfunctioning of frontal neocortex, needed for strategic retrieval. Based on his intact performance on a wide range of imagery tests, it was concluded that K.C.'s very poor, remote autobiographical episodic memory is not related to loss of visual imagery (Rubin & Greenberg, 1998; Ogden, 1993). With respect to the second alternative, unlike its effect in patients with frontal lesions (Svoboda et al., 2002), retrieval support did not significantly reduce K.C.'s impairment as measured by performance on a test of autobiographical memory that is capable of dissociating personal episodic and semantic memory impairment across multiple life periods (Levine et al., 2002). This finding is inconsistent with a strategic retrieval interpretation of K.C.'s extensive retrograde amnesia. The most likely cause of his retrograde amnesia, therefore, is medial temporal damage that includes the hippocampus. The results of each experiment are treated separately below, as are implications that may be derived from these findings.

### 5.1. Visual imagery contributions to autobiographical memory

Like K.C.'s extensive retrograde amnesia, remote autobiographical memory loss that is invariant with time has been documented in a group of patients with lesions to posterior visual neocortex (Ogden, 1993; Rubin & Greenberg, 1998). Unlike K.C. who has bilateral hippocampal damage, the majority of these patients did not display correspondingly severe anterograde amnesia for autobiographical information, presumably because their spared medial temporal lobe enables new learning through compensatory non-visual routes. Because K.C. also has damage to higher-order visual cortex, the question that remained, and that we addressed in the first experiment, is whether the retrograde portion of K.C.'s

loss of autobiographical recollections may be explained by general visual imagery dysfunction resulting from his visual cortex lesions. In short, his anterograde amnesia may be related to his hippocampal lesions but his extensive retrograde amnesia may be related to higher-order visual cortex damage.

K.C.'s performance on an extensive battery of visual imagery tests was not consistent with the hypothesis that his retrograde amnesia was caused by a general visual imagery deficit. Specifically, he showed preserved imagery for the shapes of letters and animal body parts, the relative size of objects, and the colour of objects (Farah et al., 1985, 1988; Kosslyn et al., 1985), which is particularly notable given his perceptual deficit in colour vision. Also intact was his imagery for the spatial relations of hands on a clock (Paivio, 1978; Craik & Dirks, 1992) and of a supposed route along the perimeter of block letters (Brooks, 1968), which corroborates findings of intact imagery on real-world topographical tasks (Rosenbaum et al., 2000). These results were complemented by intact performance on a sentence verification task requiring imagery (Eddy & Glass, 1981). It is highly doubtful that K.C. achieved solutions to each task through verbal representations, as the visual features selected for inspection are not ones that may be easily inferred from verbal facts highly associated with the superordinate categories to which the objects belong. In any case, over and above his ability to judge in his mind's eye a single visual property of a previously encoded letter or object is his ability to apply a series of transformations to those images to create new ones (Finke et al., 1989; Behrmann et al., 1994), which proves possible only by means of visual imagery. In all cases, his performance was equivalent to that of the controls. Because K.C. shows a pattern of remote autobiographical memory loss similar to that seen in Rubin and Greenberg's patients but his ability to evoke visual images in general remains unharmed, it is unlikely that his retrograde amnesia is due to malfunctioning of the neocortical storage component of the hippocampal-neocortical ensemble. It is still possible, however, that a route to episode-specific visual imagery is disrupted, particularly if the hippocampus is needed to access it to allow integration with conceptual autobiographical knowledge (Conway, 2001).

### 5.2. Strategic retrieval contributions to autobiographical memory

Despite intact general visual imagery ability, we again verified a flat gradient of autobiographical memory loss in K.C. that applies equally to internal and external details using the Autobiographical Interview (Levine et al., 2002), a more sensitive recall measure than used previously. Moreover, with supplementary retrieval support, K.C.'s performance continued to remain well below control levels, illustrated by a linear shift in his pre-accident retrieval function that was of the same slope and magnitude as that of controls. Those events that K.C. did manage to generate with fairly

rigorous verbal prompting were without the richness in internal or external details typical of the personal incidents recalled by control participants. His stories did not possess episodic flavor, thereby containing insufficient contextual, perceptual, and emotional qualities to qualify as simulating personal reliving of events, and were bereft of factual substance.

Even when K.C.'s lasting retrieval deficit with structured cueing relative to controls is taken into account, the slight gain in his performance from his own floor-level free recall scores is somewhat misleading in that it corresponds to the very same events that are known to be highly over-rehearsed. Consistent, repeated exposure of meaningful material within varied contexts has, in a sense, allowed for the restructuring of autobiographical information into a more personal semantic form or verbal script, thereby insulating it from hippocampal destruction (Cermak, 1984; Neisser, 1981; Weiskrantz, 1985). This resembles the phenomenon of progressive priming that helped to restore some of K.C.'s remote personal semantic memories in Tulving et al.'s (1988) seminal investigations of this patient (see also Cermak & O'Connor, 1983; Lhermitte & Serdaru, 1993). Rather than producing a reduction in the organization of effortful retrieval processes, repetition leads to the transformation of the long-standing contents of autobiographical memory into a "semantic" structure that, in itself, is more amenable to being retrieved.

The effectiveness of the Autobiographical Interview is manifest in its ability to distinguish patients with a true loss of stored personal episodic details from those who lack the executive resources needed to access or generate details that nonetheless survived insult. A number of preliminary studies suggest that this measure is capable of illustrating such dissociations. For example, whereas structured probing using the Autobiographical Interview eliminates autobiographical retrieval deficits in patients with lesions to ventral prefrontal cortex, patients with lesions to dorsolateral prefrontal cortex continue to recall large amounts of superfluous, unrelated autobiographical information even under these probing conditions (Svoboda et al., 2002). This dissociation is consistent with recent lesion and neuroimaging studies that suggest differential roles of ventral and dorsolateral prefrontal cortex in memory retrieval – namely, accessing information from long-term memory for on-line maintenance and monitoring and selecting information held on-line, respectively (e.g., Fletcher & Henson, 2001). The successful attenuation of autobiographical retrieval deficits in patients with ventral prefrontal damage and, to a lesser extent, in patients with frontotemporal degeneration (McKinnon et al., 2002) is in stark contrast to findings in K.C. and to results from an earlier study of patients with amnesia from damage to diencephalic and medial temporal structures (Moscovitch et al., 2000).

Nonetheless, cued recall as tested in the present study does not provide the maximum level of support and, as such, does not satisfy all of the conditions needed to rule out

a strategic retrieval explanation of K.C.'s autobiographical memory deficit. Autobiographical recognition, on the other hand, would offer a more definitive test of a retrieval account, as it removes the need for conjuring up a retrieval plan and strategic search, merely requiring the evaluation of candidate events as personally experienced or not. We (Gilboa, Rosenbaum, Westmacott, & Moscovitch) have recently devised such a paradigm. Based on exhaustive descriptions provided by family and friends of participants, we constructed a large number of event details from each of the same life periods as sampled in the current study and invented an equal number of event details that are plausible but that were never experienced. Testing thus far has revealed that K.C. performs at chance, such that he is unable to distinguish true from fictional event details that were derived from his near and distant personal past, which differs markedly from the near-ceiling performance demonstrated by control participants.

### 5.3. *Implications for theories of retrograde autobiographical amnesia*

Standard consolidation theory conceives of a gradual shift of declarative memories from hippocampal to neocortical dependency (e.g., Squire, Cohen, & Nadel, 1984; Squire & Alvarez, 1995). MTT, on the other hand, posits an incessant relationship between the hippocampus and neocortex in maintaining autobiographical memory traces, such that neither component relinquishes its function to the other no matter how much time has passed. Instead, the number of traces and, hence, ease of retrieval, is believed to be related positively to the frequency of recalling the episode in question; insofar as older memories are recovered more frequently, they should be represented by more widely dispersed and perhaps stronger traces, rendering them less vulnerable to hippocampal damage than newer ones. Accordingly, partial hippocampal loss would lead either to a temporally graded memory deficit similar to that predicted by the standard model (Fujii et al., 2000; Nadel & Moscovitch, 1997) or to a temporally extensive, though not severe, retrograde amnesia (Viskontas, McAndrews, & Moscovitch, 2000) but complete damage would yield a flat gradient of severe retrograde amnesia for personal incidents.

The ungraded retrograde memory loss for autobiographical information observed in K.C. is in line with the predictions of MTT and with what has been found of other patients with very extensive bilateral hippocampal damage (Cipolotti et al., 2001; Fujii et al., 2000). The only exception is a group of amnesic patients with damage largely restricted to the hippocampal formation or to the extended hippocampal complex who show preserved remote autobiographical memory on a measure that, like the Autobiographical Interview, accounts for the number of details contained in a narrative (Bayley et al., 2003). How can such a discrepancy be reconciled? For one, Bayley et al. tested participants' memory only for the most remote time period, whereas we

sampled one memory from each decade preceding the onset of the patients' brain damage. Had Bayley et al. sampled from less remote, but still distant memories, a deficit would likely have been evident as observed in previous reports of these patients (e.g., Rempel-Clower, Zola, Squire, & Amaral, 1996). Another difference between the two sets of findings is that the number of details produced by the patients and the healthy controls in the Bayley et al. study was much lower than that produced by even the oldest, healthy participants in the Levine et al. (2002) study, suggesting that differences in assessing remote memory may account for the discrepancies in the findings among patients as much as differences in lesion size, location, and etiology. Therefore, until more comparable techniques are adopted across laboratories, it will be difficult to draw any firm conclusions favoring one view or the other.

In contrast to the hippocampal complex, the neocortex is considered by both standard consolidation and MTT as crucial for maintaining remote memories. Even here, however, there are crucial differences between the theories. According to MTT, the neocortical components maintaining the rich features of a personal event are always bound into a coherent memory trace by a distributed network of neurons in the hippocampal complex, which acts as an index or pointer to these components for the life of the trace (Nadel & Moscovitch, 1997, 2001). Standard consolidation theory, on the other hand, posits that over time memories become consolidated in the neocortical component so that memories that had once relied on the hippocampus can now be retained and retrieved directly from neocortex (e.g., Squire et al., 1984; Squire & Alvarez, 1995). Though our findings rule out neocortically mediated visual imagery and strategic retrieval failure as possible explanations for K.C.'s severely deficient autobiographical memory, it is possible that other types of neocortically mediated functions and information not tested in our study are needed to sustain normal remote memory (Bayley et al., 2003). Studies of patients with greater neocortical than medial temporal degeneration, such as those with semantic dementia, are themselves controversial. Some studies show a reverse temporal gradient as predicted by consolidation theory (Graham & Hodges, 1997; Graham, 1999), whereas others report relatively preserved autobiographical memory across the life-span when greater effort is taken to elicit recollections from people whose semantic loss impedes verbal reception and production ability (Westmacott et al., 2001; Westmacott & Moscovitch, 2002; but see Graham, Kropelnicki, Goldman, & Hodges, 2003b). The latter patients score much higher than K.C. on the very same tests. Though the reason for the discrepancy in autobiographical memory loss among semantic dementia patients may not be evident, what is clear from those studies is that extensive degeneration of neocortex, with some hippocampal loss, does not by itself cause the severe and extensive retrograde amnesia observed in K.C. We do acknowledge, however, the possibility that in patients like K.C. who have traumatic brain injuries, diffuse axonal injury or some com-

bination of this with multiple discrete loci of damage may affect autobiographical episodic memory in its entirety. What may happen in such cases is that the lesions impair the integration of different types of information, represented in different regions of neocortex, with one another or with the hippocampal complex. Until evidence for such an interactionist hypothesis is presented, the most compelling and parsimonious account of K.C.'s extensive autobiographical memory loss is that it is associated with the correspondingly extensive loss of hippocampal memory representations.

#### 5.4. *Implications for studies of other patients with multiple lesions*

We have chosen to examine the source of K.C.'s severe autobiographical memory loss for two reasons: 1. K.C. has figured prominently in the development of theories of normal and pathological memory, such as those concerned with implicit and explicit memory, noetic and auto-noetic consciousness, and consolidation (Moscovitch, 1995, 2000; Schacter, 1987; Tulving, 1983; Tulving & Schacter, 1990; Wheeler, Stuss, & Tulving, 1997). Thus, information about the nature and source of his memory impairment could have important implications for memory theory. 2. Equally important, K.C. provided us with an opportunity to use him as a test case for an approach that can be used to determine what effects lesions to different areas have on remote memory.

Patients with multiple lesions, such as K.C., are often dismissed as being of little interest in specifying the neuroanatomical basis of memory and in contributing to theories that depend on such knowledge; pride of place is reserved for patients with pure, circumscribed lesions (Bayley & Squire, 2002; Suzuki, 2003). Yet rarely, if ever, in the literature on human memory is it clear that in such cases the lesions or their effects are indeed circumscribed. Most, if not all of the influential cases in neuropsychology, from Broca (aphasia) and Harlow (frontal syndrome), to Wernicke (aphasia) and Dejerine (alexia), to Lippmann (agnosia) and Korsakoff and Milner (amnesia) have complex lesions. Indeed, acknowledging that even ostensibly pure cases may contain significant impurities has been beneficial. Even as influential a case as H.M. has lesions extending beyond the hippocampus to include adjacent structures in the medial temporal lobe, and the structural damage to his hippocampus is not as extensive as was first reported (Corkin, Amaral, Gonzalez, Johnson, & Hyman, 1997). Recent studies have been able to relate his preserved and impaired abilities not just to hippocampal damage and sparing, as was thought initially, but to a network of spared and damaged regions of medial temporal lobes and neocortex, in addition to the hippocampus (Corkin, 2002). Indeed, since his case was first reported (Scoville & Milner, 1957), the great impact H.M. continued to exert on the field can be attributed not only to his lesion, but equally to the careful tests administered by Milner, Corkin, and their collaborators to elucidate its effects, and to the fact that their findings generalized to other patients.

We have tried to follow this approach with K.C. by taking note of his areas of damage and devising tests to see if their possible malfunction can account for his extensive and severe autobiographical memory loss. As we have argued earlier in this paper, as far as we could determine, they cannot, but we readily acknowledge that we have not eliminated all other possibilities. This approach, which places as much emphasis on the tests used to identify the pattern of impaired and spared function following a lesion as on the size and location of the lesion itself, has already had some influence on how autobiographical memory is studied. Using the tests we created to examine K.C.'s autobiographical memory loss, Corkin and her colleagues re-examined H.M. and found that his autobiographical memory loss was more pervasive and temporally-extended than the limited retrograde amnesia he first was reported to have (Corkin, 2002). That his retrograde semantic memory loss is temporally limited, just like K.C.'s, indicates that remote memory loss in the two patients is similar and suggests that the loss is related to the medial temporal lobe damage which the two have in common rather than to damage elsewhere in the brain which they do not share.

Our studies with K.C. and the theories of remote memory that they inspired prompted other investigators to re-examine cases of extensive remote memory loss in amnesia. The results of those studies led some investigators to re-interpret the loss as resulting from damage to memory structures, such as the hippocampal complex, rather than to incomplete consolidation or to generalized, but unspecified, effects of damage to other structures (e.g., Cipolotti et al., 2001; Piolino et al., 2003). Finally, evidence that autobiographical, episodic (but not semantic) memory always may be dependent on the hippocampus has led to functional neuroimaging studies on remote memory which, in the main, support the lesion evidence from K.C. (see Maguire, 2001; Gilboa, in press).

### 5.5. Conclusion

The overall conclusion that may be drawn from the present study is that viable neocortical tissue remains to support visual imagery in a patient who lacks the capacity for autobiographical remembering, a deficit that is best explained as resulting from impaired storage rather than strategic retrieval. Nevertheless, neuroimaging studies have shown that autobiographical memory consistently engages a network of regions in addition to those examined in our experiments. This network is generally left-lateralized and often includes retrosplenial cortex, parahippocampal gyrus, temporal pole, and temporal-parietal junction (for a review, see Maguire, 2001). Although none of these regions show clear signs of dysfunction in K.C. on behavioral tests or in functional neuroimaging studies (Rosenbaum et al., 2004), it is possible that some disruption occurred among their widespread interconnections. More work is needed to explore the functional status of this network. Nonetheless, by discounting

the effects of impaired visual imagery and of deficits in effortful, organizational retrieval on his remote memory loss, we have added support to the interpretation that hippocampal pathology alone can produce a severe and extensive retrograde amnesia for autobiographical episodic information. This approach of investigating functional loss in patients with widespread brain damage may be instructive for dealing with other patients who are interesting from a psychological perspective but complicated from a neurological one.

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