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# False recognition after a right frontal lobe infarction: Memory for general and specific information

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**Abstract**—We previously reported a case study of a man with right frontal lobe damage, BG, who showed extraordinarily high false alarm rates on remember–know recognition tests (Schacter, D. L. *et al.*, *Neuropsychologia*, 1996, Vol. 34, pp. 793–808). Experiment 1 extends his high false alarm rate to yes–no recognition tests. BG typically gives false 'remember' responses on remember–know tests, and this pattern was uninfluenced when he was asked to explain the basis for his 'remember' responses (Experiments 2 and 3). When BG was given a semantic encoding task, he stopped giving 'remember'-based false alarms (Experiment 4). Signal detection analyses revealed that BG had a discrimination deficit and an abnormally liberal response bias (especially for 'remember' responses) in most conditions. Overall, BG's high false alarm rate is interpreted as reflecting an over-reliance on the general similarity between a test item and the study episode. © 1997 Elsevier Science Ltd.

Key Words: false recognition; frontal lobes; episodic memory.

## Introduction

The contribution of the frontal lobes to human memory has been illuminated by the pioneering research of Milner and her colleagues. In one important series of studies, they showed that unilateral frontal lobe excisions specifically impair memory for the temporal order of recently studied words and pictures [36, 37]. These experiments stimulated subsequent research examining the nature of temporal memory deficits in patients with frontal lobe damage [4, 34, 57], and also set the stage for studies demonstrating that subjects with behavioral or neurological signs of frontal lobe impairment exhibit great difficulties remembering the source of acquired knowledge [7, 27, 52, 59]. Additional studies by Milner's group [33, 60], together with findings reported by other investigators (e.g., [10, 66]) have led to an increasing appreciation of the central role played by the frontal lobes in episodic memory [49, 56, 62, 66]. Recent neuroimaging research suggests that frontal brain mechanisms

(especially right-lateralized areas) may be critically involved in episodic retrieval processes that extend beyond the domains of temporal context or source information [3, 44, 50, 55, 64].

We recently reported a case study of a man with a right frontal lobe lesion, BG, who exhibited a pathologically high false alarm rate on recognition–memory tests (i.e. saying that non-studied test items were 'studied') [51]. Results from a number of recognition memory experiments led us to hypothesize that BG's high false alarm rate reflects an over-reliance on memory for general characteristics of the study episode, along with a possible deficit in retrieving specific information about individual items. Though other cases with high false alarm rates following damage to the frontal lobes have been reported [9, 42], neuropsychological research has typically suggested that recognition memory is relatively insensitive to frontal lobe injury [20, 26, 36, 60, 65].

Our initial evidence for BG's excessive false recognition was obtained with the remember–know procedure [17, 63]. In this procedure, rather than merely answering 'yes' to studied test items and 'no' to non-studied items, subjects attempt to distinguish between two qualitatively different states of recognition. Subjects are asked to say

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'remember' (R) when they possess a specific recollection from encountering the stimulus on the study list, or to say 'know' (K) when they felt like the stimulus was studied but this feeling was not accompanied by any specific recollection. Not only did BG false alarm more than his control subjects, but in contrast to control subjects who typically say 'know' when false alarming, he also claimed to specifically 'remember' non-studied items. This observation is similar to other findings that patients with frontal lobe injuries often false alarm with extreme confidence [9, 42], though 'remember' responses are not always synonymous with high confidence ratings [16].

Given that most of the previously cited research has found that recognition memory is unaffected by frontal lobe damage (but see [66]), it is conceivable that idiosyncratic features of the remember–know procedure contributed to BG's high false alarm rate, and that his recognition memory would be more accurate with standard yes–no recognition tests. The additional decision component of distinguishing between 'remembering' and 'knowing' may have increased BG's false alarm rate over that of a yes–no test. To investigate this possibility in Experiment 1, we directly compared performance on a yes–no test with performance on a remember–know test.

Even if BG's performance was similar on yes–no and remember–know tests, the significance of his tendency to false alarm with 'remember' rather than 'know' remains unclear. At face value, 'remember' false alarms might be interpreted as reflecting memorial constructions with detailed, but inaccurate, recollective content. From this perspective, BG's 'remember' false alarms might reflect a subtle form of the autobiographical confabulations that have been observed in other patients with frontal lobe injury [11, 39]. However, these inferences depend on the assumption that BG has been exactly conforming to instructions, and only saying 'remember' when he possessed a specific recollection of the study episode. For this reason, we decided to undertake a more detailed investigation of the information on which BG bases his 'remember' responses. Experiments 2–4 examined qualitative aspects of BG's false recognition by asking him to give detailed explanations of the content upon which his 'remember' responses were based.

All four experiments examined the possibility that BG's high remember-based false alarm rate might be related to inappropriate decision criteria. 'Remember' and 'know' responses are often thought to represent different forms of phenomenal experience that can arise during recognition. From this perspective, the remember–know paradigm not only introduces an additional response criterion (compared to old–new tests), but this criterion is believed to entail a qualitative separation between aspects of recognition memory. Contrary to this view, Donaldson [14] has argued that remember–know data are typically consistent with a signal-detection model of recognition memory, with two decision criteria operating on a single memory process—R responses reflect a conservative criterion and K responses reflect a more liberal criterion. If R and K are merely different decision criteria for a single memory process, discrimination based on 'remember' responses would be equal to overall discrimination (R + K). In support of this perspective, Donaldson used signal-detection measures of discrimination ($A'$) and bias ($B''_D$) to show that remember-based discrimination [$A'$(R)] is usually no higher than overall discrimination [$A'$(R + K)]. Such analyses suggest that remember and know responses are not necessarily based on qualitatively different information sources (also see [24]), though qualitatively different sources are not necessarily ruled out by these analyses. To address these issues, we calculated signal-detection measures of discrimination and bias in each experiment.

## Experiment 1

Experiment 1 directly compared recognition memory under remember–know (RK) versus yes–no (YN) testing conditions. The experiment included two sessions: first with YN tests and second with RK tests. Each session included two study test blocks with number of study list presentations (one versus three) manipulated between blocks. Within each block, stimuli were either words or pronounceable pseudowords. Presentation frequency and stimulus type were manipulated in order to insure generality across different accuracy levels and different materials.

### Method

*Subjects.* A detailed case report of BG has been published previously [51], but his most notable characteristics are summarized here. BG is a 67-year-old man with a right frontal lobe infarction, possibly of embolic origin. BG's lesion primarily involves the motor and premotor cortex (Broadmann's areas 4 and 6). Other affected areas include the inferior frontal gyrus, pars opercularis and the anterior upper bank of the sylvian fissure. Subcortical damage included enlarged ventricles, atrophy of the right caudate nucleus and thalamus, and a small amount of damage to the left putamen. BG possesses a masters degree (18 years of education), and currently his language and intelligence appear to be normal. BG exhibited moderate impairments on two tests that are typically sensitive to frontal lobe damage: the phonemic word generation task (FAS) and the Wisconsin Card Sorting Task. His overall Memory Quotient (100) was normal, but he showed some information loss in his Delay Score (93) and was mildly impaired on the Attention subtest (84). He also showed mild to moderate impairment in immediate and delayed recall on the California Verbal Learning Test. On the Warrington Recognition Test (two alternatives, forced choice), BG was within normal levels for words, but recognition of faces was poorer. Clinically, BG exhibited no obvious difficulties remembering his life experiences and did not confabulate spontaneously.

All experiments included eight control subjects whose age (mean = 65.88 years) and education (mean = 17.0 years) were closely matched to BG. All eight control subjects participated in each of the four experiments.

*Materials, design and apparatus.* The experimental stimuli

were 192 common English words and 192 pseudowords. An initial set of 96 words was obtained, then the other 96 words were selected by matching word frequency ($M = 15.52$, S.D. $= 23.52$, range $= 0–172$ [32]) and length ($M = 6.88$, S.D. $= 1.04$, range $= 4–10$) on an item-by-item basis. One set of 96 was assigned to the YN test and the other set was assigned to the RK test. Pseudowords were matched with the experimental words for length and first letter, and they were created by randomly replacing vowels from a different set of 192 words. Pseudowords were all pronounceable, and we attempted to select pseudowords that were not immediately reminiscent of real words. Each set of 96 words and pseudowords were broken into four subsets that were roughly equated for length and word frequency. These subsets were randomly assigned to the studied and non-studied conditions of the first or second study test block. Another 22 words and 22 pseudowords with similar characteristics were used as buffer and practice items.

Two experimental sessions were separated by at least 1 week. In the first session, recognition tests used a standard YN procedure. In the second session, recognition tests used the RK procedure. Two study test blocks were given within each session. The first study list included 24 words intermixed with 24 pseudowords and surrounded by two-item (one word and one pseudoword) primacy and recency buffers. The second study list included the same number of items but was repeated three times, each in a different order. The recognition tests for both sessions contained 96 items, half from the study list and half non-studied. Studied words, studied pseudowords, non-studied words and non-studied pseudowords were randomly intermixed with the constraint that no more than three of the same type appeared consecutively.

Words were visually presented on a Macintosh Powerbook in upper case, 24-point Geneva font. All responses were spoken aloud and transcribed by the experimenter.

*Procedure.* At the beginning of each session, subjects completed a short practice block: a study list of 10 items (five words and five pseudowords) followed by an eight-item test list (four studied items and four non-studied). After practice, subjects completed the two experimental study test blocks.

Subjects were asked to memorize and make lexical decisions about each item on the study list. Subjects responded aloud by either saying 'Word' or 'Not a word' to each item. Stimuli were presented for 4 sec with a 1-sec inter-stimulus interval. In the second study block, subjects were allowed a short rest between the three presentations of the study list. Subjects performed an unrelated serial reaction time task within the 2-min retention interval prior to each recognition test.

In the first session (YN), subjects were instructed to say 'yes' for studied items and 'no' for non-studied items. In the second session (RK), subjects responded with 'remember', 'know' or 'new' to each item on the recognition tests (instructions adapted from Rajaram [47]). The recognition tests were self-paced such that stimuli appeared on the screen until subjects responded and initiated presentation of the next word with a key press. The response options were displayed vertically below the test item. In the YN session, the response options were 'Yes (I saw it)' or 'No (I did not see)'. In the RK session, the response options were 'Remember' (R), 'Know' (K) or 'New' (N).

## Results and discussion

The results are presented separately for words (Fig. 1) and pseudowords (Fig. 2). Responses to studied items are presented in the top panels and responses to non-studied items in the bottom panels. For the RK test, the proportion of R, K and combined (R + K) responses
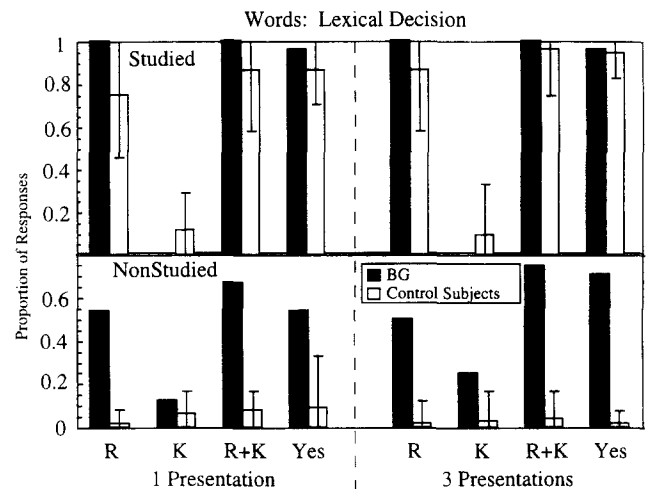


Fig. 1. Mean proportion of 'remember' (R), 'know' (K), combined (R + K) and 'Yes' responses in each condition with words for BG and control subjects in Experiment 1. Error bars denote the maximum and minimum proportion of responses observed for any individual control subject.



Fig. 2. Mean proportion of 'remember' (R), 'know' (K), combined (R + K) and 'Yes' responses in each condition with pseudowords for BG and control subjects in Experiment 1. Error bars denote the maximum and minimum proportion of responses observed for any individual control subject.
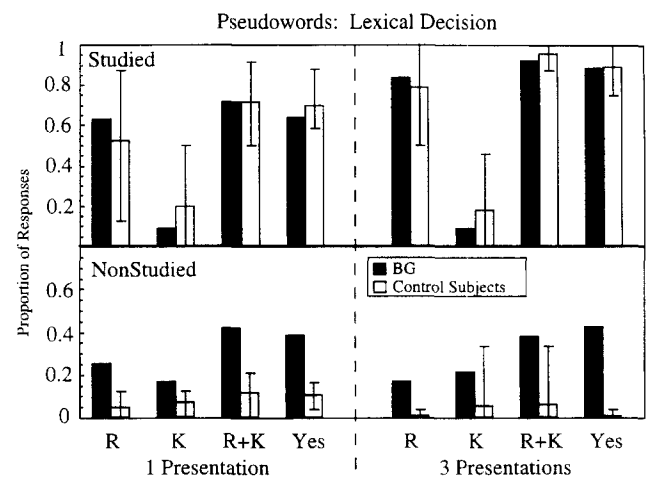
are presented. For the YN test, the proportion of 'yes' responses is presented. In each condition, BG's mean scores are plotted alongside the control subjects' grand mean, with bars representing the highest and lowest means of individual control subjects (the range). In this and all subsequent experiments, differences between BG and control subjects will be considered in two ways. First, BG's mean will be compared to the range of control subjects' means in each condition. Second, statistical significance will be assessed with a non-parametric comparison of counts test [1].

We estimated discrimination ($A'$) and bias ($B''_D$) measures for each response category (R, R + K, Yes). These parameters were not computed for K alone because the area between the low (new versus know) and high (know versus remember) decision criteria is not handled by signal-detection theory [14], but multiple criteria can be

handled by treating data cumulatively (i.e. R + K). $A'$ was chosen as the discrimination parameter because it is more robust to criterion fluctuations than $d'$ [13]. $A'$ ranges from 0 to 1, with chance performance being 0.5. The corresponding bias measure, $B''_D$, ranges from $-1$ (extremely liberal) to 1 (extremely conservative). Since these measures are undefined with hit and false alarm rates of zero or one, all response probabilities [$P(R)$, $P(R + K)$, $P(Yes)$] were transformed by computing $P(x)$ as $(x + 0.5)/(n + 1)$ rather than as $x/n$ (as recommended by Snodgrass and Corwin [61]). Differences between BG and controls on these parameters will be assessed by comparing BG to the range of control subjects' means (cells in which BG is outside the range are denoted with an asterisk in Tables 1 and 2).

For studied words (Fig. 1, top panel), BG said 'remember' to every studied item in the RK test condition. After both one and three study list presentations, BG said 'remember' to studied words more often than control subjects, and 'know' less than control subjects (both $P < 0.01$). This resulted in an overall higher hit rate (R + K) for BG compared to control subjects after one presentation ($P < 0.01$), but not after three presentations. Failure to detect a difference in this latter condition is probably attributable to a ceiling effect. In contrast, no

hit rate differences between BG and controls emerged for studied words tested in the YN format ('Yes' responses in Fig. 1). For non-studied words (Fig. 1, bottom panel), BG was above the range of and significantly different from controls subjects in all comparisons (all $P < 0.01$), except 'K' responses after one presentation. Like his hit rate, BG's false alarm rate was higher in the RK than YN conditions (comparing R + K to Yes).

Signal-detection analyses revealed that BG had a discrimination impairment in all conditions with words ($A'$, top of Table 1) as well as an abnormally liberal response bias ($B''_D$, bottom of Table 1). His response bias fell within the normal range only for words presented once in the YN condition. This change reflects slightly more conservative responding by BG in the YN than RK condition, but is also attributable to one control subject who became more liberal in the YN condition. As explained previously, if $A'(R)$ equals $A'(R + K)$, the results would be consistent with quantitatively different decision criteria operating on a unitary memory dimension. The similarity between $A'(R)$, $A'(R + K)$ and $A'(Yes)$, in both BG and control subjects, supports this possibility.

The results for the pseudowords are presented in Fig. 2. For studied pseudowords, no significant differences emerged between BG and the control subjects. The results

Table 1. Signal-detection measures of discrimination ($A'$) and bias ($B''_D$) for Experiment 1

| Presentation frequency | Stimuli | Response | BG | Control subjects | | |
|---|---|---|---|---|---|---|
| | | | | Mean | Min | Max |
| | | | | $A'$ | | |
| 1 | WD | R | 0.85 | 0.92 | 0.85 | 0.99 |
| | WD | R + K | 0.82 | 0.93 | 0.88 | 0.96* |
| | WD | Yes | 0.83 | 0.93 | 0.88 | 0.97* |
| 3 | WD | R | 0.86 | 0.96 | 0.88 | 0.99* |
| | WD | R + K | 0.79 | 0.98 | 0.86 | 0.99* |
| | WD | Yes | 0.76 | 0.98 | 0.95 | 0.99* |
| 1 | PW | R | 0.77 | 0.85 | 0.74 | 0.96 |
| | PW | R + K | 0.72 | 0.88 | 0.78 | 0.96* |
| | PW | Yes | 0.69 | 0.88 | 0.79 | 0.92* |
| 3 | PW | R | 0.89 | 0.93 | 0.86 | 0.99 |
| | PW | R + K | 0.85 | 0.96 | 0.91 | 0.99* |
| | PW | Yes | 0.82 | 0.96 | 0.93 | 0.99* |
| | | | | $B''_D$ | | |
| 1 | WD | R | −0.97 | 0.63 | 0.00 | 0.97* |
| | WD | R + K | −0.98 | 0.10 | −0.83 | 0.95* |
| | WD | Yes | −0.90 | 0.25 | −0.92 | 0.69 |
| 3 | WD | R | −0.96 | 0.75 | −0.78 | 0.95* |
| | WD | R + K | −0.99 | 0.76 | −0.78 | 0.69* |
| | WD | Yes | −0.95 | 0.75 | −0.68 | 0.83* |
| 1 | PW | R | 0.27 | 0.76 | 0.52 | 0.99* |
| | PW | R + K | −0.26 | 0.78 | −0.43 | 0.78 |
| | PW | Yes | −0.02 | 0.78 | −0.04 | 0.78 |
| 3 | PW | R | 0.00 | 0.67 | 0.00 | 0.96 |
| | PW | R + K | −0.69 | 0.15 | −0.92 | 0.69 |
| | PW | Yes | −0.65 | 0.54 | 0.00 | 0.89* |

Min and Max are the minimum and maximum scores obtained by any control subject. WD, words; PW, pseudowords. Asterisks denote cells in which BG was outside the control range.

Table 2. Signal-detection measures of discrimination ($A'$) and bias ($B''_D$) for Experiments 2–4

| Experiment (condition) | | No explanation | | | | Explanation | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | BG | Control subjects | | | BG | Control subjects | | |
| | | | Mean | Min | Max | | Mean | Min | Max |
| | | | | | | $A'$ | | | |
| 2 | R | 0.77 | 0.80 | 0.63 | 0.94 | 0.77 | 0.85 | 0.74 | 0.95 |
| (T-junctions) | R+K | 0.80 | 0.86 | 0.70 | 0.96 | 0.73 | 0.86 | 0.74 | 0.97* |
| 3 | R | 0.81 | 0.87 | 0.80 | 0.93 | 0.42 | 0.83 | 0.74 | 0.93* |
| (Pseudowords) | R+K | 0.78 | 0.88 | 0.83 | 0.94* | 0.42 | 0.88 | 0.80 | 0.96* |
| 4 | R | 0.96 | 0.95 | 0.86 | 0.99 | 0.96 | 0.93 | 0.82 | 0.99 |
| (Liking) | R+K | 0.95 | 0.97 | 0.94 | 0.99 | 0.83 | 0.95 | 0.88 | 0.98 |
| | | | | | | $B''_D$ | | | |
| 2 | R | −0.27 | 0.88 | 0.65 | 0.99* | 0.44 | 0.93 | 0.78 | 0.99* |
| (T-junctions) | R+K | −0.83 | 0.20 | −0.59 | 0.89* | −0.56 | 0.24 | −0.69 | 0.96 |
| 3 | R | −0.29 | 0.77 | 0.15 | 0.98* | 0.46 | 0.92 | 0.78 | 0.99* |
| (Pseudowords) | R+K | −0.85 | −0.11 | −0.95 | 0.65 | −0.31 | 0.46 | −0.47 | 0.96 |
| 4 | R | 0.78 | 0.54 | 0.00 | 0.96 | 0.78 | 0.43 | −0.27 | 0.98 |
| (Liking) | R+K | −0.83 | −0.21 | −0.87 | 0.78 | −0.77 | −0.23 | −0.83 | 0.69 |

Min and Max are the minimum and maximim scores obtained by any control subject. Asterisks denote cells in which BG was outside the control range.

for non-studied pseudowords were similar to those for non-studied words. All non-studied pseudoword comparisons except for K responses following one presentation revealed significantly higher false alarm rates in BG than control subjects (all $P < 0.01$). Of these significant differences, BG was outside the range of control subjects in all but K responses after three presentations. In this latter condition, one control subject had an extremely high rate of K-based false alarms. No differences appeared, for control subjects or BG, between the RK and YN conditions when overall false alarm rates were compared. However, the upper range of control subjects' false alarms is noticeably lower for 'yes' responses than for R+K. This difference is attributable to the one subject who said 'know' more than BG. It seems likely that this subject used the 'know' category for loose guesses that would have been given 'no' responses with the standard YN procedure.

As observed with words, BG had a discrimination impairment for pseudowords ($A'$, Table 1). Again, the similarity between $A'$(R), $A'$(R+K) and $A'$(Yes) is consistent with the signal detection model. BG's response criteria were more conservative for pseudowords than for words, but he was still more liberal than any control subject in two conditions: R responses after one presentation and 'yes' responses after three presentations.

Overall, the results for words and pseudowords demonstrate that BG's high false alarm rates cannot be attributable to vagaries of the RK procedure. All RK and YN results were very similar. BG's discrimination was impaired in all conditions, and his bias was typically more liberal than that of control subjects, though less so for pseudowords than words. It is interesting that BG showed little or no discrimination differences between conditions in which discrimination differed for controls

(one versus three presentations, pseudowords versus words). Thus, his overall discrimination impairment may reflect an insensitivity to certain variables that would normally improve memory.

## Experiment 2

The results from Experiment 1 suggest that BG's high false alarm rate is not an artifact of the RK procedure because the pattern generalized to standard YN conditions. Next, we address the further question of whether or not the RK distinction provides useful information about qualitative aspects of BG's false recognition. Is BG really constructing false memories with specific content, comparable to the content of veridical episodic recollections? Signal-detection results from Experiment 1 are consistent with the idea that R responses are not based on qualitatively more discriminative information than K responses; R and K might represent two different ways of partitioning a unidimensional memory signal.

In Experiments 2–4 we asked subjects to explain or describe the information that was recollected whenever they gave a 'remember' response. It is conceivable that BG does not truly recollect false information, but merely has misused the 'remember' category in our previous experiments. If his explanations lacked specific fabrications— containing only vague statements like "it just seemed very familiar"— it would indicate that BG's false alarms are not qualitatively different from control subjects who typically say 'know' when they false alarm. Another possibility is that BG would be more careful when explanation was required, so his rate of 'R' false alarms might decrease altogether.

The basic design of these experiments was identical. Subjects completed two study test blocks. Explanation of R responses was required in the second, but not the first, block.† The experiments differed according to stimulus type and encoding task: Experiment 2 used words and T-junction counting, Experiment 3 used pseudowords and pronunciation ratings, and Experiment 4 used words and liking ratings. Though different encoding tasks were used, subjects were always told to intentionally study the words for an upcoming test.

## Method

*Materials, design and apparatus.* The experimental stimuli were 96 common English words, none of which were presented in the previous experiment. The words were divided into four subsets of 24 that were roughly equated for word length and frequency of usage. Across subsets the average word length was 7.06 (S.D. = 1.90, range = 3–11) and the average frequency of usage was 15.54 (S.D. = 23.87, range = 0–99 [32]). Each subset was assigned to one of four conditions: old/new × explanation (no/yes). Another 48 words of similar characteristics were used as buffer items.

Each subject completed two study test blocks within a single session. The primary independent variable (no explanation versus explanation) was manipulated between blocks. In the first test list (the no explanation condition), subjects only responded with 'remember' (R), 'know' (K) or 'new' (N) to each test word. In the second block (the explanation condition), subjects responded R, K or N then were required to explain their R responses. Each study list contained 48 items—a 24-item experimental list was surrounded by 12-word primacy and recency buffers. The large number of non-tested buffers were included to increase study list length (to keep performance from the ceiling) while keeping the test list short enough so that explaining 'remember' responses would not become too tiresome. Each test list contained 48 words, half studied and half non-studied, presented in random order.

Words were presented visually on a Macintosh Powerbook. R, K and N responses were written on response forms by subjects, and 'remember' explanations were tape recorded.

*Procedure.* In each study phase, the word list was presented at an exposure duration of 4 sec with a 1-sec inter-stimulus interval. For each word, subjects counted the number of instances in which two lines within a letter intersect in a T-shaped formation and wrote down the T-junction count before the next word appeared. Subjects were told to intentionally study each word while they were engaged in the T-junction task. Prior to each test list, subjects performed a serial reaction time task for 2 min.

In both test lists, subjects were asked to answer 'remember', 'know' or 'new'. For the second test list only (the explanation condition), subjects were asked to explain their 'remember' responses with the following instruction: "Whenever you respond with R we would like you to give a brief description, out loud, of what exactly you remember from seeing it previously". These tests were self-paced.

*Method for rating subjects' explanations.* To characterize the qualitative content of subjects' explanations, we had two raters evaluate the explanations according to four criteria. The criteria were: (1) reference to the study phase, (2) autobiographical reference, (3) presence of associative or recollective content (as opposed to raw familiarity), and (4) reference to the encoding task (in this experiment, the T-junction counting task). These criteria were selected *post-hoc*, based on an initial assessment of how BG's explanations related to the explanations given by controls.

The first criterion, 'reference to the study phase', was meant to index whether or not the subject was remembering details pertaining to the presentation of the target word at study. To meet this criterion, the explanation referred to an action, thought, or event which (1) took place in the past and (2) could plausibly relate to the presentation of the target word at study. More specifically, the explanation had to either (1) use the past tense or (2) be of the form "I remember [X]", where 'X' is any specific content other than the target word itself (such as YELLOW: "I remember a banana"). Statements of the form, "I remember the word because..." were evaluated on what followed 'because'. Also, explanations were disqualified if they were explicitly linked to an event other than the presentation of the target word at study (so, DOG: "I thought of my dog" is acceptable, as is DOG: "When this word was presented, I thought of my dog", but DOG: "Yesterday I thought of my dog" is not acceptable).

The second criterion, 'autobiographical reference', was meant to index the extent to which subjects referred to their life outside the experiment. To meet this criterion, an explanation had to refer to one of the following: (1) people, places or things from the person's life (e.g., "my wife", "my house", "my job"), (2) past events involving the subject (either unique events or habitually performed events, e.g., DOG: "I walk my dog every day", (3) characteristics of the subject himself (e.g., TALL: "I am very tall"), (4) the subject's hopes, desires or future plans.

The third criterion, 'presence of associative or recollective content', is meant to index the extent to which subjects provided some information in their explanations, apart from simply stating "I remember the word" or "This word just seems familiar".

The fourth criterion, 'reference to the encoding task', indexes the extent to which subjects recalled details pertaining to the T-junction counting task (e.g., "I remember being surprised by how few T-junctions this word had").

The two raters were given an instruction packet describing all four criteria. For each of the four criteria, the raters were provided with a random ordering of the complete set of explanations for this experiment; the raters were blind regarding which subjects gave which explanations, and whether a given explanation corresponded to a hit or a false alarm. The raters were instructed to place a '1' beside explanations which met the criterion in question, and to place a '0' beside explanations which failed to meet the criterion. Inter-rater reliabilities for the second, third and fourth criteria were high: 0.95, 0.98 and 0.99 respectively. Inter-rater reliability for the first criterion was relatively low (0.86), because one of the raters misunderstood the instructions. We went over the instructions again with the raters and had them re-do their ratings for this criterion; the new reliability score was 0.98. For this experiment, and for all experiments that follow, the rating data we report for the first criterion ('reference to the study phase') will be taken from this second pass, not the first. In all cases, the qualitative conclusions that we make about 'reference to the study phase' are true of both the first and second passes.

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† An initial experiment was conducted in which explanation was required for all 'remember' responses. The stimuli were words and the encoding task was liking ratings. BG's performance in this experiment was entirely normal. Unfortunately, we could not unambiguously attribute his normal performance to the explanation requirement because we have observed one other instance of normal performance when words were studied with a pleasantness rating task and no explanation was required ([51], Experiment 6). Thus, the present experiments all included a control condition in which no explanation was required.

Table 3. The proportion of explanations that met each rating criterion

| | BG | | Control subjects' hits | | |
|---|---|---|---|---|---|
| Criteria | False alarms | Hits | Mean | Min | Max |
| **Experiment 2** | | | | | |
| Reference to the study phase | 0.00 | 0.12 | 0.43 | 0.11 | 0.75 |
| Autobiographical reference | 0.75 | 0.62 | 0.15 | 0.00 | 0.53 |
| Associative or recollective content | 1.00 | 1.00 | 0.86 | 0.67 | 1.00 |
| Reference to T-junction task | 0.00 | 0.00 | 0.10 | 0.00 | 0.33 |
| **Experiment 3** | | | | | |
| Reference to study phase | 0.17 | 0.13 | 0.53 | 0.00 | 1.00 |
| Autobiographical reference | 0.00 | 0.00 | 0.02 | 0.00 | 0.06 |
| Associative or recollective content | 1.00 | 1.00 | 0.98 | 0.83 | 1.00 |
| Reference to similar word | 0.89 | 0.81 | 0.76 | 0.56 | 1.00 |
| **Experiment 4** | | | | | |
| Reference to the study phase | | 0.00 | 0.33 | 0.04 | 0.63 |
| Autobiographical reference | | 0.31 | 0.21 | 0.00 | 0.48 |
| Associative or recollective content | | 1.00 | 1.00 | 0.96 | 1.00 |
| Reference to liking task | | 0.40 | 0.45 | 0.30 | 0.63 |

For each criterion, we will report the percentage of each subject's explanations that meet that criterion (Table 3); these percentages were obtained by averaging together the percentages reported by the two raters. For BG, we report data for his false alarms as well as hits. Since only one control subject made a single 'remember' false alarm, we only present explanations for control subjects' hits.

## Results and discussion

The results from each condition are presented in Fig. 3. For studied words, when not required to explain R responses, BG answered with R more often than control subjects ($P < 0.05$). When explanation was required, BG's hit rates were very similar to control subjects. Thus, BG appeared less likely to give positive responses to studied



Fig. 3. Mean proportion of 'remember' (R), 'know' (K) and combined (R + K) responses in each condition for BG and control subjects in Experiment 2. Error bars denote the maximum and minimum proportion of responses observed for any individual control subject.

words (especially R responses) when he was asked for an explanation, whereas explanation had little effect on control subjects. BG's rate of R responses to non-studied words also decreased with explanation, but most importantly, BG's false alarm rate remained well above that of controls in both the explanation and no explanation conditions. Both R and R + K false alarms were above the range of controls in both conditions (all $P < 0.01$).

Signal-detection measures revealed that BG's discrimination was below all control subjects in the explanation condition ($A'$, Table 2). R-based discrimination was similar to overall discrimination (R + K) for all subjects. BG's response bias was more conservative in the explanation condition [where only $B''_D(R)$ was lower than all control subjects] than in the no explanation condition [where both $B''_D(R)$ and $B''_D(R + K)$ were lower than all control subjects], even though his false alarm rate remained outside the range of control subjects, regardless of the explanation condition.

Table 3 shows the proportion of explanations that met each of the four criteria that were given to our raters. The explanations that BG gave for his 'remember' responses predominantly consisted of associations made to the test word, and these associations often included autobiographical information regarding his recent life experiences. For example, after claiming to remember DISEASE he said, "I remember this word because one of the reasons I'm going to the dentist this afternoon is some gum disease" and to SLUSH he said, "I remember this basically because of the kids with their ice cream slush, and also today with the snow". These sorts of explanations were given to both studied and non-studied words, but BG was somewhat more likely to refer back to the study list for hits than for false alarms. In general, however, BG made few references to the study episode, so it is not entirely clear if he was merely free associating
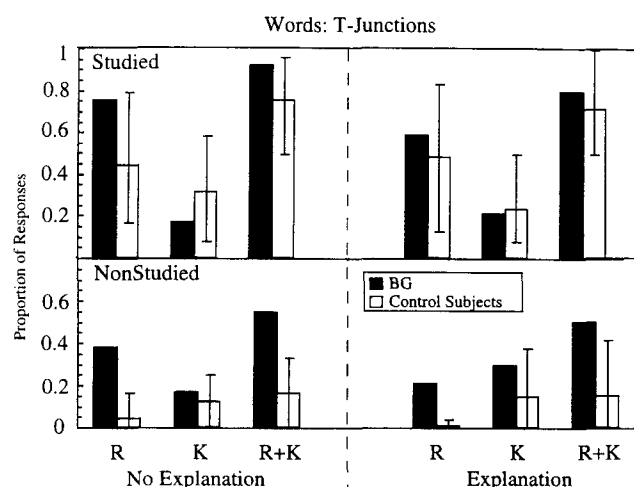
or was relating associations that he believed to remember from the study episode.

The vast majority of explanations given by control subjects were also associations to the 'remembered' words (only one control subject made a single 'remember' false alarm), but they included proportionately fewer auto-biographical references. Only one control subject produced autobiographical explanations (53% for hits) at a rate that approached BG (75% for hits and 62% for false alarms). Control subjects included more references to the study phase—with only one control subject making less study list references than BG did to studied words (11% versus 12%)—but the overall rate of these references was rather low (43% on average).

In summary, the explanation requirement caused BG to use the 'remember' response somewhat more conservatively, but his false alarm rate remained above that of control subjects (who seemed completely unaffected by the explanation requirement). All subjects' explanations were somewhat vague and were dominated by associations to the target words, but compared to control subjects, BG made many more autobiographical associations. Experiment 3 was similar to Experiment 2, except that stimuli were pseudowords and the encoding task was pronunciation ratings. Pseudowords were chosen because they seemed less likely to trigger the sorts of associations to extra-experimental autobiographical events that dominated BG's 'remember' explanations in Experiment 2.

## Experiment 3

### Method

*Materials, design and procedure.* The experimental stimuli were 96 pronounceable non-words (pseudowords) that were not among those from Experiment 1, but they were created in the same manner. Another 48 pseudowords of similar characteristics were used as buffer items.

The encoding task required subjects to rate the pronounceability of each pseudoword on a five-point scale. All other aspects of the design and procedure were identical to Experiment 2.

*Method for rating subjects' explanations.* For this experiment, we also had our raters score subjects' explanations according to (1) reference to the study phase, (2) autobiographical reference and (3) presence of associative or recollective content; the definitions of these criteria were unchanged from the preceding experiment. We noticed that subjects were frequently explaining their responses by mentioning a real word that sounded similar to the target pseudoword. We therefore also asked raters to count the number of times that subjects mentioned similar sounding words in their explanations. The actual rating procedure was identical to the procedure used in the preceding experiment. Inter-rater reliabilities were high: 0.98, 1.00, 0.99 and 0.94 for the first, second, third and fourth criteria, respectively.

### Results and discussion

Results are presented in Fig. 4. In general, these results are similar to those of Experiment 2. The explanation
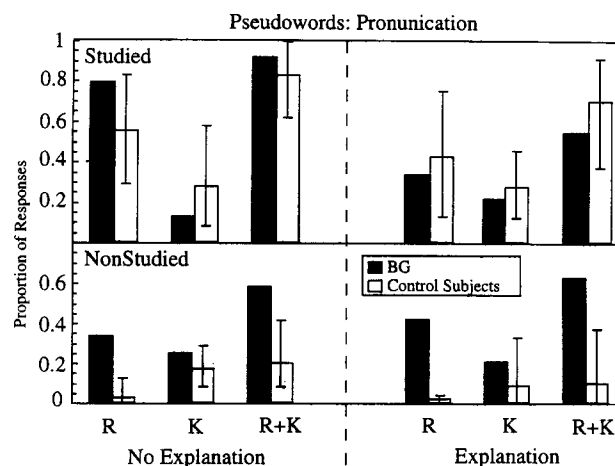


Fig. 4. Mean proportion of 'remember' (R), 'know' (K) and combined (R+K) responses in each condition for BG and control subjects in Experiment 3. Error bars denote the maximum and minimum proportion of responses observed for any individual control subject.

requirement decreased BG's hit rate (both R and R+K). Compared to control subjects, BG's hit rate tended to be higher with no explanation but lower with explanation, though these differences were not statistically significant. BG's false alarm rate showed little sensitivity to the explanation requirement. In both test conditions, his false alarm rates were outside the range of control subjects for both R and R+K (all $P < 0.01$).

As in the previous experiments, $A'(R)$ was consistently similar to $A'(R+K)$. BG showed a discrimination impairment ($A'$, Table 2), especially in the explanation condition. In fact, in contrast to control subjects who were not affected by explanation, BG's discrimination was substantially reduced by the explanation requirement. Although he used the remember response somewhat more conservatively when explanation was required ($B''_D$, Table 2), his criterion for saying 'remember' was lower than control subjects in both conditions.

The explanation given to remember responses (see Table 3) almost exclusively referred to real words that the subjects thought were similar (often similar sounding) to the pseudowords: TIRBET, "reminds me of turbo, almost the word turbo"; CLUMOX, "I remember because it sounds like dumb ox"; CITSIP, "sounds like the word ketchup". These sorts of explanations dominated BG's responses to studied and non-studied items, as well as control subjects' responses to studied items. The only instance in which BG did not give such a response was a false alarm (PULT: "I remember it simply because of the odd spelling. It reminded me of nothing, but I do remember it."). As anticipated, BG did not give autobiographical associations when tested with pseudowords, and his explanations were virtually indistinguishable from those of control subjects. However, all subjects failed to consistently make direct references to the study episode that would enable us to differentiate between recollection of words thought about during the

study list, and mere generation of these words during the test.

# Experiment 4

Experiment 4 was intended to increase the specific recollection of stimuli. Previous research has shown that 'remember' responses increase when the encoding task focuses on semantic rather than physical aspects of the studied words [15]. The use of perceptually oriented encoding tasks (Experiments 2 and 3) and pseudowords (Experiment 3) might have been somewhat responsible for the impoverished recollective content of subjects' explanations. Presumably, richer recollective experiences would be fostered if words were studied with a semantic encoding task. Furthermore, if a semantic encoding task gives more detailed 'remember' explanations for studied items, any difference between 'remembered' hits and false alarms may become more apparent. In addition to the doubt raised by subjects' 'remember' explanations, the consistent similarity between $A'(R)$ and $A'(R+K)$ suggests that a unitary dimension of recognition could alone account for results from the first three experiments. Evidence for a recollective process with higher discrimination might be observed with a semantic encoding task.

## Method

*Materials, design and procedure.* The experimental stimuli were 96 common English words that did not appear in the previous experiments. Words were matched, on an item-to-item basis, to stimuli used in Experiment 2 on length, frequency and first letter. Across subsets the average word length was 7.06 (S.D. = 1.90, range = 3–11) and the average frequency of word usage was 15.58 (S.D. = 23.90, range = 0–98 [32]). Again, the words were divided into four subsets of 24 words that were randomly assigned to each condition. Forty-eight additional words with similar characteristics were used as buffer items.

The experiment was procedurally similar to Experiments 2 and 3, except for the encoding task. Subjects rated each word on a five-point scale according to how much they liked its meaning—1 was given to words they strongly disliked, 3 to neutral words and 5 to words they strongly liked.

*Method for rating subjects' explanations.* As in the preceding two experiments, we had our raters score subjects' explanations according to (1) reference to the study phase, (2) autobiographical reference and (3) presence of associative or recollective content; the definitions of these criteria were unchanged from the preceding experiment. However, we emphasized to the raters that statements of preference (e.g., "I like ice cream") did not satisfy the 'autobiographical reference' criterion. We also wanted to measure the extent to which subjects reported thoughts from the liking rating task they performed at study. For an explanation to meet this 'liking' criterion, the subject had to either (1) explicitly state how much they like the referent of the target word (e.g., BANANAS: "I love bananas") or (2) express an opinion regarding the target word from which the rater could infer how much the subject likes the meaning of the word (e.g., STAMP: "Stamp collecting is a fun hobby" or HONEST: "One should strive to be honest").

To assist our raters, we told them that if the explanation contained an adjective which (1) refers to the target word and (2) has an evaluative (positive, negative or neutral) connotation (e.g., DEATH: "Death is an unpleasant concept" or DANCE: "Square dancing is fun"), then it meets this criterion. The actual rating procedure was identical to the procedure we employed in the preceding two experiments. Inter-rater reliabilities were high: 1.00, 0.95, 1.00 and 0.97 for the first, second, third and fourth criteria respectively.

## Results and discussion

Results are presented in Fig. 5. No differences were found between BG and control subjects for studied items. Overall hit rates (R + K) were near the ceiling, but R responses were below the ceiling, and BG's R-based hits remained near the control subjects' mean. The explanation requirement had little or no effect on hits, but drastically increased BG's K-based false alarm rate. When no explanation was required, BG's false alarm rates (K and R + K) were near the upper limit of the control subjects' range, but no differences were significant. In contrast, with the explanation requirement, BG's overall false alarm rate was substantially above that of control subjects ($P < 0.01$), and his false alarms were exclusively K responses.

BG's discrimination was within the range of control subjects in the no explanation condition, but $A'(R + K)$ was below control subjects in the explanation condition (Table 2). Compared to all other experiments, BG, but not control subjects, showed the largest discrepancy between $A'(R)$ and $A'(R + K)$ in the explanation condition of Experiment 4. Higher R-based than overall discrimination is suggestive of a recollective influence that qualitatively differs from K-based discrimination. The bias measures ($B''_D$) were relatively similar between BG and control subjects, as well as between the two explanation conditions.
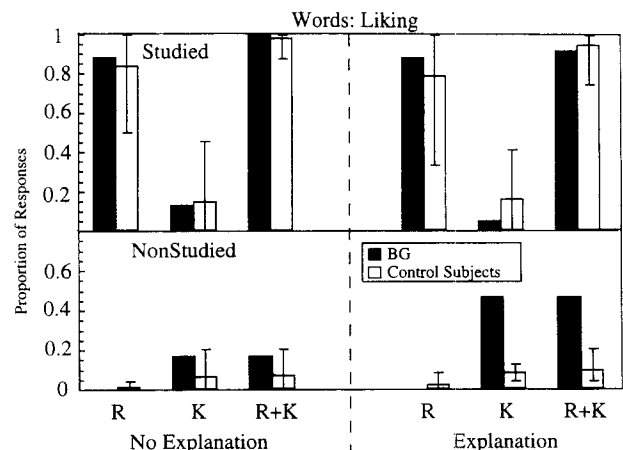


Fig. 5. Mean proportion of 'remember' (R), 'know' (K) and combined (R + K) responses in each condition for BG and control subjects in Experiment 4. Error bars denote the maximum and minimum proportion of responses observed for any individual control subject.

Three aspects of the Experiment 4 results were unexpected. First, BG's false alarm rate was not significantly above that of control subjects in the no explanation condition. Schacter et al. [51] included three experiments in which, like the present experiment, the only encoding task involved liking ratings. For auditory words (word lists have been presented visually in all other experiments with BG), BG's false alarms were significantly higher than control subjects ([51], Experiment 2). When the non-studied condition included semantic associates of studied words, BG's rate of R-based false alarms was above control subjects, but not drastically so ([51], Experiment 4). Finally, when studied and non-studied words were limited to members of six semantic categories, BG's false alarm rate appeared quite normal ([51], Experiment 6). We also observed normal performance after pleasantness ratings in our preliminary experiment that required 'remember' explanations (see earlier footnote). Thus, there are some indications that BG may false alarm less after the liking rating task. These results raise the possibility that BG's recognition impairments are at least partially attributable to encoding deficits, but this has not been explored systematically.

The second unexpected finding was that BG made more false alarms when explanation was required than when no explanation was required. This is inconsistent with the idea that the explanation requirement would, if anything, make him more conservative. Third, in contrast to all of our previous research in which BG false alarmed predominantly with R, false alarms were exclusively given K responses. It might be expected that an increase in K responses with explanation would be a by-product of decreased R responses. That is, items given an R in the no explanation condition would be given a K in the explanation condition. This effect was observed to some extent in Experiment 2. However, the present effect cannot be explained in terms of a trade-off between R and K responses, because BG did not give a single R-based false alarm—with or without explanation.

The explanations that BG gave to 'remembered' words were somewhat like those given in Experiment 2, but they were not as autobiographical and were often related to the liking task. For example, RAINSTORM: "Basically because I do detest rainstorms, I don't mind a slight rain, but rainstorms I do"; SEDATIVE: "Basically because I really don't like sedatives or things that make you sleepy"; and FUDGE: "Basically because it is pleasing, I like it as a candy". However, as in Experiments 2 and 3, BG did not directly state that he was remembering a thought that occurred during the study phase, but it seems reasonable to infer that these were evaluations that he was remembering from the liking task. This inference is supported by the observation that such evaluative explanations were much less frequent in the previous experiments that did not use liking ratings. Control subjects often gave explanations that seemed related to their liking ratings as well, but as in Experiment 2, their explanations referred back to the study phase more often than

BG's explanations. Nonetheless, on an absolute scale, control subjects did not make many explicit references to the study episode.

## General discussion

We previously reported that BG, a patient with right frontal lobe damage, shows a pathologically high false alarm rate on recognition memory tests that use the RK procedure [51]. The present experiments replicated this basic finding, and provided new insight into the nature of his high false alarm rate. In Experiment 1, BG's false alarm rate remained substantially above that of control subjects with both RK and YN test formats. Thus, his high false alarm rate is not entirely attributable to idiosyncrasies of the RK procedure. In Experiments 2–4, performance under standard RK instructions was compared with testing conditions in which subjects were required to explain the basis of their 'remember' responses. In all three experiments, the explanation requirement had little effect on the pattern of control subjects' responses. In Experiments 2 and 3, explanation made BG respond somewhat more conservatively (explanation also made control subjects more conservative in Experiment 3), but it did not bring his false alarm rate down to the level of control subjects. In Experiment 4, a surprising pattern of results was observed in which BG performed normally in the condition without explanation, his false alarm rate dramatically increased when he was required to explain 'remember' responses, but he only false alarmed with 'know' responses.

Examination of the explanations that subjects gave for their 'remember' responses lead to a number of interesting observations. Overall, we could discern no consistent differences between BG's 'remember' responses associated with hits versus false alarms. However, the content of BG's explanations differed from control subjects in two primary respects. First, BG's explanations rarely referred back to the study phase. Second, BG made many more autobiographical references than control subjects in Experiment 1. Across the experiments, the content of subjects' explanations was greatly influenced by requirements of the encoding task and characteristics of the stimuli.† When words were studied with a T-junction task, all subjects predominantly gave associations to the test items, though BG's associations were more autobiographical than those of control subjects. When stimuli were pseudowords, almost all explanations made ref-

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† These cross-experiment comparisons can be compromised by confounding factors. However, Experiments 2–4 used the same subjects and identical list lengths, and some item characteristics were also controlled (item length in Experiments 2–4; word frequency in Experiments 2 and 4). Therefore, the only remaining confounds are uncontrolled item characteristics and any change in the subjects between the experiments (motivation, etc.).

erence to real words that the subjects believed to be similar to the test items. Together, these results raise the possibility that BG's false alarm rate is driven by pre-experimental familiarity to the test items. We had previously attempted to rule out this possibility by using pseudowords as stimuli because they would not be pre-experimentally familiar [51], but the explanations given to pseudowords make it clear that associations to real words contribute heavily to pseudoword memory. Thus, pseudoword false alarms could be attributable to the pre-experimental familiarity of similar words. For example, when a real word was brought readily to mind by a pseudoword, BG might have misattributed the ease with which the word comes to mind as indicating that the word was generated during the study list (e.g., [25]). We return to the considerations of such source mis-attributions later.

As a whole, subjects' explanations often lacked clear recollective content in Experiments 2 and 3. The similarity of BG to control subjects in this respect suggests that BG's false 'remember' responses cannot be attributed to using the response category in a manner that substantially differed from control subjects. However, all subjects' vague explanations raise doubts about taking 'remember' responses at face value—as indicative of conscious recollection of a specific episode. It might be expected that recollection would be poor in the present experiments because it is impaired by age [43], shallow encoding tasks [15] and use of non-words [16]. Ideally, however, these conditions should create less 'remember' responses rather than creating a looser criterion for using 'remember'.

Signal-detection analyses were consistent with the apparent dearth of recollective content in Experiments 2 and 3. These analyses revealed two consistent results. First, BG typically showed a discrimination deficit and a more liberal response bias compared to control subjects. Second, for BG as well as control subjects, R-based discrimination [$A'(R)$] was consistently similar to overall discrimination [$A'(R+K)$]. As discussed previously [14], similar levels of $A'(R)$ and $A'(R+K)$ would be predicted by a model in which R and K responses reflect merely quantitatively different criteria on a unitary memory signal. In contrast, higher $A'(R)$ would be expected if 'remember' responses were based on a qualitatively richer memory source that is capable of discrimination superior than the memory source underlying 'know' responses.

Models of recognition memory based on signal-detection theory typically assume that the memory 'signal' is a measure of the total similarity between the test item and all items from the study episode (e.g., [19, 21, 30]; for review see [5]). In our original case report with BG [51], inspired by various two-process theories of memory retrieval [2, 6, 22, 23], we suggested that BG's false alarms might be attributable to over-reliance on the general similarity of the test item to the study episode, together with a deficit in retrieving specific information about individual items. As we noted [51], however, insofar as 'remember' responses indicate the retrieval of specific content from memory, BG's high R-based false alarm rate cannot be attributed to an undifferentiated match between the test item and the entire memory episode. The present results bear on this interpretation by showing that 'remember' responses are not always indicative of retrieving specific information about study items (Experiments 2 and 3). Therefore, an over-reliance on general similarity (i.e. BG's 'remember' and 'old' criteria are too liberal) and a deficit in retrieving specific information remains a viable interpretation. Given this interpretation, it is also notable that the laterality of BG's brain damage is consistent with evidence from split-brain patients, suggesting that the right hemisphere stores information that is more specific than the left hemisphere [35, 45].

Experiment 4 may represent a case in which BG was able to successfully recollect specific information from the study list, allowing him to counteract general similarity and suppress R-based false alarms. Experiment 4 was the only experiment in which BG's explanations seemed to include information from the study episode, insofar as references to his liking of test items can be interpreted as the recollection of his liking ratings. The difference between BG's vague explanations in Experiments 2 and 3 and his more specific recollections in Experiment 4 may shed some light on the absence of R-based false alarms in Experiment 4. Though BG never gave an R-based false alarm in Experiment 4, his hits were dominated by 'remembering'. Thus, BG may have avoided false alarming with the 'remember' response in Experiment 4 because the semantic encoding task was more conducive to specific recollection, and many studied items triggered relatively specific recollections of the encoding episode that allowed him to clearly differentiate between 'remembering' and 'knowing'.[†] In Experiments 2 and 3 (and probably in Experiment 1 as well), BG may have experienced few true recollections to serve as a standard for making a qualitative distinction between 'remembering' and 'knowing'. The signal-detection analyses also suggest that BG was more likely to have recollected specific information in Experiment 4 than in the other experiments. In the explanation condition of Experiment 4, BG showed the largest advantage for $A'(R)$ over $A'(R+K)$, so this condition seems inconsistent with the signal detection prediction that $A'(R)=A'(R+K)$. Taken together, the signal-detection analyses and the content of BG's explanations both converge on the conclusion that BG was more likely to have experienced detailed recollection in Experiment 4 than in the other experiments. The observation that BG's recollection of specific information increased with the semantic encoding task leads us to believe that BG may have a general deficit in spontaneously employing encoding/retrieval strategies that are useful for recollecting specific information. This is broadly consistent with a recent set of findings linking

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† The reason for the difference in 'know' false alarms between the explanation and no explanation conditions remains unclear.

impaired free recall in dorsolateral frontal patients to impaired use of organizational strategies at encoding [18]. Further research will be needed to explore possible encoding deficits in BG.

Control subjects' recollection of specific information should also improve with an effective encoding task, but we found no evidence for this in the current experiments. Control subjects were neither more likely to give explanations that referred back to the study list in Experiment 4 compared to Experiments 2 and 3, nor showed more of a difference between $A'$(R) and $A'$(R + K) in Experiment 4 than the others. The latter result might be attributable to a ceiling effect on $A'$(R) and $A'$(R + K) for control subjects in Experiment 4, but this cannot account for the consistency of subjects' study list references across experiments. As discussed previously, control subjects did not make a large number of study list references in any experiment. Thus, it is possible that control subjects' performance was rarely influenced by the recollection of specific information in any experiment. BG may have capitalized on the retrieval of specific information in Experiment 4 in order to counteract misleading similarity information. Control subjects, on the other hand, may not have to resort to retrieving specific information when general similarity is sufficient. By this interpretation, BG's only deficit may be an overly liberal criterion for accepting general information that can be overcome in conditions that foster the retrieval of specific information. This interpretation is consistent with Hintzman and Curran's [22] suggestion that recollection of specific information may only be necessary when it contradicts general similarity (similar views are reviewed in [5]). In contrast, fuzzy-trace theory [2] holds that hit rates are normally dominated by the retrieval of specific information, though fuzzy-trace theory shares the perspective that general similarity is the major cause of false alarms.

Other indications suggest that the retrieval of specific information played a more prominent role in the present experiments. For Experiments 2–4, even though BG's explanations (as well as most control subjects' explanations) were not richly detailed, they consistently contained specific references to the test words (if not to the study episode). That is, BG said more than "It just seemed very familiar", so 'remember' responses seem to be driven by more than undifferentiated similarity. It is possible that subjects' explanations reflect ad hoc rationalizations that are poor indicators of the memorial content that truly guided 'remembering', but other possibilities exist.

If BG's false alarms were based on the retrieval of specific—but incorrect—information, his false alarms might be related to a source monitoring problem [28]. In the present context, recognition memory can be conceptualized as requiring the proper attribution of retrieved information to the study list (the correct source in a recognition test). According to Johnson et al. [28], proper source attribution depends not only on retrieving specific information from memory (as opposed to general similarity), but it most critically depends on retrieving

the right kind of information. Therefore, the qualitative characteristics of retrieved information determine memory judgments more than the mere amount of information that is retrieved. BG's high false alarm rate would thus not be characterized as setting a criterion that is too liberal (i.e. not requiring that a sufficient amount of information is retrieved from memory), but rather as not requiring that the correct kind of information is retrieved (e.g., perceptual or contextual details from the study episode). These considerations return us to the widely accepted idea that frontal lobe damage causes deficits in specifying the source [27, 52, 59] or context [49] of memories, or an inability to filter irrelevant or competing information [56, 58]. In the present experiments, we may be observing the extent to which such source, context or filtering mechanisms contribute to recognition memory.

The pattern of false recognition shown by BG can be contrasted with a recent study of false memory in amnesic patients [54]. Subjects studied word lists (e.g., BED, REST, AWAKE, TIRED, DREAM, WAKE, NIGHT, BLANKET, DOZE, SLUMBER, SNORE, PILLOW, PEACE, YAWN, DROWSY) comprised of associates to a critical, non-studied word (SLEEP). Normal subjects exhibit extremely high false alarm rates to the critical word in recognition tests, and the critical word is the most common intrusion error on free recall tests [8, 48]. Schacter et al. [54] found that amnesic subjects also false alarmed more to critical words than non-critical lures, but their critical false alarm rate (as well as their hit rate) was well below control subjects' rate. Furthermore, control subjects were better able to discriminate between studied words and critical lures than were amnesic subjects. Thus, amnesic patients appear to exhibit both degraded general similarity—causing fewer false alarms to critical lures—along with poor specific recollection that would allow studied words to be discriminated from critical lures. This pattern contrasts with BG, who appears to show an enhanced influence of general similarity.

Recent positron emission tomography (PET) studies are also relevant to the present experiments. Schacter et al. [53] compared true and false recognition in the previously described paradigm with semantically similar lures. Consistent with the results from amnesic patients [54], both true and false recognitions were associated with activity in the left parahippocampal gyrus. Furthermore, right frontal activation was found in conditions with semantically similar lures, but not in conditions with studied words. One interpretation of this pattern would be that right frontal processes are needed to counteract the misleading similarity signal that is elicited by similar lures. Right frontal processes could evaluate the verticality of the similarity signal, or could recollect specific information that can contradict the similarity information. Either of these possibilities is entirely consistent with BG, whose right frontal lesion appears to make him over-reliant on general similarity.

In another PET study, Schacter et al. [50] compared

two study conditions that were intended to induce different amounts of retrieval effort during a subsequent cued-recall test with word-stems. In the low recall condition, subjects performed a perceptual encoding task and study words were presented only once. In the high recall condition, subjects performed a semantic encoding task and study words were presented four times. Compared to a baseline condition with non-studied stems, significantly greater right frontal activity was observed in the low recall condition, but not the high recall condition, although there was a trend for right frontal activation in the high recall condition that fell short of statistical significance. If frontal lobe retrieval mechanisms are most important when impoverished encoding conditions necessitate effortful retrieval (also see [31, 41]), this would be consistent with BG's poor performance in the first three experiments, compared to his improved performance in Experiment 4.

Recollection of specific information and source monitoring would be expected to be effortful processes. For example, both recollection [22] and source monitoring [29] appear to have slower time-courses than recognition judgments based on simpler information (i.e. general similarity). It is likely that the extra effort involves setting up effective retrieval cues [40], extensive search processes [46], and evaluation of whether or not the retrieved information is qualitatively predictive for the recognition judgment [28]. These interpretations are entirely consistent with ideas put forth by Smith and Milner [60] (and others, e.g., [38]), who posited that the frontal lobes play a critical role in search and retrieval processes.

Though our discussion has pointed out a number of respects in which BG's recognition impairment is related to existing ideas about frontal lobe contributions to memory, it should be emphasized that BG's lesion is not typical. Most studies examining memory impairment following frontal damage have examined patients with relatively circumscribed dorsolateral frontal lesions [18]. BG's lesion differs from the typical frontal lesion discussed in the memory literature in two respects. First, BG's lesion primarily involves the posterior frontal cortex, not the dorsolateral prefrontal cortex. Second, BG's lesion extends subcortically, affecting white matter, the right caudate nucleus, the thalamus and (to a lesser extent) the left putamen. Either or both of these atypical lesion characteristics might be important in explaining his tendency to falsely recognize non-studied items. At the same time, we should note that BG's lesion is not typical of patients with similar false recognition deficits; other recently reported cases of false recognition [9, 42] involved ruptured anterior communicating artery aneurysms and, as such, these patients probably suffered some damage to basal forebrain structures in addition to frontal and striatal damage [12]. BG's case is, to our knowledge, unique, insofar as it shows that false recognition can arise in situations where the basal forebrain appears to be intact.

In summary, the present results, along with our initial

case report with BG [51], indicate that recognition memory can be severely impaired by damage to the right frontal lobes. BG exhibits an extremely high false alarm rate, overly liberal response criteria (for saying 'old' as well as for saying 'remember'), and a discrimination impairment. We have suggested that BG's recognition deficit may primarily reflect an over-responsivity to a memory signal based on the general similarity of test items to studied items. This over-responsivity may be a consequence of impaired right frontal mechanisms that normally would help to retrieve specific information that would supplement the non-discriminative similarity information, or mechanisms that would normally set decision criteria (quantitative or qualitative) for evaluating the similarity information. Alternatively, the right frontal damage may directly cause similarity to be non-discriminative through ineffective encoding or retrieval processes. Future research will be needed to better understand BG's memory impairment, the memory impairments shown by other patients with frontal lobe lesions, and the memory processes that are subserved by the frontal lobes.

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