

Contribution of the Left Dorsomedial Thalamus to Recognition Memory: a Neuropsychological Case Study

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Abstract

This study reports a patient with a unilateral left thalamic lesion which was centred on the dorsomedial thalamic nucleus. Cognitive neuropsychological assessment revealed a severe impairment in verbal memory and symptoms of executive dysfunction, in the presence of relatively intact visual and facial recognition, working memory, praxis, language and IQ. Verbal and visual recognition memory were investigated using the remember–know paradigm. The results indicated a profound impairment in recollection-driven verbal recognition memory. These results are discussed in the context of the role of the dorsomedial thalamic nucleus in recognition memory, and functional models of memory.

Introduction

Memory impairment is a well-documented sequela of thalamic damage. Traditionally, diencephalic amnesia has been characterized by deficits in encoding and recollection (both free recall and recognition), resulting in a severe anterograde episodic memory impairment in the presence of preserved IQ, motor learning, perceptual functions and short-term memory (e.g. Von Cramon *et al.*, 1985; Weiskrantz, 1985; Graff-Radford *et al.*, 1990; Aggleton and Saunders, 1997; Squire and Zola, 1997). However, most of the evidence linking thalamic pathology to memory deficits has been reported in patients with alcoholic Wernicke-Korsakoff Syndrome (e.g. Victor *et al.*, 1989). Many of these patients had large lesions, which extended well beyond individual thalamic nuclei, and often included the frontal lobes (Jacobson, 1989). The lack of circumscribed neuropathology coupled with evidence of widespread neuronal damage, which results from prolonged exposure to alcohol (Okazaki, 1989), have obscured which thalamic structures are critical for the development of diencephalic amnesia (Graff-Radford *et al.*, 1990; Mennemeier *et al.*, 1992).

More recently, an attempt has been made to reformulate the anatomy underlying anterograde amnesia and in so doing it has been claimed that the distinction between temporal lobe and diencephalic amnesia is of limited value (Aggleton and Brown, 1999). The main argument for this is based on the premise that diencephalic and medial temporal lobe anterograde amnesia arise from damage to a common 'extended hippocampal' memory system, which is comprised of reciprocal connections between the hippocampus, the

mamillary bodies and the anterior thalamic nucleus, via the fornix (Aggleton and Shaw, 1996; Aggleton and Saunders, 1997; Aggleton and Brown, 1999). Aggleton and Brown proposed that this extended hippocampal-diencephalic system was critical for the encoding and subsequent recall of contextual information about a previous episode. Furthermore, they suggested that this memory system was not necessary for efficient recognition. This proposal builds on earlier suggestions that recognition memory arises out of two functionally independent components, i.e. contextual recollection and familiarity detection (Mandler, 1980; Jacoby and Dallas, 1981). Aggleton and Brown claimed that contextual recollection was dependent on the extended hippocampal system, and that a second non-hippocampal system, which extended from the perirhinal cortex to the dorsomedial thalamic (DMT) nucleus and the prefrontal lobes, subserved the ability to evaluate the contextual memory strength, or familiarity, of an item.

However, a number of authors have claimed that Aggleton and Brown's anatomical model is incompatible with empirical evidence reported from behavioural studies of rats (Mair *et al.*, 1999) and monkeys (Parker, 1999) as well as patients (Mayes *et al.*, 1999; Van der Warf *et al.*, 1999; Witter and Van der Warf, 1999; Hanley *et al.*, 2001). For instance, Witter and Van der Warf (1999) described a patient who displayed evidence of impaired familiarity-but intact recollection-driven recognition in the context of a thalamic lesion which spared the DMT. While not disputing the neuroanatomical separation of recall from familiarity, the authors claimed that it was

projections from the perirhinal cortex to the intralaminar nuclei, rather than the DMT, which subserved familiarity-driven recognition. From a different perspective, the case reported by Hanley *et al.* (2001) also questioned the validity of Aggleton and Brown's claims. Their patient, ROB, exhibited a severe deficit in free recall of verbal material following a lesion which damaged the fornix and the anterior thalamic nucleus. However, there was no evidence of impaired recollection-driven recognition memory. The authors acknowledged that damage to the extended hippocampal circuit had a major impact on recall relative to recognition, but their findings did not support the suggestion that the extended hippocampal system was necessary for recognition memory decisions which were based on contextual recollection.

Recognition memory has also been investigated using signal detection models (Yonelinas, 1994; Donaldson, 1996). Typically, such studies make use of Tulving's (1985) remember–know paradigm, which requires subjects not only to identify target stimuli from distracters during recognition testing, but also to select the basis of their decisions in terms of either explicit retrieval (i.e. remember) or feelings of familiarity (i.e. know). Remember–know studies have led to a number of dissociations between retrieval and familiarity responses being identified. For instance, word frequency and levels of processing have been shown to influence selectively remember judgements (e.g. Gardiner and Java, 1990; Rajaram, 1993); whereas conceptual fluency only affects know responses (Rajaram and Geraci, 2000).

Reports of amnesic patients with widespread damage of the medial temporal lobe using the remember–know paradigm have yielded inconsistent results. Studies by Verfaellie and Treadwell (1993), Kroll *et al.* (1996) and Schacter *et al.* (1996) found that amnesics were more likely to use know responses, based on feelings of familiarity, than remember judgements. Whereas a later report by Knowlton and Squire (1995) claimed that amnesics were less likely to make know responses and concluded that familiarity responses were disrupted.

Both Donaldson's and Yonelinas' signal detection models allow for a dissociation between the two component processes of recognition. However, they differ in terms of their theoretical predictions. Donaldson proposes that a single underlying memory system based on a continuum of familiarity, subserves both know and remember judgements. It assumes that subjects cannot directly determine whether an item is familiar or not; rather individuals are only aware of an item's level of familiarity. Therefore, in order to label an item familiar or unfamiliar, a criterion value of familiarity must be set, such that items which exceed it are labelled familiar and those which do not are labelled as unfamiliar. A second more stringent criterion value of familiarity is used to determine whether a target item accesses stored recollective information or not. Items whose level of familiarity is sufficiently strong to exceed this second criterion result in the retrieval of contextualizing information and are labelled remember, while those which fail to do so are labelled know. In contrast,

Yonelinas suggested that familiarity and retrieval are best accounted for by a dual-process model, in which know responses are familiarity driven, whereas remember judgements are dependent on a separate non-familiarity-based mechanism operating in parallel (Yonelinas *et al.*, 1996; Dobbins *et al.*, 2000).

Lesions of the thalamus not only give rise to memory disorders, but can also lead to a disruption of prefrontal processes [see review by Van der Warf *et al.* (2000)]. Extensive reciprocal projections exist between the DMT and ipsilateral medial and orbital regions of the prefrontal cortex (Bachevalier and Mishkin, 1986; see also Aggleton and Brown, 1999). Thus, a lesion centred on the DMT is likely to cause widespread dysfunction within prefrontal areas, leading to disturbances of executive abilities, attention, initiation, inhibition and temporal organization of behaviour [see review by Van der Warf *et al.* (2000)]. It is known from studies of animals and patients that frontal/temporal interaction is essential for the encoding of novel items (Parker *et al.*, 1988) and in key executive memory functions involved in strategic memory search, monitoring and decision making (Shallice, 1980; Squire, 1981; Kapur *et al.*, 1995; Markowitsch, 1995; Parker and Gaffan, 1997, 1998; Parker *et al.*, 1997; Rapcsak *et al.*, 1999; Ward *et al.*, 1999). For instance, in normal subjects, when exposed to an unfamiliar face which elicits false feelings of familiarity because of certain physical similarities to known faces, this uncertainty may be resolved by attempts to retrieve more detailed contextual information. Patients with damage to their prefrontal lobes may not spontaneously engage in this effortful search, and therefore produce high levels of false recognition, which is evident in an elevated false alarm rate (Rapcsak *et al.*, 1999).

Thus, memory problems may arise either as a direct consequence of prefrontal damage, or secondarily as a result of prefrontal cognitive deficits such as inattention. Memory problems due to the latter rather than a disruption to memory processes *per se* are evident in terms of an impairment in the active recall from the memory store in the presence of spared recognition or aided retrieval (Van der Warf *et al.*, 2000).

The current study sought to examine the effects of DMT pathology on retrieval- and familiarity-driven recognition in a single case study. The specific aims of the study were, first, to characterize the patient's memory deficits in terms of familiarity- and retrieval-driven recognition using the remember–know paradigm. Second, by manipulating the level of target familiarity within the recognition memory system, to determine whether the observed profile was more readily accounted for by the single or dual memory system signal detection models.

Methods

Subjects

Patient. QX, a 55-year-old, right-handed male university lecturer, woke to find that he was 'talking rubbish' and had

slurred speech. He noted that his right arm felt heavy, but this returned to normal. For 2 days he was very confused. QX developed disinhibited behaviour, reduced motivation, memory problems and apraxia. For instance, he was unable to return to his hobby of bell ringing because he could not remember the complex sequences of actions involved. A magnetic resonance imaging scan revealed a discrete lacuna infarction involving the DMT of the left thalamus, which extended superolaterally and involved the medial part of the ventrolateral nucleus (see Fig. 1).

There was an incidental minor area of ischaemia in the subcortical white matter of the left parietal lobe (Fig. 1b).

The patient's initials have been changed to preserve anonymity and informed consent was obtained.

Neuropsychological profile. A detailed neuropsychological profile is presented in Table 1.

QX's current IQ [Revised Wechsler Adult Intelligence Scale (WAIS-R); Wechsler, 1981] was placed in the high average range. This score indicates a slight decline in general intellectual functioning from premorbid levels which placed him in the superior range [National Adult Reading Test (NART); Nelson, 1982]. There was a large discrepancy between his high score on the verbal IQ subtests which placed him in the superior range, and scoring on the performance IQ subtests, which fell within the low average range. QX was particularly poor on block design, object assembly and digit symbol. Successful completion of block design and object assembly requires orderliness and planning, and are notable in that they do not lend themselves to verbalization (Lezak, 1995). Digit symbol is a non-specific indicator of brain dysfunction, in that it involves the integration of many different components, which include visuomotor processing, visual search and shifting (Lezak, 1995).

QX displayed little difficulty in successfully completing the facial and visual processing tasks. He was able (1) to sort a pack of 50 famous faces drawn from a variety of different 'professions' (including sport, politics, royalty, film and television) from 50 unfamiliar faces and then (2) to name the 'famous' faces. Similarly, he had no problems naming 32 animate (16 animals and 16 fruit and vegetables) and 32 inanimate (drawn from a variety of categories including work tools, kitchen implements, vehicles, etc) line drawings. He was able to mime the use (i.e. function) of inanimate objects and to identify another object with which it would be associated (association: e.g. a target item 'cup' would be associated with a 'saucer'). While for the animate exemplars he was able to label their superordinate category (e.g. for 'apple' it would be 'fruit', or for 'dog' it would be 'animal').

Formal tests of language function [Psycholinguistic Assessments of Language Processing in Aphasia (PALPA); Kay *et al.*, 1992] failed to elicit the word-finding difficulties reported during casual conversation. Similarly, there was no evidence of buccofacial, ideomotor or constructional apraxia.

Despite the reported personality and motivational changes, no deficits were evident on the tasks which tap executive

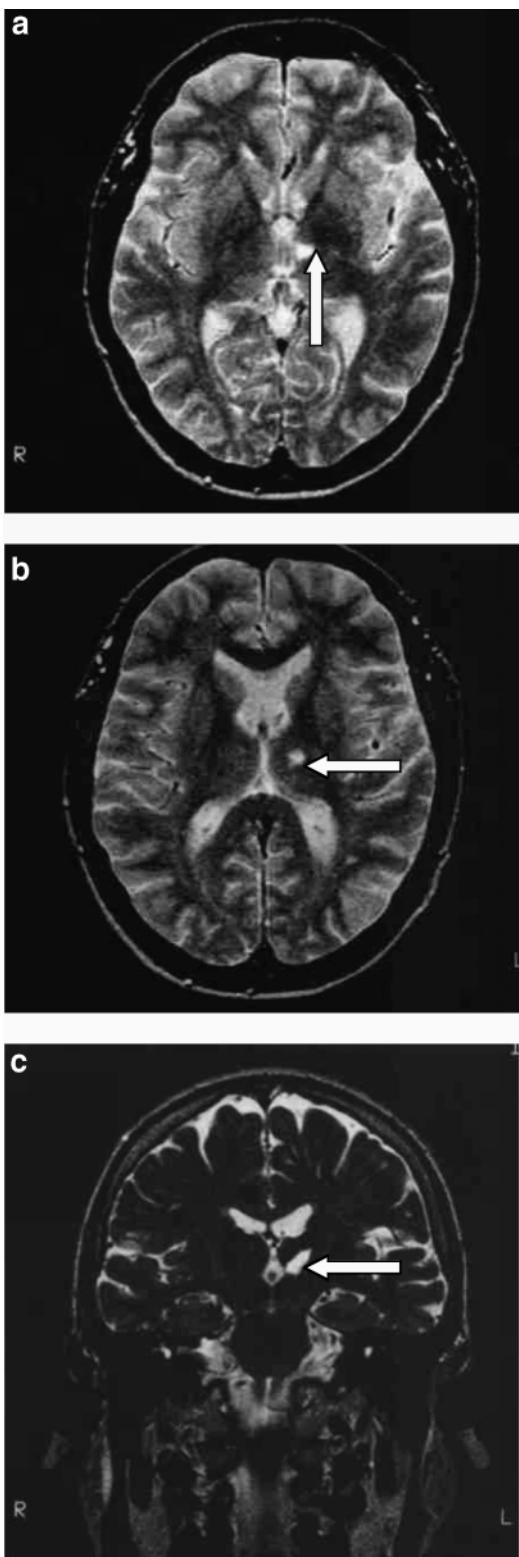


Fig. 1. Magnetic resonance scans of QX showing the extent of the left thalamic damage. (a) T2-weighted magnetic resonance scan demonstrating the lacuna infarction in the inferior medial part of the left thalamus. (b) T2-weighted magnetic resonance scan demonstrating the lacuna infarction in the superior lateral part of the left thalamus and a minor area of ischaemic change in the parietal white matter. (c) T2-weighted coronal magnetic resonance scan demonstrating the ischaemic lacuna infarct in the left thalamus involving inferior medial structures and more lateral structures superiorly.

Table 1. Neuropsychological profile of QX

Neuropsychological test	QX	Percentile/range
NART		
Full-scale IQ	124	Superior
WAIS-R		
Information	13 ^a	84th percentile
Digit symbol	12	75th percentile
Vocabulary	12	75th percentile
Arithmetic	14	91st percentile
Comprehension	16	98th percentile
Similarities	12	75th percentile
Picture completion	10	50th percentile
Picture arrangement	12	75th percentile
Block design	8	25th percentile
Object assembly	8	25th percentile
Digit symbol	5	5th percentile
Verbal IQ	124	Superior
Performance IQ	88	Low average
Full-scale IQ	119	High average
Stroop		
Word	112/112 ^b	100th percentile
Colour	99/112	52nd percentile
WCST		
Categories	6 ^b	>16th percentile
Failure to maintain set	0	>16th percentile
Perseverative errors	6	55th percentile
Fluency (FAS)	35 ^c	32
Facial processing		
Un/familiar face sorting	50/50 ^b	NAD
Familiar face naming	49/50	NAD
Visual processing		
Function (inanimate)	64/64 ^b	NAD
Association (inanimate)	64/64	NAD
Naming (animate and inanimate)	64/64	NAD
WMS		
Auditory delayed recognition	6 ^a	9th percentile
Auditory delayed	9	1st percentile
Visual delayed	17	27th percentile
Auditory immediate	12	6th percentile
Visual immediate	12	5th percentile
General memory	32	5th percentile
Immediate memory	24	3rd percentile
Working memory	18	32nd percentile
Rey Complex Figure		
Copy	30/36 ^b	NAD
Immediate recall	9.5/36	<1st percentile
Delayed recall	11.5/36	<1st percentile
AMI		
Childhood		
Personal semantic	20/21 ^b	16–21
Autobiographical incidents	8/9	6–9
Early adult life		
Personal semantic	19/21	17–21
Autobiographical incidents	9/9	7–9
Recent life		
Personal semantic	14/21	19–21
Autobiographical incidents	6/9	7–9
Personal semantic	53/63	54–63
Autobiographical incidents	23/27	19–27

NART, National Adult Reading Test; WAIS-R, Wechsler Adult Intelligence Scale; WMS, Wechsler Memory Scale; AMI, Autobiographical Memory Inventory; WCST, Wisconsin Card Sorting Test; NAD, no abnormalities detected.

^aScaled score.

^bRaw score.

^cMean score.

functions [Stroop, 1989; Wisconsin Card Sorting Test (WCST), Heaton *et al.*, 1989; and verbal fluency].

Assessment of memory revealed a complex pattern of preserved and deficient abilities [Autobiographical Memory Inventory (AMI), Kopelman *et al.*, 1990; Rey Complex Figure, Myers and Myers, 1995; Wechsler Memory Scales (WMS), Wechsler, 1997]. Working memory (WAIS-R, WMS) and autobiographical memory (AMI) for childhood and early adult life were intact. However, more recent memories for incidents and personal semantic information showed signs of impairment. Assessment of immediate and delayed visual and auditory memory (Rey Complex Figure, WMS) showed differential rates of impairment. Whereas auditory memory was impaired on all assessments, delayed visual memory appeared intact on the WMS but deficient on the Rey Complex Figure. This discrepancy may be accounted for in terms of task demands: whereas the WMS delayed visual memory subtest does not involve a visuomotor/visuoconstructive component, the Rey Complex Figure does (refer to previous outline of WAIS-R performance IQ subtests).

Controls. The performance of two groups of normal controls are reported: a larger cohort of 29 young psychology undergraduate and A level student volunteers (NC[y]) aged between 16 and 29 years (mean 19.5 years) and a smaller group (NC[o]) of five older age-matched (range 41–49 years, mean 45.6 years) university employees. All subjects were right-handed, had English as their first language, had normal/corrected visual acuity and no reported dyslexia, neurological or psychiatric history.

Anterograde memory experiments

Procedure. Recognition memory for words and faces was assessed separately, using the same procedure. A standard recognition memory format was used, which consisted of a study phase, during which time the target stimuli were presented, and a recognition phase, when target stimuli were discriminated from novel distractors.

A total of four recognition memory tasks were administered: two facial recognition memory (FRM) tasks and two verbal recognition memory (VRM) tasks. Both FRM tasks and VRM tasks were matched in all respects apart from the duration of target exposure during the study phase. In one version, the facial and verbal targets were exposed for 3000 ms and in the other version it was 6000 ms.

Visual stimuli were presented in a program written in Microsoft Visual C++ using MFC on a personal computer running Windows 95. The images presented in the FRM tasks consisted of 100 black and white photographs of unfamiliar male faces (images extended 8 cm horizontally and 9 cm vertically, and viewed at a visual angle of 9°). The words used in the VRM tasks were a mixture of 50 high- and low-frequency unfamiliar adjectives (mean 137, range 2–2035). All stimuli were viewed one at a time in the centre of the screen.

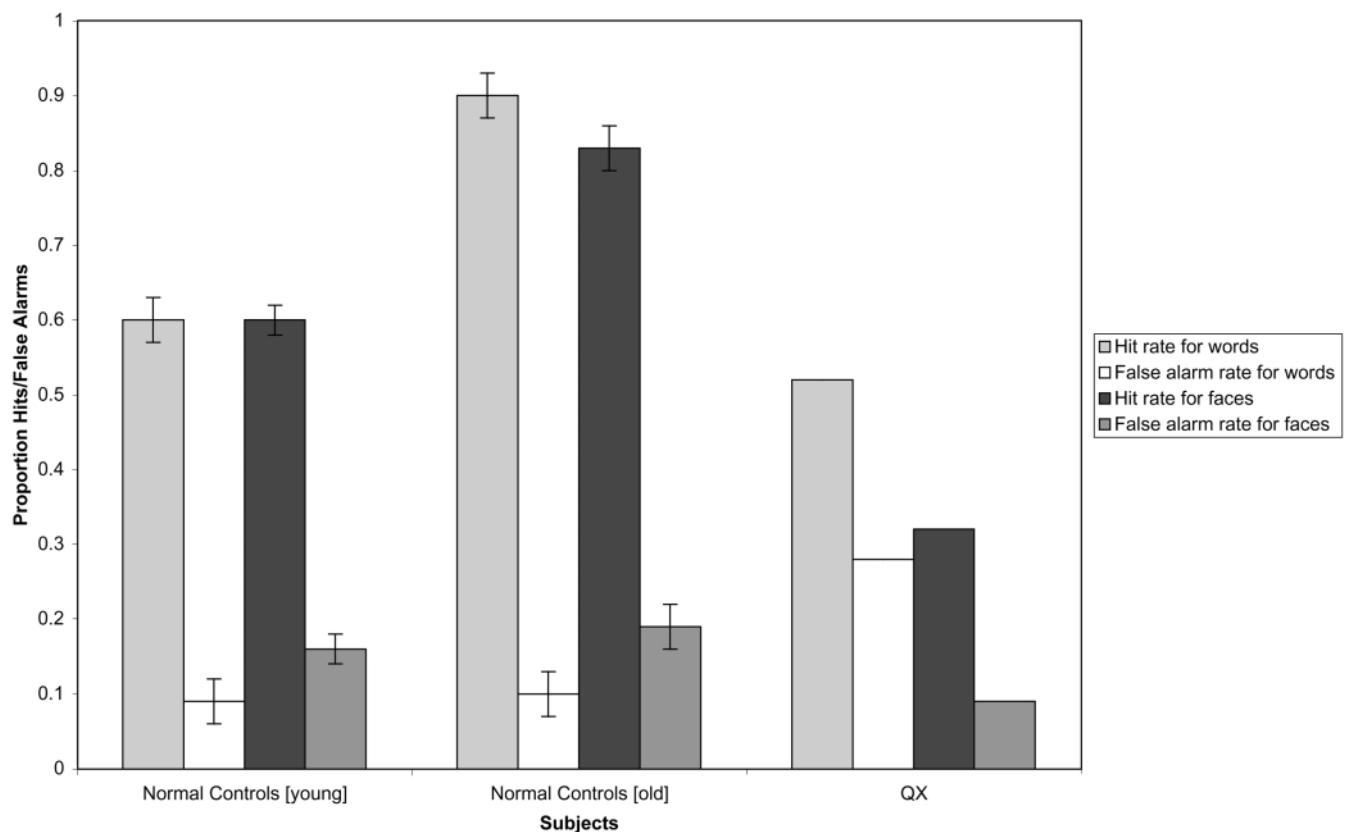


Fig. 2. Hit and false alarm rates in experiment 1.

Fifty target items were presented during the study phase. To help concentration, the subjects were instructed to state whether the item (face or word) was pleasant or not. During the recognition phase, which immediately followed completion of the study phase, the studied targets were mixed with 50 unfamiliar distractors. The subject's task was to identify the target items from the distractors. This process was achieved by pressing one of two hand-held buttons: pressing the button held in the right hand indicated a 'yes' response for a positive recognition (i.e. an old item) while pressing the left-hand button indicated a 'no' response to an unrecognized item (i.e. a new item).

The subjects had a 3000 ms window in which to register their choice before the next stimulus item appeared. The participants were instructed to respond as quickly and as accurately as possible. The subjects were familiarized with the experimental set-up using a practice test prior to starting the experimental tasks. The presentation order of the recognition memory tasks (verbal versus facial; 3000 versus 6000 ms) was counterbalanced across subjects.

Correct identification of an old item was defined as a hit, while false recognition of a distracter was termed a false alarm. Following each positive identification, irrespective of whether it was a target hit or a false alarm, the subjects had to decide the basis of their decision in terms of whether the item elicited (a) feelings of familiarity (i.e. a know response) or (b) a specific retrieval of the item having been presented

in the study phase (i.e. a remember judgement). A third category, (c) guess, which was based on a superordinate category decision, was included during a pilot study but dropped for the reported tasks because the subjects failed to make use of it. The selection of remember–know choices was not time constrained and was achieved using the hand-held buttons.

Results

Experiment 1. Short duration (3000 ms) recognition memory tasks

Hit rates, defined as the conditional probability of responding yes to an old item, and false alarm rates, defined as the conditional probability of responding yes to a new item, were calculated [number of hits (or false alarms) + 0.5/number of targets (or distractors) + 1] for both recognition memory tasks and are presented in Table 2 and Fig. 2.

In this and subsequent analyses, QX's performance was considered to be significantly impaired if his score was 2.0 standard deviations or more away from either of the two normal control group means. The two control groups differed in terms of their means and standard deviations, such that, on occasion, QX's score fell outside the normal range of one group but not the other. Such cases are highlighted and may be interpreted in terms of the differences in numbers and

Table 2. Data summary table for QX and both normal control groups for experiments 1 and 2

QX	Normal controls [old]			Normal controls [young]		
	Mean	1 standard deviation	Normal range ^a	Mean	1 standard deviation	Normal range ^a
Experiment 1: 3000 ms exposure						
Hit rate/words	0.52	0.9	0.06	0.78–1	0.6	0.17
False alarm rate/words	0.28	0.1	0.05	0–0.20	0.09	0.08
Hit rate/faces	0.32	0.83	0.06	0.71–0.95	0.6	0.14
False alarm rate/faces	0.09	0.19	0.06	0.07–0.31	0.16	0.11
Remember judgements/words	0	39	6.6	26–50	24	10.7
Know judgements/words	26	7	5.4	0–17	11	6.6
Remember judgements/faces	3	28	8.4	11–45	16	8.9
Know judgements/faces	13	14	9.7	0–33	14	7.1
Discrimination accuracy/words	0.7	0.93	0.03	0.87–0.99	0.88	0.07
Discrimination accuracy/faces	0.74	0.89	0.03	0.83–0.95	0.82	0.06
Response bias/words	0.41	–0.2	0.33	–0.86–0.46	0.57	0.37
Response bias/faces	0.91	–0.07	0.29	–0.65–0.51	0.58	0.35
Experiment 2: 6000 ms exposure						
Hit rate/words	0.48	0.9	0.05	0.80–1	0.88	0.11
False alarm rate/words	0.28	0.08	0.02	0.04–0.12	0.07	0.12
Hit rate/faces	0.95	0.9	0.06	0.78–1	0.74	0.11
False alarm rate/faces	0.07	0.21	0.12	0–0.45	0.17	0.14
Remember judgements/words	1	34	9.8	14–50	35	11.9
Know judgements/words	23	12	8.7	0–29	7	5.4
Remember judgements/faces	29	30	3.4	23–37	23	6.2
Know judgements/faces	19	15	3.7	8–22	15	4.7
Discrimination accuracy/words	0.82	0.95	0.02	0.91–0.99	0.95	0.04
Discrimination accuracy/faces	0.98	0.91	0.04	0.83–0.99	0.87	0.04
Response bias/words	0.87	0.11	0.19	–0.03–0.41	0.41	0.59
Response bias/faces	–0.17	–0.35	0.04	–0.43–0.27	–0.31	0.55

QX's score is in bold type when it falls outside the normal range.

^aMean \pm 2 standard deviations.

educational background between the two cohorts. QX displayed evidence of both VRM and FRM impairment, which was apparent in terms of a significantly elevated false alarm rate for words and a reduced hit rate for faces.

A breakdown of hit rate in terms of remember–know judgements for the VRM and FRM tasks is presented in Table 2 and Fig. 3. Both normal control groups recorded higher numbers of remember responses relative to know responses. QX, however, displayed significant impairment in terms of his paucity of remember judgements, which were compensated for by a significantly elevated number of know responses. The number of remember judgements was also significantly reduced in the FRM task when his performance was compared with the NC[o] group only.

Subsequent analyses converted hit rates and false alarm rates into the non-parametric signal detection indices of A' (Snodgrass and Corwin, 1988) and B''_D (Donaldson, 1992) which provided measures of discrimination accuracy and response bias, respectively (see Table 2). B''_D values of 0 indicate a neutral response bias, i.e. when in an uncertain state a yes or no response is registered with equal probability, whereas positive ($B''_D = 0.1$ –1) and negative ($B''_D = –0.1$ to –1) values indicate conservative and liberal bias, respectively. A conservative bias is defined by the increased probability of no responses when in an uncertain state and a liberal bias is defined by the increased probability of yes judgements.

QX's discrimination accuracy on the VRM task was significantly impaired relative to both normal control groups' normal ranges, and on the FRM task compared with the NC[o] set. Both normal control sets varied in terms of their response bias. Whereas the NC[o] group tended to exhibit a slightly liberal response bias on both recognition memory tasks, the NC[y] group displayed a more conservative one. QX also exhibited a conservative bias, which fell outside the NC[o] normal range for the FRM task only.

Experiment 2. Long duration (6000 ms) recognition memory tasks

Extending target exposure during the study phase facilitated VRM for the NC[y] group; this was evident in an increased hit rate and a reduced false alarm rate (see Table 2, Fig. 4).

The NC[o] group showed little change from their already high level of performance on the shorter target exposure version. QX's VRM, however, remained significantly impaired. Both his hit rate and his false alarm rate fell outside the normal range of both control groups. In contrast, a strong facilitatory effect was evident during the facial version, with both his hit rate and his false alarm rate falling well within the normal range of both control groups.

A breakdown of hit rate in terms of remember–know judgements for both recognition memory tasks is presented in Table 2 and Fig. 5.

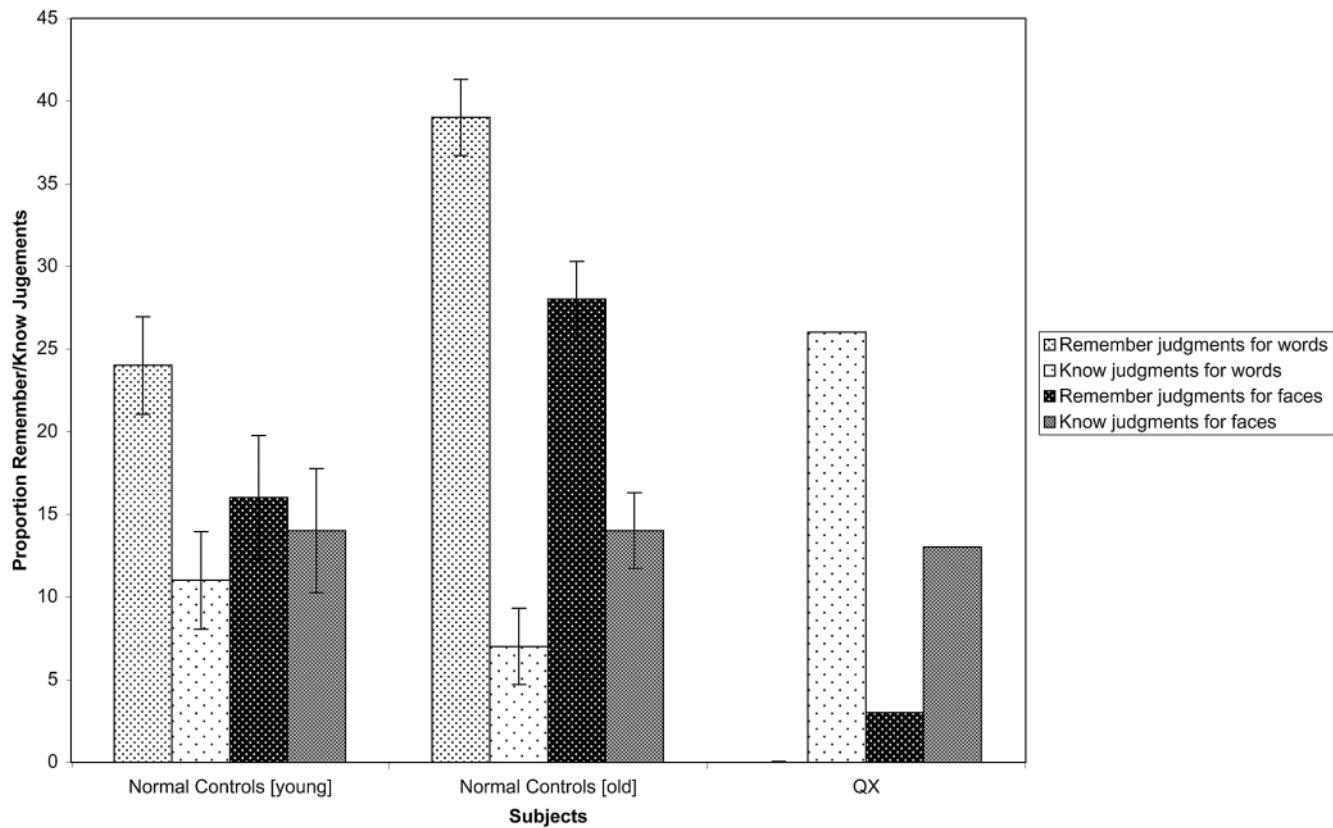


Fig. 3. Remember and know judgements in experiment 1.

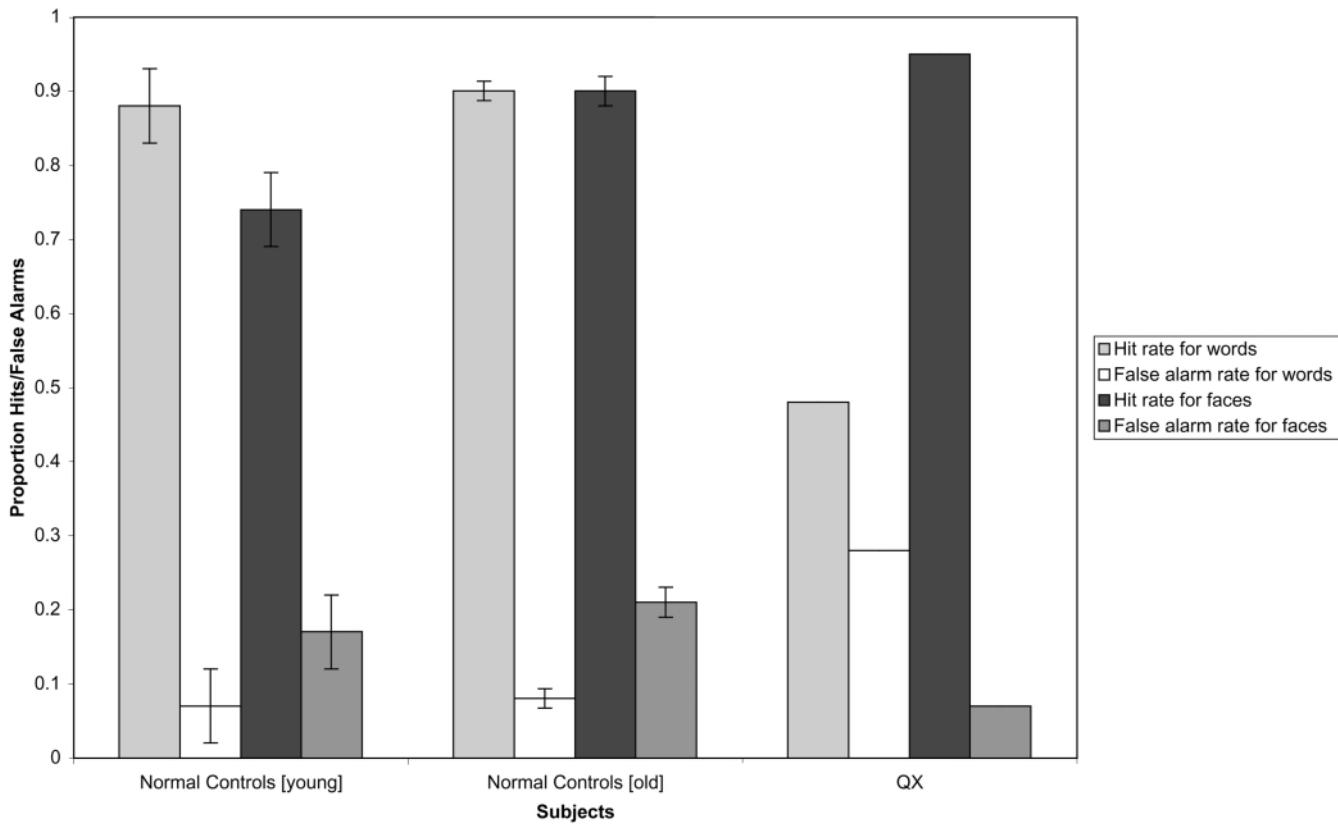


Fig. 4. Hit and false alarm rates in experiment 2.

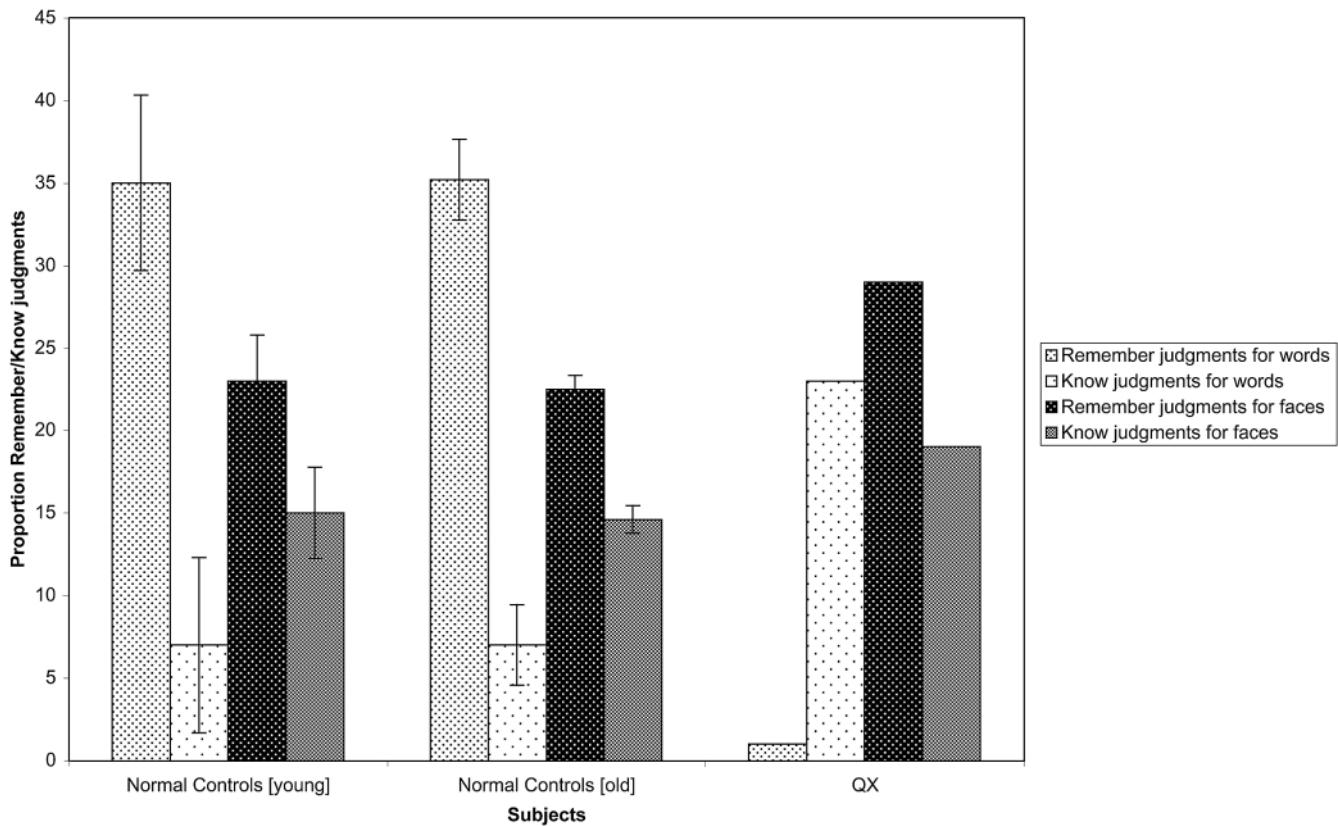


Fig. 5. Remember and know judgements in experiment 2.

The number of remember judgements recorded during the VRM task remained significantly impaired relative to the normal ranges of both control groups. The paucity of remember judgements was again compensated for by a significantly elevated number of know responses, which fell outside the NC[y] normal range only. In contrast, a large increase in recorded remember judgements was evident in the FRM task, such that the numbers of recorded remember and know responses fell within the normal range of both normal control groups.

QX's discrimination accuracy during the VRM task remained significantly impaired relative to both normal control groups. However, a slight improvement was noted in the longer compared with the shorter exposure duration VRM task. This is attributed to the decrease in his false alarm rate. A dramatic improvement in discrimination accuracy was evident in the FRM version. This result is underpinned by an increased hit rate and a reduced false alarm rate. Finally, a slight change in response bias was noted. Both sets of normal controls displayed a conservative response bias on the VRM task and a liberal one on the FRM task. QX followed this trend. However, his stringently conservative response evident on the VRM task fell outside the NC[o] normal range. Measures of discrimination accuracy and response bias are presented in Table 2.

Discussion

The reported results are broadly consistent with other studies showing that amnesia is associated with a disproportionate disruption of retrieval- compared with familiarity-driven recognition memory (e.g. Verfaellie and Treadwell, 1993; Kroll *et al.*, 1996). The paucity of QX's recollection judgements was most evident on the two VRM tasks, where the absence of a demonstrable remember response rate was compensated for by an increased know response rate. The performance profiles on the FRM tasks were more variable. The shorter exposure version was characterized by a low remember rate but no evidence of a compensatory increase in know rate, whereas the longer exposure version was marked by a significant increase in remember judgements to the extent that they were more numerous than know responses. The significant increase in the contribution of remember judgements to FRM on the longer exposure version suggests that recollection- and familiarity-driven recognition memory can be independently manipulated. However, it remains uncertain whether the nature of the dissociation between remember and know judgements on the VRM tasks reflects qualitatively distinct memory processes (Yonelinas, 1994; Yonelinas *et al.*, 1996; Dobbins *et al.*, 2000) or a memory system based on trace strength (Donaldson, 1996).

Currently in the literature there is an ongoing debate as to

whether the raw number of know responses is an accurate measure of familiarity (Gardiner *et al.*, 1996; Richardson-Klavehn *et al.*, 1996) or not (Jacoby, 1991; Yonelinas and Jacoby, 1996; Kho *et al.*, 2000). Yonelinas and Jacoby (1996) claim that the number of recorded know responses is mathematically constrained by the proportion of remember judgements in the remember–know procedure. They argue that the contribution of familiarity to recognition memory performance should be calculated from the proportion of know responses, given that the subjects are allowed to make such a response [i.e. familiarity = know/(1 – remember)]. This is an important debate, but has little impact on QX's VRM performance given his near complete reliance on know responses.

There are also questions regarding the extent to which the recollective component of recognition memory, as measured by remember judgements, maps on to the contextual–recollection processes operating during free recall of verbal material (Hanley *et al.*, 2001). Hanley *et al.* reported a patient who exhibited a severe impairment of free recall of verbal material in the presence of intact use of remember and know judgements of tests of recognition memory. Drawing on the neural network model of the hippocampus proposed by Hasselmo and Wyble (1997), the authors suggested that during free recall, context is used as a cue to retrieve an associated item, whereas during recollective-driven recognition the item is used as a cue to retrieve context. This case raises important questions as to whether important differences exist between the contextual–recollection processes used during free recall and recollective-driven recognition, which in turn has implications for Aggleton and Brown's (1999) proposals regarding a common extended hippocampal system subserving free recall as well as retrieval-driven recognition. QX displayed clear evidence of contextual retrieval on verbal tests of both free recall as well as recollection-driven recognition. According to Hanley *et al.*'s interpretation of Hasselmo and Wyble's neural network model, this implies disruption of both context- as well as item-cue retrieval. However, performance on the tests of visual memory was more variable, with clear deficiencies evident on immediate and delayed retrieval of the Rey Complex Figure and the recollection-driven FRM (short exposure duration), yet spared delayed visual memory (WMS) and recollection-driven FRM (long exposure duration). His ability to use recollection-driven recognition in both FRM tasks, albeit to a lesser extent in the short duration version, suggests that QX does experience conscious recollective memory of the context in which target faces were presented at encoding. And unlike VRM, his FRM decisions are based on contextual retrieval and do not rely disproportionately on familiarity-driven recognition. The fact that QX's lesion is restricted to the left DMT suggests that this recollection-driven recognition for visual material is being supported by his right episodic memory system.

Evidence regarding the neuroanatomical regions and pathways implicated in familiarity- and recollection-driven recognition memory remains equivocal. In their anatomical model,

Aggleton and Brown (1999) proposed that processes involved in familiarity-driven recognition memory depend on a DMT–perirhinal–prefrontal network whereas recollection-driven recognition memory is supported by a hippocampal–diencephalic system. Thus, damage restricted to the DMT should result in a selective deficit of familiarity not recollection. However, in the reported case, extensive left DMT damage was associated with deficient recollection–not familiarity-driven recognition memory. Van der Warf *et al.* (1999) also questioned DMT involvement in familiarity-driven recognition memory. Their patient exhibited evidence of impaired familiarity but spared recollection in the context of a thalamic lesion that spared the DMT, anterior thalamic nucleus and the mammillothalamic tract but involved the region of the right lateral internal medullary lamina (IML). The authors concluded that the IML and/or nuclei within, rather than the DMT, is involved in familiarity-driven recognition memory.

In addition to the reported verbal memory problems, QX also displayed evidence of a mild impairment of processes ascribed to the prefrontal cortex. For instance, QX's behaviour had become increasingly apathetic and disinhibited, and he performed poorly on tasks which required high levels of orderliness and planning (WAIS-R performance subtests). Surprisingly, however, high levels of preservation were evident on traditional tests of executive processing (WCST and Stroop). In addition, there were also signs of executive memory dysfunction on the recognition memory tasks. This was evident in QX's extremely high false alarm rates on both VRM tasks, and to a lesser extent, his abnormal response bias exhibited on the short duration FRM and long duration VRM tasks.

It has been claimed that the precise pattern of 'prefrontal' deficits depends on the focus of damage within the thalamus, as specific thalamic nuclei have reciprocal projections with different parts of the prefrontal cortex. Thus, QX's behavioural symptoms are suggestive of dysfunction in the medial-orbital prefrontal cortex (Duffy and Campbell, 1994); while the presence of mild executive dysfunction suggests increased levels of preserved dorsolateral prefrontal processing (Fuster, 1989). The presence of behavioural and cognitive evidence of prefrontal dysfunction following DMT damage is broadly consistent with Van der Warf *et al.*'s review of the neuropsychology of thalamic infarction, in which the authors tentatively concluded that destruction of the midline nuclei (IML or the DMT) may lead to executive dysfunction. Interestingly, the authors go on to suggest that lesions of only one of these nuclei may be insufficient to produce a pronounced dysexecutive syndrome, which may account for the mild prefrontal signs and symptoms reported for QX.

Taken together, these findings suggest that QX's verbal memory problems may be linked to recollection-based problems, which have their origins in impaired retrieval that involves using context as well as items as cues and abnormal strategic memory search strategies. Furthermore, when considering Aggleton and Brown's neuroanatomical model, their

prediction of impaired familiarity-driven recognition memory following DMT damage is not supported. In sum, rather than advocating a key role for the DMT in familiarity, it may be that the DMT acts in an integrative role with respect to the prefrontal cortex (Parker, 1999).

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Contribution of the left dorsomedial thalamus to recognition memory: a neuropsychological case study

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Abstract

This study reports a patient with a unilateral left thalamic lesion which was centred on the dorsomedial thalamic nucleus. Cognitive neuropsychological assessment revealed a severe impairment in verbal memory and symptoms of executive dysfunction, in the presence of relatively intact visual and facial recognition, working memory, praxis, language and IQ. Verbal and visual recognition memory were investigated using the remember-know paradigm. The results indicated a profound impairment in recollection-driven verbal recognition memory. These results are discussed in the context of the role of the dorsomedial thalamic nucleus in recognition memory, and functional models of memory.

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Primary diagnosis of interest

Severe impairment in verbal memory and symptoms of executive dysfunction

Author's designation of case

QX

Key theoretical issue

- Relationship between the (left) dorsomedial thalamus and the component processes of recognition memory

Key words: dorsomedial thalamus; recognition memory; neuropsychology; recollection; familiarity

Scan, EEG and related measures

Magnetic resonance imaging

Standardized assessment

Revised Wechsler Adult Intelligence Scale (WAIS-R), National Adult Reading Test (NART), Psycholinguistic Assessments of Language Processing in Aphasia (PALPA), Stroop, Wisconsin Card Sorting Test (WCST), verbal fluency, Wechsler Memory Scales (WMS), Autobiographical Memory Inventory (AMI), Rey Complex Figure

Other assessment

Unfamiliar/famous face sorting, familiar face identification, inanimate naming (including function and association assessments for inanimate items), two versions of a recognition memory test for words and faces (3000 and 6000 ms target exposure)

Lesion location

- Left dorsomedial thalamus

Lesion type

A discrete lacuna infarction

Language

English