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Long-Lasting Perceptual Priming and Semantic Learning in Amnesia: A Case Experiment

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An investigation of perceptual priming and semantic learning in the severely amnesic subject K.C. is reported. He was taught 64 three-word sentences and tested for his ability to produce the final word of each sentence. Despite a total lack of episodic memory, he exhibited (a) strong perceptual priming effects in word-fragment completion, which were retained essentially in full strength for 12 months, and (b) independent of perceptual priming, learning of new semantic facts, many of which were also retained for 12 months. K.C.'s semantic learning may be at least partly attributable to repeated study trials and minimal interference during learning. The findings suggest that perceptual priming and semantic learning are subserved by two memory systems different from episodic memory and that both systems (perceptual representation and semantic memory) are at least partially preserved in some amnesic subjects.

Organic amnesia caused by irreversible brain damage is a selective impairment of memory that occurs in the absence of any other intellectual and cognitive dysfunction (Mayes, 1988; Parkin, 1988; Rozin, 1976; Shimamura, 1989; Squire, 1987). General intelligence, language functions, perception, and thought remain largely intact in amnesia, as do memory functions that have to do with short-term memory, learning of procedural memory tasks (such as perceptual-motor skills and simple conditioning) and perceptual priming (the enhanced identification of words and other objects as a function of prior encounters with them). The impairment of memory in amnesia consists of severe difficulty in learning new factual information and the impossibility of remembering daily happenings (anterograde amnesia) and, to an extent that varies from case to case, grave deficits in remembering happenings from a period of time preceding the onset of amnesia (retrograde amnesia).

Contemporary psychological theories of amnesia represent attempts to make sense of the pattern of preserved and impaired memory functions in amnesia in terms of the operations of a variety of memory systems (e.g., Butters, Granholm, Salmon, Grant, & Wolfe, 1987; Cermak, 1984; Cohen, 1984; Kinsbourne & Wood, 1975; Parkin, 1988; Rozin, 1976; Shallice, 1988; Squire, 1987; Warrington & Weiskrantz, 1982; Weiskrantz, 1987, 1989; Wood, Ebert, & Kinsbourne, 1982). Although these theories differ from one another in more or less important ways, they are all in agreement that in anterograde amnesia procedural memory functions and priming are essentially preserved, whereas episodic memory functions are lost.

The grey area of uncertainty concerns semantic memory, especially with reference to the patients' postmorbid ability to acquire new semantic or factual information (Schacter, 1987a). Relevant empirical evidence seems to be inconsistent, and theoretical positions on the matter are contentious. Thus, on one side there are theories that posit the impairment of both episodic and semantic memory but the preservation of procedural memory and priming (e.g., Cohen, 1984; Cohen & Squire, 1980; Squire, 1987). According to these theories, amnesic subjects are no more capable of acquiring new semantic information than they are of remembering any personal happenings. On the other side, there are theoretical claims that amnesia is essentially an impairment of episodic memory with relative preservation of semantic (and procedural) memory (Kinsbourne & Wood, 1975; Parkin, 1982; Shallice, 1988; Wood et al., 1982). According to these theories, amnesic subjects are capable of new semantic learning even in the absence of any episodic recollections of such learning.

Empirical evidence exists to support both of these positions. On the one hand, it is a well known and widely accepted clinical fact that amnesic subjects are incapable of learning new factual information. In a comprehensive review and analysis of memory and memory disorders, Rozin (1976) aptly summarized this feature of amnesia as follows:

> A most striking deficit in the amnesic syndrome, even in mild cases, is an inability to learn new things, such as names of people. The dismal performance of amnesics on paired-associate paradigms, where the pairs are randomly rather than meaningfully associated (so that they would not have been in memory prior to presentation), strikingly indicates new-learning inability (Diamond and Rozin, unpublished data; Scoville and Milner, 1957; Sweet, Talland, and Ervin, 1959; [V.] Meyer and Yates, 1955). Most dense amnesic subjects score zero correct on the three trials of six arbitrarily paired associates on the Wechsler Memory Scale ([V.] Meyer & Yates, 1955).

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The amnesic subjects' grave difficulty in learning unrelated paired associates (e.g., Cutting, 1978) is regarded as a major distinguishing mark of amnesia, as is their inability to remember, in a delayed test, the contents of a short story (e.g., Squire & Shimamura, 1986). In addition, systematic experiments have been reported in which amnesic patients have failed to learn the meaning of words not known to them, despite many trials of practice (Gabrieli, Cohen, & Corkin, 1983, 1988).

On the other hand, a number of studies have been reported in which amnesic subjects were found to be capable of learning factual and semantic information. The tasks that have been used in the relevant studies have included critical target words embedded in meaningful sentences (Shimamura & Squire, 1988) or meaningful text (Kovner, Mattis, & Goldmeier, 1983; Mattis & Kovner, 1984), statements of facts about people, places, things, and the like (Schacter, Harbluk, & McLachlan, 1984; Shimamura & Squire, 1987), new computer-related vocabulary (Glisky & Schacter, 1988; Glisky, Schacter, & Tulving, 1986b) or simple computer commands that were components of simple programs (Glisky & Schacter, 1988; Glisky, Schacter, & Tulving, 1986a), and one-word semantic interpretations of ambiguous descriptions of generic happenings (McAndrews, Glisky, & Schacter, 1987). The learning observed in these studies was invariably slow and inefficient when compared with that of nonamnesic control subjects, but it did occur.

In addition to these studies of new semantic learning, there are also several reports of conceptually driven learning or priming (Jacoby, 1983b; Roediger & Blaxton, 1987b; Roediger, Weldon, & Challis, 1989), or *conceptual priming* (Tulving & Schacter, 1990), in amnesic subjects. The experimental paradigms used in studies of conceptual priming are similar to those used in studies of perceptual priming; that is, the subject examines individual target words and then produces them in response to cues. In conceptual priming tests, however, the cues specify some of the conceptual or semantic properties of the targets rather than the perceptual properties specified in perceptual priming.[1] The kinds of conceptual cues that have been used with amnesic subjects have included names of conceptual categories of which targets represent individual instances (Gardner, Boller, Moreines, & Butters, 1973; Hamann, 1990; e.g., *fruit*—BANANA); associated words (Shimamura & Squire, 1984, e.g., *table*—CHAIR); and the first word of a two-word idiom (Schacter, 1985, e.g., *sour*—GRAPES). Amnesics have also been shown to be capable of learning related paired associates (e.g., Cutting, 1978; Warrington & Weiskrantz, 1982; Winocur & Weiskrantz, 1976), a fact that has been interpreted in terms of priming of preexisting representations.

Although both perceptual and conceptual priming have been demonstrated in amnesic subjects, the situation is less clear with respect to priming that occurs in tests in which combined conceptual and perceptual cues are used. Graf and Schacter (1985; Schacter & Graf, 1989) tested amnesic subjects as well as normal controls in a study of implicit memory for new associations. Subjects would see a pair of unrelated words (such as *window*—REASON) at study and would then be presented with cues (*window*—REA—— [old semantic context] or *kitchen*—REA—— [new semantic context] under implicit-memory instructions (namely, to produce the first word that comes to mind as a completion of the word stem REA---). Thus, the cue provided both conceptual and perceptual information about the designated target word: The intralist context word that had accompanied, and been encoded in relation to, the target word at study was the conceptual component of the cue, and the three initial letters of the target word constituted the perceptual component. The conceptual cue in the control condition (*kitchen*—REA---) had appeared in the study list but had been paired with another target word. Graf and Schacter (1985) found that amnesic subjects' performance was higher in the old semantic context than in the new semantic context, and they concluded that amnesic subjects in their experiment had exhibited implicit memory for new associations. The idea was that, even though amnesic subjects cannot learn new associations explicitly, they can do so implicitly.

A subsequent reanalysis of Graf and Schacter's (1985) data, together with the results of a replication study (Schacter & Graf, 1986b), however, showed implicit memory for new associations only in mild amnesics and not in severe amnesics. This outcome suggested that the positive finding of new implicit associative learning that was observed in less severely impaired amnesics may have reflected a residual explicit memory capability. Severe amnesics, who presumably lack any explicit memory capability, did not show any context effect in Graf and Schacter's (1985) *window*—REASON paradigm, because their condition includes the inability to learn any new associative information.

These conclusions were reinforced by two studies reported by Shimamura and Squire (1989) that were patterned after Graf and Schacter's (1985) experiments. Shimamura and Squire (1989) taught their amnesic subjects sentences such as "A BELL was hanging over the baby's CRADLE" and later assessed the extent to which the subjects would respond with the word *cradle* to the word stem CRA— in the presence or absence of *bell* as the conceptual component of the combined cue. Shimamura and Squire (1989) found no difference between the two conditions and concluded that in their study "word completion priming for amnesic patients was not significantly facilitated by the presence of word cues that had been newly associated with target words" (p. 727). In discussing the variable results that had been reported regarding conceptual priming in amnesic subjects, Shimamura and Squire concluded that the observed differences can be attributed to the severity of amnesia—that is, to differences in the residual declarative or explicit memory in amnesic patients—as well as to different etiologies or the exact nature of cognitive impairments of the patients who had participated in various experiments. Shimamura and Squire (1989) extended the same explanation to semantic learning by amnesics, including their own findings in this respect (Shimamura & Squire,

[1] The term *conceptual priming* has been used by other researchers (e.g., Hirshman, Snodgrass, Mindes, & Feenan, 1990) to refer to situations in which conceptual processing of the target at study, in the absence of the perceptual presentation, produces priming in perceptual tests. This meaning is different from ours.

1988). Severely impaired amnesics, according to Shimamura and Squire's (1989) analysis, cannot learn new associations, implicitly or otherwise.

In this article, we report the results of an extensive investigation of an amnesic subject's ability to learn new semantic information. The single subject of the study, K.C., is as severely impaired an amnesic as any described in the literature. He cannot learn a list of unrelated paired associates, and in a delayed test under standard conditions, he cannot remember the contents of a short story. On the basis of our observations of K.C. over a number of years, it is safe to conclude that he has no functional episodic memory. For these reasons it would be difficult to attribute anything that he learns to residual explicit or episodic memory.

Our study showed that, over a longer period of training, and under special conditions, K.C. learned a great deal of purely semantic information. The study and its findings throw some light on the reasons for apparent discrepancies between different sets of empirical findings and point to a possible reconciliation between the otherwise incompatible theoretical positions regarding new semantic learning by amnesic subjects. Our results suggest that whether or not amnesic subjects can learn and retain new semantic information depends on the conditions under which such learning occurs.

In our study, we also examined K.C.'s perceptual priming ability. In a perceptual priming task, subjects are first exposed to a collection of target items, such as familiar words, and then subsequently tested for their ability to identify the target items from impoverished or reduced cues that provide information about physical or perceptual properties of the targets (Musen & Treisman, 1990; Schacter, 1990; Schacter, Cooper, & Delaney, 1990; Schacter & Graf, 1986a; Tulving & Schacter, 1990). Priming is said to be demonstrated if the probability of identification of studied items is greater than that of comparable items not encountered in the first phase of the experiment.

It is well known that perceptual priming is preserved in amnesia (Richardson-Klavehn & Bjork, 1988; Schacter & Graf, 1986b; Shimamura, 1986; Warrington & Weiskrantz, 1968), although it is less clear how long priming effects last in amnesic subjects. In some studies, the effects seem short-lived (Graf, Squire, & Mandler, 1984; Mayes, Pickering, & Fairbairn, 1987; Shimamura & Squire, 1984), but in other studies, perceptual learning or priming effects in amnesia appear to be long-lived (e.g., Crovitz, Harvey, & McClanahan, 1981; Moscovitch, Winocur, & McLachlan, 1986; Warrington & Weiskrantz, 1970, 1978). One of our reasons for including tests of perceptual priming in the study was to test the replicability of the reported findings, as well as to test the longevity of any perceptual priming effects that might be found. Another reason had to do with our interest in the relation between perceptual priming and new semantic learning: If both kinds of learning occur in a group of subjects or, in this case, a single subject, do they represent different expressions of one and the same set of processes or one and the same memory system? As no previous studies have been reported in which the relation between perceptual priming and semantic learning has been systematically examined in amnesic subjects, our results fill an existing gap.

The results of our investigation of perceptual priming and semantic learning, and the relation between them, provide useful insights into the relations among episodic memory, semantic memory, and the perceptual representation system (PRS) that has been postulated as subserving perceptual priming (Schacter, 1990; Tulving & Schacter, 1990). It is difficult to study the acquisition of new semantic memory information in normal subjects independently of episodic memory, because the outcomes of tests of such acquisition may be inextricably influenced by both the episodic and semantic memory systems. In the case of any densely amnesic subject who has no functional episodic memory, these problems do not arise. Thus, studying semantic learning in amnesic subjects can be thought of as a model of learning of factual knowledge in the absence of any contribution to this learning by the episodic memory system. The relation between such learning and perceptual priming can also be examined independently of the involvement of episodic memory.

In summary, the purpose of this article is threefold: (a) We describe the findings of an extended study of new semantic learning as well as perceptual priming, and the retention of the effects of these two forms of learning over 12 months, in an amnesic subject who possesses no functional episodic memory and is therefore incapable of explicit remembering; (b) we report some novel data concerning the relation between semantic learning and perceptual priming; and (c) we discuss the implications of our findings for the broader issues of amnesia and multiple forms of memory.

The Subject

The single subject of our study, K.C., has been previously described in a report that was focused on his retrograde amnesia (Tulving, Schacter, McLachlan, & Moscovitch, 1988). In that article, we described and analyzed his memory-based knowledge originally acquired at some time before the accident that caused his amnesia. His intellectual status has not changed greatly since that report, and much of what we said about him then is still valid. We summarize the essential features of K.C.'s cognitive functioning here and add a few new relevant details.

K.C. is a 39-year-old man who, at the time of this experiment, had been amnesic for 8 years following a closed-head injury in a traffic accident in 1980. Computerized X-ray tomographic and magnetic resonance (MR) methods as described by Damasio and Damasio (1989) were used to localize K.C.'s cerebral damage (Figure 1). The MR studies reveal a predominance of observable abnormal signal in the left hemisphere, particularly in the superior frontal-parietal, medial temporal, medial occipital-temporal-parietal, and occipital regions. These areas include cortical association, limbic, and white-matter structures. Abnormal signal in the right hemisphere is less severe, observable only in a small portion of the medial temporal region and in the superior aspects of the medial parietal region. The abnormality in the medial temporal region appears to be bilateral but asymmetric, being much more extensive on the left. In addition, there is indication of abnormality in the region of the left retrosplenial cortex.

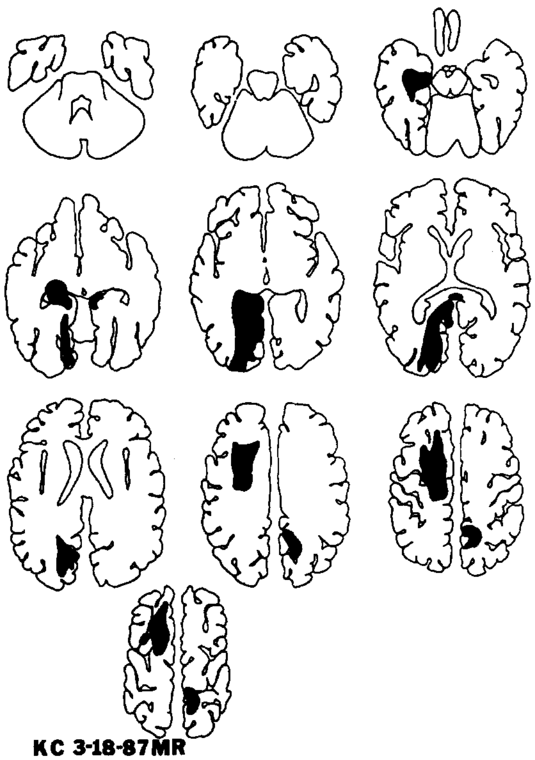

Figure 1. Templates showing areas of K.C.'s brain damage, based on the magnetic resonance (MR) studies. The left hemisphere is on the left, and the right hemisphere is on the right. (Templates were drawn by Paul J. Eslinger.)

Although K.C.'s other intellectual functions are largely intact, he does not remember a single event or happening from any period of his life (Tulving, 1989; Tulving et al., 1988). Such a total dysfunctioning of his episodic memory makes him a rather unusual subject; not many amnesic patients with such total anterograde and retrograde amnesia have been described in the literature. (For a report of a similar case, see Cermak & O'Connor, 1983). Whatever K.C. knows from the past, and whatever he learns and retains from new experiences, appears to be independent of any conscious recollection of the learning episode or awareness of the origin and source of the expressed knowledge.

K.C.'s neuropsychological testing revealed that his cognitive functioning, with the exception of memory, is reasonably intact. His IQ as determined by the Wechsler Adult Intelligence Scale—Revised is 94 (Verbal = 98; Performance = 91). Language comprehension as assessed by the Token Test is normal. He shows near-normal performance (achieving five categories out of six) on the Wisconsin Card Sorting Test, which is assumed to assess the functioning of the frontal lobes, but on the Benton Word Fluency (FAS) Test, another putative frontal-lobe test, his performance is poor, at the level of the 4th percentile. He copies the Rey figure perfectly, and his performance on the Hooper Visual Organization Test, which requires perceptual integration of parts of line-drawn objects, is normal. (See Lezak, 1983, for descriptions of all of these tests.) K.C.'s short-term memory is normal: He can recall 8 digits forwards and 5 backwards, and he gets 9 items correct on both the forward and backward visual memory span tests of the Wechsler Memory Scale—Revised (WMS—R; Wechsler, 1987). His thought processes are normal; there is no confusion or disorganization of any kind. Other aspects of his intellectual functioning have been summarized in Tulving et al. (1988).

In contrast to these largely normal manifestations of his intelligence, K.C.'s long-term memory performance is very poor. Most of his scores on the WMS—R are comparable to the mean scores of amnesic subjects used in experiments in other laboratories (e.g., Shimamura & Squire, 1988). His scores are as follows: Attention and Concentration, 99; Verbal Memory, 70; Visual Memory, 76; and General Memory, 67. However, K.C. scores much lower than typical amnesic subjects on (a) the Warrington Recognition Test (Warrington, 1984), on which his scores of 26/50 for both words and faces indicate chance performance, placing him below the published norms, and (b) the Delayed Recall test of the WMS—R, on which his score of less than 50 also places him below the published norms. In comparison, the average Warrington Recognition Test scores of 10 amnesic patients studied by Squire and Shimamura (1986) were 37/50 and 38/50, for words and faces, respectively.

K.C.'s overall demeanor and general behavior have not changed much over the last few years. As before, he is eager to cooperate in testing and seems to enjoy the challenge presented by the tests. The experiment reported here was carried out in parallel with a number of other studies, involving 4- to 5-h visits to the laboratory once or twice a week. Not once did he complain of fatigue or express disinterest in continuing with the proceedings. During this last series of tests, he also seemed a bit more relaxed in the testing situation than he had at the time of the study involving his retrograde amnesia (Tulving et al., 1988). He made occasional jokes and was more likely to ask questions and initiate action than he had been previously.

A good deal of the scientific value of the information obtained in the present study depends on the validity of K.C.'s verbal reports of his own mental states. Especially important in this respect is the validation of his negative claims, claims that he does not remember something, or that something does not look or feel familiar. Direct validation of such claims, of course, is not possible; there always remains a certain likelihood that his verbal statements do not faithfully reflect his mental state. Nevertheless, we can offer two observations in indirect support of our belief that his verbal statements concerning his mental states are as valid as those of people with normal memory capabilities, and especially, that his denial of remembering does directly reflect the state of his conscious awareness.

First, as far as we have been able to tell in several years of work, K.C. never confabulates. When he does not know an answer to a question, or does not feel confident about an answer, he says so. He uses two expressions quite frequently: "I do not know" and "I guess." Therefore, whenever he says, for instance, that X is not familiar, his statement represents a deliberate choice over a perfectly possible alternative, namely, that he guesses that X *is* familiar. To the extent that he does not use the latter expression, and instead says that he does not know, or does not remember, it is highly probable that he tells the truth as he perceives or conceives it.

Second, and more important, K.C. acts very much like a normal person in responding to queries and in making verbal statements about his memorial experiences in situations in which he in fact does remember happenings, namely, in situations in which he can rely on his intact short-term memory. Thus, he says that he remembers seeing a stimulus a few seconds after its removal from the field of view—be it an object, a picture, a sentence, or a word—and he readily asserts that it is familiar in the sense that he just saw it or heard it. This fact indicates that he is quite capable of and willing to describe verbally his mental states governed by recently experienced impressions. The negative responses in corresponding long-term memory situations, therefore, can be regarded as reflecting different (absent?) mental states, rather than inability or unwillingness to respond positively.

Overview of Study

In the first part of the experiment, K.C. was tested in a total of 22 sessions distributed over a time span of 21 weeks. The first 8 sessions were held once a week, Sessions 8 and 9 were held 2 weeks apart, Sessions 9 through 14 were again held once a week, Sessions 14 through 18 were held twice a week (3 or 4 days apart), Sessions 18 and 19 were separated by 2 weeks, Sessions 19 through 21 were 3 or 4 days apart, and the final session was held 2 weeks after Session 21.

The second part of the experiment consisted of a single session 12 months after Session 22. In that single session, K.C. was tested three times for the material that he had learned more than a year earlier.

The critical study materials consisted of 64 picture–sentence items. Each item was composed of a colored complex picture of a scene and a three-word stripped-down noun–verb–object sentence. For example, a picture of a lake with a boat carrying a person was accompanied by the sentence "VACATIONER attracted MOSQUITO." The object noun of the sentence (*Mosquito* in the example given) was the studied (or "old") target word. Learning and retention were assessed with respect to K.C.'s ability to produce the target word in response to different cues.

In the first six sessions, K.C. was both presented with material to study and tested for his knowledge of this material. He was also tested for knowledge of unstudied material. After Session 6, K.C. did not see any material for study. That is, in all the sessions beginning with Session 7, K.C. was tested, without any feedback, only for the material that he had studied in Sessions 1 through 6. In Sessions 7 through 22, K.C. was exposed only to the test cues and the correct and incorrect responses that he himself produced.

The fact that in every session we were assessing the combined and cumulative effects of the study and test events of all preceding sessions might be regarded as a weakness in the design, militating against the possibility of drawing valid conclusions from the study. However, because of very slow session-to-session changes in K.C.'s performance, and because of the overall stability of the data, we believe that this feature of the experiment, although undesirable, is probably not an important source of misinformation.

It is important to keep in mind that at no time were we able to assess what K.C. remembered, that is, consciously recollected, of the material presented to him, for the simple reason that he remembers an event only if it has occurred within the last few minutes. Consequently, our assessment was always of his implicit memory or knowledge of the material, as revealed through the production of appropriate responses to given cues.

We made no systematic attempt to compare K.C.'s performance with that of control subjects. For one thing, it would have been difficult to do with a group of normal control subjects everything that we did with K.C. For another thing, some comparisons of interest are possible, based on data reported by others, and other such comparisons involve K.C.'s own performance under different conditions. We did, however, have some data permitting direct comparisons from another study that we had done, and we collected some data from two control subjects in a single session, under conditions paralleling those used with K.C. These data allow some statements regarding the overall performance of K.C. in relation to nonamnesic control subjects.

Materials

The critical materials of the experiment consisted of 96 picture–sentence pairs. Additional pairs were used for practice and as buffers. The pictures were selected from the *National Geographic* magazine and made into 35-mm color slides. They included photographs of complex scenes, people, and animals. Three-word (subject–verb–object) sentences were constructed to accompany each picture. The sentences described an action that could be related to the corresponding picture but that would be unlikely to be generated in response to the picture alone. For example, the sentence "MEDICINE cured HICCUP" was paired with a picture of a man in a hospital setting whose forehead was dotted with electrodes.

The critical target words were the object nouns from the sentences. They were selected from a set of words used by Hayman and Tulving (1989b) and contained five to eight letters. We observed two selection criteria.

First, the target words had to be difficult to predict, on preexperimental grounds, from the picture, from the sentence frame (the subject noun and the verb of the sentence), or from the picture and sentence frame presented together. This meant that when pictures, parts of the sentence, or both, were used as cues in semantic learning tests, K.C.'s probability of correctly responding with new targets would be low.

Second, there had to exist two complementary unique-solution graphemic fragments for each target that could serve as cues in perceptual priming tests. A fragment was formed by removing three to five letters from the target word and replacing them with dashes in such a way that the fragment could be completed by only a single English word, the target word. In the complementary fragment, letters replaced the dashes, and dashes replaced the letters, of the original fragment. For example, for the target word *hiccup*, the original fragment was –I–C–P, and the complementary one was H–

C–U–. The original fragment of each target word was arbitrarily assigned to Set A; their complements were assigned to Set B.

Sixty-four of the 96 sentences constituted the studied materials. Their object nouns were the old targets in the priming tests. The remaining 32 sentences were unstudied materials; their object nouns were "new" targets. The studied materials, and hence the old targets, remained constant throughout all the sessions of the experiment, and so did the unstudied materials and the new targets.

Fragment Set A was used in the training segments of Sessions 1 through 6, in which K.C. was presented with the study materials, as well as in the tests in those sessions, which included both old and new targets. Because these Set A fragments were used repeatedly in early tests, we will henceforth refer to them as *old fragments*. K.C. was also tested for the target words (both old and new) with fragments of Set B. This happened for the first time in Session 16 and happened again in Session 20. Because of their late appearance in the experiment, we will henceforth refer to these Set B fragments as *new fragments*.

In addition to the 96 critical items, we used 26 picture–sentence pairs and their corresponding targets and fragments as buffer and practice items. Data from these items were not scored.

In summary, then, there were 64 old (studied) targets and 32 new (unstudied) targets. Each target could be cued with a conceptual cue, a fragment cue, or both. Conceptual cues of an old target could be the picture or part of the sentence that had accompanied the target at study or both; conceptual cues of new targets were predetermined as the corresponding parts of the compound item of which the new target was a part. Moreover, each target, old or new, could be cued with an old fragment cue from Set A, which K.C. encountered in the early sessions of the experiment, or with a new fragment cue from a statistically equivalent Set B, which K.C. encountered only late in the experiment.

Method and Results

As a combined result of some foresight and some improvization, our exploratory experiment had a complex design. Moreover, its large data base yields virtually unlimited possibilities for description and analysis of findings. To simplify the task of communicating the results of the study, we describe what we did and what we observed from session to session.

Session 1

Method. In the first session, K.C. was shown the total set of study materials and then immediately tested for fragment completion of old and new target words. During the presentation of the material for study, the picture–sentence pairs were shown side by side on two screens located approximately 36 in. (91.44 cm) in front of K.C. The pictures were shown on a 20 × 20 in. (50.8 × 50.8 cm) rear projection screen. The sentences were presented on the monitor screen of a computer that also controlled the slide projector. The three-word sentences were centered on the screen, with the subject and object nouns appearing in uppercase letters and the verb appearing in lowercase letters. When a picture–sentence item was presented, K.C. was asked to "Say how well the sentence fits the picture" and was given two possible ratings: "it fits" and "does not fit." The experimenter entered K.C.'s responses—a large majority of which were "does not fit"—into the computer. Only a few reminders of these encoding decisions were necessary at the beginning of each series. After the first few, K.C. made the judgments without prompting.

The study list consisted of 84 picture–sentence items: 4 practice items, 16 buffer items, and 64 critical study items. The pictures were arranged in two slide trays with 60 pictures in one tray and 56 in the other. The first four items in the first tray were practice items, and items in Positions 5–8 and 57–60 in the first tray and 1–4 and 53–56 in the second tray served as buffers. Presentation of the remaining 48 items in each tray was controlled by the computer in such a way that, during the study presentation, K.C. saw 64 picture–sentence pairs.

The word-fragment completion test comprised six retrieval conditions: four involving old targets and two involving new targets. In each condition, the fragment of a target word was presented in a different conceptual context. The four old target conditions represented a 2 × 2 design, defined in terms of (a) presence or absence of the picture as a cue (in addition to the fragment) and (b) presence or absence of the subject noun of the sentence as a cue (in addition to the fragment). The various combinations of contextual cues and fragments constituted four types of cues: (a) picture, subject noun (or word), and fragment (abbreviated PWF); (b) subject noun and fragment (WF); (c) picture and fragment (PF); and (d) fragment alone (F). Each cue type was directed at 16 old targets. In one new target condition, 16 fragments of nonstudied words were presented together with a picture and the subject noun of the corresponding (nonstudied) sentence; in the other, 16 fragments of nonstudied words were presented alone. The four cue types occurred in the test sequence in a semirandom order.

The test list comprised 107 items—64 old (16 in each cue-type condition), 32 new (16 in a PWF condition and 16 in an F condition), 4 practice, and 7 buffer items. The pictures were arranged in three slide trays with 39 pictures in the first and 34 pictures in each of the second and third trays. The first 4 pictures in the first tray were practice items, and the next 3 were buffer items. The first 2 items in the second and third trays were also buffer items. The test order was constrained so that at least 24 items intervened between initial study of an item and its later test for fragment completion.

At the beginning of the test phase, K.C. was told that he would be seeing word fragments, or words with some of the letters missing. His task was to complete the fragment with a word and to say the word out loud. He was also told that a picture, a word, or both might accompany the fragment and help him to solve the fragment. He had no difficulty following these instructions.

For each test item, the experimenter pressed a button when K.C. gave a correct response; the button press effected the recording of the response latency by the computer. If K.C. had not given a response after 20 s, the fragment was removed, and the next fragment was presented. Responses for buffer items were not scored. The experimenter recorded incorrect responses on a sheet of paper.

Control subjects. Data for 6 control subjects were available for comparison with K.C.'s data from Session 1. Control Subjects 1 through 4 were University of Toronto students who had participated in an experiment that was identical with Session 1 of the experiment reported here in all important respects. Identical materials were presented, and subjects were tested immediately for fragment completion, under implicit-memory instructions. (Other subjects in that experiment were administered other sets of materials, within the general scheme of counterbalancing items among experimental conditions.) In addition, a study-and-test session identical to that given to K.C. was administered to two other control subjects, both women in their early 30s whose vocabulary test scores were similar to K.C.'s.

Results. The proportions of old and new target words produced in each of the six conditions (four old targets, two new) of Session 1 are listed in Table 1. Also listed are estimates

Table 1
Performance of K.C. and Control Subjects in Session 1: Proportion of Old and New Targets Completed and Adjusted Priming Scores

Subject	Old targets					New targets			Adjusted priming scores
	PWF	PF	WF	F	*M*	PWF	F	*M*	
C1	.88	.75	.38	.31	.58	.38	.12	.25	.44
C2	.69	.62	.62	.31	.56	.44	.06	.25	.41
C3	.50	.62	.50	.31	.48	.31	.25	.28	.28
C4	.69	.62	.62	.62	.64	.44	.44	.44	.36
C5	.56	.44	.25	.19	.36	.12	.00	.06	.32
C6	1.00	.88	.50	.50	.72	.38	.19	.28	.61
Mean	.72	.66	.48	.38	.56	.34	.18	.26	.40
KC	.44	.25	.63	.56	.47	.31	.13	.22	.32

Note. Adjusted priming score = (mean old targets − mean new targets)/(1.00 − mean new targets). P = picture; W = word (subject noun of the sentence); F = fragment of the target word.

of the relative amount of priming, that is, production of old targets adjusted for the production of new targets, as discussed and recommended by Snodgrass (1989). K.C.'s adjusted overall priming effect (.32) falls within the range of comparable scores of the six control subjects (.28 to .61).

The data in Table 1 show that all six control subjects did very well in completing the fragments of old targets in the two conditions involving the presentation of the picture as a part of the cue (PWF and PF), with a mean completion rate of .69, whereas K.C.'s performance in those two conditions was notably poorer (mean of .34). A plausible interpretation of this difference is that the control subjects were explicitly reminded of the studied material by the picture cues and thus benefited from their intact episodic memory, whereas K.C. did not. In contrast, in the two old target conditions in which no picture was presented (WF and F) K.C.'s mean score (.59) fell into the upper range of the control subjects' mean score (.43).

K.C.'s performance with new targets was comparable to that of the control subjects. Moreover, both K.C. and the controls produced a higher proportion of new targets in the presence of conceptual cues consisting of the picture and the subject noun of the sentence than they did with the fragment alone: Conceptual cues do facilitate unprimed fragment completion, just as they facilitate performance on other unprimed perceptual identification tasks (e.g., Tulving & Gold, 1963; Tulving, Mandler, & Baumal, 1964).

Three conclusions are suggested by the data of Session 1: (a) K.C.'s perceptual priming is indistinguishable from that of control subjects; (b) when completing fragments of unprimed target words, both K.C. and the control subjects benefited from the presence of relevant conceptual cues; and (c) in contrast to priming observed with the controls, K.C.'s perceptual priming did not benefit from the presence of additional conceptual cues at the time of both study and test.

Sessions 2 Through 4

For K.C., Sessions 2 through 4, given at weekly intervals, were identical in every respect to Session 1. Control subjects were not given repeated study and test sessions. The purpose of Sessions 2 through 4 was twofold: We wanted to examine the replicability and stability of K.C.'s performance in Session 1, and we wanted to see to what extent, if any, his performance would improve as a function of repeated presentations and tests.

The first four lines in Table 2 summarize the results of Sessions 1 through 4. The data show that K.C.'s performance did gradually improve over the sessions, with the overall priming effect increasing from .32 in Session 1 to .54 in Session 4. Most of this improvement occurred in the two conditions that included pictures as cues (PWF and PF), in which the old-target completion rate increased from .34 in Session 1 to .59 in Session 4. Nevertheless, there was no change regarding the conceptual context effect in fragment completion: There was no more evidence for it in Session 4 than there had been in Session 1.

Sessions 5 and 6

Sessions 5 and 6 were devoted to gathering additional and converging evidence on one of the major findings of Sessions 1 through 4, namely, that K.C.'s performance exhibited some evidence of perceptual priming but no evidence of conceptual context effects in such priming. In Sessions 5 and 6, the same study materials were presented exactly as they had been in Sessions 1 through 4, but all target words were tested with word fragments only as cues. We reasoned that if the conceptual context in Conditions PWF and WF did not facilitate K.C.'s fragment completion, then the removal of these cues would not affect performance.

One of four old-target conditions in Sessions 1 through 4, Condition F, had involved testing with word fragments only, but the subsets of 16 targets were perfectly confounded with cuing condition. The absence of conceptual context effects might have been a consequence of this confounding: For whatever reason, the subset of 16 items and target words in the fragment-only condition might have been easier for K.C. to complete than the other three subsets, thus counteracting any potential context effects. Therefore, in Session 5, targets in all conditions were tested with word fragments only. Session 6, conducted a week later, was identical to Session 5.

Table 2
K.C.'s Performance in Sessions 1–7: Proportion of Old and New Targets Completed and Adjusted Priming Scores

	Old targets					New targets			Adjusted priming score
Session	PWF	PF	WF	F	*M*	PWF	F	*M*	
1	.44	.25	.62	.56	.47	.31	.12	.22	.32
2	.44	.38	.69	.56	.52	.31	.12	.22	.38
3	.44	.56	.69	.50	.55	.44	.06	.25	.40
4	.75	.44	.75	.62	.64	.38	.06	.22	.54
5	.69	.56	.81	.62	.67	.38	.06	.22	.58
6	.69	.50	.62	.62	.61	.25	.06	.16	.54
7	.62	.56	.75	.56	.62	.25	.06	.16	.55

Note. Adjusted priming score = (mean old targets − mean new targets)/(1.00 − mean new targets). P = picture; W = word (subject noun of the sentence); F = fragment of the target word.

The procedure for presentation of the study material in Sessions 5 and 6 was identical to that used in Sessions 1 through 4 except that during testing, only word fragments were presented as cues for the 64 old and the 32 new targets. K.C. was informed, orally and through the ever-present instruction card, that he would be seeing word fragments and that his task was to complete the fragment with a word and to say the word out loud.

The results of Sessions 5 and 6 are summarized in lines 5 and 6 of Table 2. The data are largely indistinguishable from those of Session 4, and they suggest that the conceptual context did not facilitate K.C.'s fragment completion in Sessions 1 through 4, as removal of that context had no deleterious effects on K.C.'s performance.

The removal of the conceptual context (the picture and the subject noun of the sentence) for new targets in Sessions 5 and 6 did not diminish production of those words in response to fragment cues alone. In Sessions 5 and 6, K.C. still completed a larger proportion of the new targets that had originally been tested in the presence of pictures and subject nouns than of the new targets originally tested with fragments only. Thus, it looks as if, during testing, the conceptual context for the new targets may have originally served a positive modulating role in enhancing access to the word information in the PRS, but once such access was achieved, the subsequent benefit accrued to the effectiveness of the fragment cue alone as well, or perhaps solely so.

The data of Sessions 5 and 6 suggest that there were no conceptual context effects for K.C. in primed fragment completion: Fragment cues were as effective by themselves as they were in combination with conceptual context cues.

Session 7

The result of Sessions 1 through 6 showed that K.C. exhibited perceptual priming effects when tested with word-fragment cues and that the addition of conceptual cues did not augment his performance. In these early sessions, testing commenced immediately after the presentation of the 84 study-list items. The duration of the study phase was approximately 6 min and the testing phase lasted approximately 12 min, so that a typical item was tested only some 9 min after its presentation for study. Squire, Shimamura, and Graf (1987) reported previously that priming exhibited by amnesic subjects in a word-fragment completion test lasts no longer than 2 hr. The purpose of Session 7 was to assess the extent to which, if any, K.C. could retain what he had learned in the course of repeated study and testing in the first six sessions over a retention interval of 1 week.

In Session 7, a week after Session 6, there was no study trial. All 96 target words (64 old and 32 new) were tested only with fragment cues, with no conceptual context present. Thus, the procedure was the same as in Sessions 5 and 6, with the sole difference that in both of those sessions the test immediately followed the presentation series (average delay for an individual item was about 10 min), whereas the test in Session 7 was given 7 days after K.C. had last seen the materials.

The results of Session 7 are summarized on Line 7 in Table 2. The overall priming effect was .55, essentially identical with the overall priming effect a week earlier in Session 6 (.54). The conclusion to be drawn from these data is clear: there was no forgetting over the interval of 7 days.

Sessions 7 and 8

In addition to the fragment-completion test just described, in Session 7 we also gave K.C. a recognition test for the pictures and sentences that he had encountered in Sessions 1 through 6. The picture recognition test was given first. It commenced 5 min after the fragment-completion test just described. K.C. was shown all 107 pictures: 91 that he had seen in Sessions 1 through 6 (4 practice, 7 buffer, and 80 target items) and 16 that he had not previously seen. An individual picture was projected on the back-projector screen exactly as it had been shown in Sessions 1 through 4, and K.C. was asked whether he thought he had ever seen that particular picture before or whether the picture looked familiar to him. Of the 96 target pictures, 32 had been seen by K.C. during both study and testing in Sessions 1 through 4 and during study in Sessions 5 and 6; 32 had been seen only during study in Sessions 1 through 6; 16 had been paired with new-target fragments and subject nouns in the test phases of Sessions 1 through 4; and 16 had never been seen. The pictures were ordered in two slide trays. There was a delay of 5 min at the end of the first test tray. During the interval, K.C. participated in an unrelated experiment.

The results of the picture recognition test were straightforward: K.C. responded negatively to every single one of the 107 pictures. He thought he had never seen a single picture before; they all looked unfamiliar to him.[2]

Following a delay of about 30 min, K.C. was tested for recognition of sentences. He was shown all 116 sentences that he had encountered in Sessions 1 through 6 (4 practice, 20 buffer, and 96 target sentences) and was asked to say whether he thought he had ever read that particular sentence before or whether the sentence looked familiar to him. Of the 96 target sentences, 64 had been viewed during study in Sessions 1 through 6, and 32 had never been seen.

The results of the sentence familiarity test were identical with the picture familiarity test: K.C. responded negatively to all 116 sentences. He thought he had never read any of the sentences before; they all looked unfamiliar to him.

Session 8 constituted an attempt to assess K.C.'s implicit knowledge of the association between the pictures and sentences he had encountered in Sessions 1 through 6. Although Session 7 had revealed that neither the pictures nor the sentences as such produced any sense of familiarity for K.C., it was conceivable that he had learned something implicitly about the association between the (unfamiliar) pictures and the (unfamiliar) sentences. Thus, we thought that if he was asked to give a nonliteral description of a picture, he might, at least in some proportion of cases, produce a word or phrase from the sentence associated with the picture. Implicit learning of this sort in an amnesic subject named E.R. was reported by Schacter and Tulving (1982).

K.C. was shown the 116 pictures that he had encountered in Sessions 1 through 6 (4 practice, 20 buffer, and 96 target). He was asked to give a creative or imaginative description of each picture, rather than simply describing what was present in the picture. He was told that the description could be a single word, a couple of words, a simple sentence, and so forth. At the beginning of the test, K.C. was shown the four practice pictures used in Sessions 1 through 6 together with the sentences with which they had been paired in the presentation phase. He was told that these picture–sentence combinations served as examples of the kind of description we had in mind. The four examples were given again halfway through the test to remind K.C. of the task. Throughout the test, the experimenter periodically repeated the instructions. When K.C. gave a veridical description of a picture, he was reminded that the experimenter wanted him to give a creative or imaginative description rather than simply stating what could be seen in the picture.

The results were again unequivocal: K.C. did not respond appropriately to even one picture. Even with the most lenient scoring criterion imaginable (such as considering a single word or its synonym from the associated sentence as a positive response), K.C.'s performance was zero. Thus, there was no evidence whatsoever of implicit learning of associations between pictures and sentences.

In summary, we can conclude (a) that K.C. failed to show any conscious recollection for, or any familiarity with, the materials that he had encountered repeatedly during the first 6 weeks of the experiment and (b) that there was no evidence of implicit associations between the study-list pictures and the sentences that had accompanied them during the same initial 6-week period.

Sessions 9 Through 14

In the next phase of the experiment we explored the issue of implicit conceptual learning in a somewhat different manner. We initially wanted to know whether K.C. could produce the target words in a situation in which he was given both the relevant picture and the first two words of the sentence (sentence frame; Se) as cues. This situation can be regarded as a test of implicit conceptual learning and retention, inasmuch as the test did not provide any fragment cues of the target words to the subject. This test was given in Session 9.

Because K.C. did well in this semantic learning test, we next wondered to what extent his performance would change when only the sentence frames were presented as cues for targets. After Session 9, it was possible to think that K.C.'s performance in that session was governed by associations between (a) only the picture and the target, (b) only the sentence frame and the target, or (c) between both the picture and the target. Correspondingly, in Session 10 we tested him with sentence frames only.

K.C.'s performance in Session 10 was somewhat lower than in Session 9, indicating that his responding was sensitive to variations in the number and the nature of the retrieval cues. To further assess the sensitivity of the performance to the number and nature of the cues, in Session 11 we tested K.C. with both conceptual and perceptual cues. The cues consisted of pictures, sentence frames, and graphemic fragments of the target words (PSeF condition). This combination of cues is formally rather similar to the type of cue used by Graf and Schacter to demonstrate implicit memory for new associations (Graf & Schacter, 1985; Schacter & Graf, 1989), consisting of both a conceptually related context (e.g., *window*) and a perceptual component of the target word (e.g., REA- - -). In Sessions 12, 13, and 14 we replicated the procedure of Sessions 9, 10, and 11 exactly to assess the stability of K.C.'s performance under variable cue conditions. We next present the procedure used in Sessions 9 through 14 in detail, together with a summary of the results.

In Session 9, K.C. was tested for the production of the target words (object nouns of the sentences) from all of the previously encountered items. The retrieval cues for a given target consisted of the corresponding picture and the sentence frame. The sentence frame consisted of the subject noun and the verb of the sentence; the object noun was replaced with three question marks. K.C. was first tested for the production of 116 words: 4 practice words, 16 buffers, and 96 targets (64 old and 32 new). He was instructed to look at the picture and to use it as an aid for completing the action described in the sentence. He was given a maximum of 20 s to respond to

[2] On the basis of some other observations we have made in working with K.C., we doubt that his performance would have been much different if we had tested him in a forced-choice test of recognition.

each combined cue. When he responded sooner, the next cue was immediately presented.

In Session 10, K.C. was tested for the production of the target words in the presence of the sentence frames (subject and verb). He was presented with 116 sentence frames (4 practice, 16 buffer, 64 old, and 32 new) and was told that he would be seeing simple three-word sentences in which the last word was missing and had been replaced with question marks. He was asked to look at the two words of each sentence that were given and to supply the missing word. He was told that there were no right or wrong answers. He was given a maximum of 20 s for each picture–sentence-frame pair.

In Session 11, K.C. was tested for the production of the target words from the study sentences in the presence of pictures, corresponding sentence frames, and fragments of the target words. He was shown 116 such combined cues and was asked to look at the picture and to use it as a background for completing the action described in the sentence. He was told that the fragment might help him to think of an appropriate word. He was given a maximum of 20 s for each response. If he produced an incorrect solution for a particular fragment, he was asked if he could think of another word. He was periodically reminded to look at the picture during the course of testing. Session 12 constituted a replication of Session 9: K.C. was tested with pictures and sentence frames. Session 13 constituted a replication of Session 10: K.C. was tested with only the sentence frames. Session 14 was a replication of Session 11: K.C. was tested with combined cues consisting of pictures, sentence frames, and graphemic fragments of target words.

The results of Sessions 9 through 14 are summarized in Table 3. For easier comparisons, the sessions are grouped by the nature of the test, rather than chronologically as in previous summaries. Three findings should be noted. First, K.C. exhibited implicit conceptual learning: The production of old targets was higher than that of new targets in the presence of pictures and sentence frames, as well as in the presence of only the sentence frames. Second, pictures and sentence frames together do not seem to be much more effective cues than sentence frames alone. Third, the combined conceptual and perceptual cues—fragments of targets together with pictures and sentence frames—led to the highest level of production of target words, both old and new.

The third finding, which portrays the facilitative effect of conceptual context on fragment completion, seems unexpected in comparison with the absence of any such effect in Sessions 1 through 4. In those sessions, K.C.'s performance was no higher when cued with the picture, the subject noun of the sentence, and the fragment of the target word (Condition PWF in Table 2) than it was when cued with the fragment alone (Condition F in Table 2). Why this apparent discrepancy?

The most plausible explanation is that the association between the subject noun and the target word in Condition PWF in Sessions 1 through 4 lacked the kind of meaningfulness that characterized the association between the complete sentence frame (the subject noun and the verb) and the target word in Condition PSeF in Sessions 11 and 14. The former condition resembles the test of implicit memory for new associations that severe amnesics have failed in other experiments (Schacter & Graf, 1986b; Shimamura & Squire, 1989). We discuss the role of meaningfulness in semantic learning by amnesics later in the article.

Sessions 15 Through 22

The final phase of the experiment consisted of a number of different tests. Some of these introduced new cues and new combinations of cues, and some served as checks on the stability and reliability of earlier findings. Measures of reliability are presented later in the article. We describe the procedure and primary results of Sessions 15 through 22 here.

Session 15 was an exact replication of Session 7. K.C. was shown 107 graphemic fragments of target words (64 old, 32 new, and 11 buffers) and was asked to complete each fragment with any word that fit the fragment.

In Session 16, K.C. was again tested only with fragments, but this time with alternate fragments, that is, complements of the original fragments. K.C. had not encountered these fragments at any time before. The purpose of this test was to assess the extent to which his, by now well-established, perceptual priming transferred to previously unencountered frag-

Table 3
K.C.'s Performance in Sessions 9 Through 14: Proportion of Old and New Targets Produced and Adjusted Scores

		Old targets					New targets			
		Original encoding condition					Original encoding condition			
Session	Cues	PWF	PF	WF	F	*M*	PWF	F	*M*	Adjusted score
10	Se	.50	.50	.44	.38	.45	.00	.06	.03	.43
13	Se	.44	.56	.44	.50	.48	.00	.06	.03	.46
9	PSe	.56	.50	.38	.50	.48	.00	.00	.00	.48
12	PSe	.56	.69	.38	.56	.55	.00	.00	.00	.55
11	PSeF	.88	.75	.81	1.00	.86	.50	.25	.38	.77
14	PSeF	.94	.81	.88	1.00	.91	.63	.31	.47	.83

Note. Adjusted score = (mean old targets − mean new targets)/(1.00 − mean new targets). P = picture; W = word (subject noun of the sentence); F = fragment; Se = sentence frame.

ments. He was shown 107 alternate fragments of target words and was asked to complete each fragment with any word that fit.

In Session 17, the alternate fragments that K.C. had seen in Session 16 were combined with their corresponding pictures and sentence frames. Thus, the test cues were similar to those used in Sessions 11 and 14, except that alternate fragments replaced the original fragments. The purpose was to assess the effectiveness of the mixed cues: previously frequently encountered conceptual cues and the novel perceptual cues. A total of 116 cue complexes were presented to K.C. in the same order in which they had appeared during the study sessions, and he was instructed to complete the fragment, paying attention also to the picture and sentence. He was told that the picture and the sentence frame might help him think of a word to complete the fragment.

In Session 18, two similar tests were given. In each, the cues consisted of the original fragment, the picture, and one word from the sentence frame, either the subject noun or the verb of the sentence. K.C. was told that the picture and the word might help him to solve the fragment. In the first test, the combined cues for half of the 96 target words included the noun and for the other half, the verb. In the second test, the noun and verb components of the cues were reversed for the two sets of targets.

Session 19 constituted a replication of Sessions 7 and 15: K.C. was tested with original fragment cues. Session 20 replicated Session 16: K.C. was tested with alternate fragment cues. Session 21 replicated Session 17: K.C. was tested with combined cues consisting of pictures, sentences, and alternate fragments.

Session 22 was a replication of Sessions 10 and 13, in which cues consisted of sentence frames, except that sentence frames were read aloud to K.C. by the experimenter, and K.C. was asked to respond to each sentence frame with a word that came to mind. The purpose of this test was to examine cross-modality transfer of conceptual learning. Perceptual priming is usually reduced if retrieval cues at test are presented in a modality that differs from the presentation modality at study, for instance, when study is auditory but test cues are visual (Graf, Shimamura, & Squire, 1985; Jacoby & Dallas, 1981; Roediger & Blaxton, 1987a) or when pictures are studied but test cues are verbal (Roediger & Weldon, 1987; Weldon, Roediger, & Challis, 1989). Semantic learning, on the other hand, should not be affected by the change in the sensory modality in which relevant information is presented.

The results of Sessions 15 through 22 are summarized in Table 4. As in Table 3, sessions are grouped by the nature of the test, rather than chronologically. Also, we do not present the data separately for the six subsets of targets but rather pool them for the four old and the two new subsets because the overall picture with respect to subsets remained largely the same in these sessions as it had been in the earlier sessions. That is, the rate of correct responding was approximately the same in the four old target subsets, whereas the original PWF subset of new targets retained its superiority over the F subset throughout the study.

Six findings worthy of note are summarized in Table 4. First, in general, K.C.'s performance was stable: When the same test cues were repeated, the production of old and new targets, and the priming effect, was largely unchanged, although there was a mild increase in performance across successive tests.

Table 4
K.C.'s Performance in Sessions 15 Through 22: Proportion of Old and New Targets Produced and Adjusted Scores

Session	Cues	Old targets	New targets	Adjusted score
15	OF	.67	.28	.54
16	NF	.42	.34	.12
17	PSeNF	.84	.56	.64
18a	PVOF	.75	.28	.65
18b	PWOF	.69	.34	.53
19	OF	.70	.28	.58
20	NF	.40	.31	.13
21	PSeNF	.88	.56	.73
22	Auditory Se	.59	.09	.55

Note. Adjusted score = (old targets − new targets)/(1.00 − new targets). OF = old fragment; NF = new fragment; P = picture; Se = sentence frame; V = verb of the sentence; W = subject noun of the sentence.

Second, K.C.'s performance in tests in which old fragments served as cues remained high throughout the experiment. In Session 19, the priming effect (.58) was identical with that in the immediate test in Session 5.

Third, relatively little priming was observed with alternate fragments. The priming effect was .12 and .13 in Sessions 16 and 20, respectively. We note this low level of priming, but because the design of the experiment does not allow any meaningful analysis of this result, we do not mention it in any subsequent discussion.

Fourth, despite the relative ineffectiveness of the alternate fragments when presented alone, they were quite effective when presented together with pictures and sentence frames. The priming effects, .64 and .73 in Sessions 17 and 21, were only slightly lower than the priming effects observed in Sessions 11 and 14 (.77 and .83) in which pictures, sentence frames, and old fragments served as cues. (Note that pictures and sentence frames alone, as in Sessions 9 and 12, produced priming effects of .48 and .55).

Fifth, K.C.'s performance in Session 18, in which cues consisted of the picture, one of the two words in the sentence frame, and the old fragment (mean of .59), was indistinguishable from that observed in Session 4 under the comparable PWF condition (.60). There was little difference in the cuing power of the verb versus the subject noun of the sentence, when these were presented with the other cues. However, the priming effects were less with the picture, one word from the sentence frame, and the fragment than they were with picture, both words of the sentence frame, and the fragment, as mentioned in our third point: .62 and .55 versus .79 and .83.

Finally, the test with auditory sentence frames in Session 22, 2 weeks after Session 21, showed the same level of priming effect (.55) that had been observed in Sessions 9 and 12, in which the sentence frames were presented visually (.48 and .55, respectively). Because there was no reduction in performance when test cues were presented in a new modality, the conclusion may be drawn that K.C. had acquired and retained new semantic knowledge in this experiment. Without the data from Session 22, it would have been possible to imagine that K.C. had, in the course of the many study and test sessions, perceptually integrated or unitized the complex items (pictures and corresponding sentences), analogous to the perceptual integration of individual letters into a visual word. If so, the purely perceptual features of what we have referred to as *conceptual cues* could have been responsible for the observed priming effects: The target word could have been just the missing piece of a perceptual display. The results of Session 22 rule out this hypothesis: There was no evidence of any reduction in performance from visual to auditory sentence frames. It seems reasonable to conclude, therefore, that the new semantic learning observed in Sessions 9, 10, 13, and 14 is indeed conceptual, rather than perceptual priming in disguise.

Assessment of 12-Month Retention

Twelve months after Session 22, we tested K.C. for the retention of the perceptual priming and semantic learning of the 96 target words. For the purpose of this assessment of long-term retention, the 64 old and the 32 new targets were divided into two lists, A and B, each consisting of 32 old and 16 new targets. The lists served as the to-be-produced responses in three sets of identical tests, all given on the same day. The first and second tests were separated by 3 hr and the second and third tests by 2 hr. Each set consisted of four tests, always given in the same order: (a) fragment completion of List A, (b) sentence completion of List B, (c) sentence completion of List B, and (d) fragment completion of List A. The instructions were the same as in the first part of the study. K.C. had no difficulty comprehending or following them. The cues, either sentence frames or fragments of targets, were presented on the computer screen. K.C. had up to 15 s to make a response.

The results of the 12-month assessment are summarized in Table 5. These results show that K.C.'s performance increased from the first test to the second and remained stable in the third. In the third test, his fragment-completion performance was indistinguishable from what it had been in Session 19, the last session in which he had been tested with old fragments alone. His sentence-completion performance in the third test was approximately 80% of what it had been in Session 13, the last session in which he had been tested with visually presented sentence frames, and approximately 65% of what it had been in Session 22, in which he had been tested with auditory sentence frames. All in all, these data point to a remarkably high level of retention of the information acquired a year earlier.

Internal item-by-item analyses of these data indicated that the increase in K.C.'s performance from the first test to the third test was probably attributable to warm-up and that the data represent true retention of what he had learned a year earlier rather than relearning of the material in the course of the first test. For instance, most of the fragments that he did not complete on the first test but did complete on the second or the third belonged to target words that he did not produce on the sentence-completion tests. Similarly, the target words that he did not produce in response to sentence-frame cues on the first test but did produce on the second or third were independent of their production on the fragment-completion tests.

These item-by-item contingency analyses are discussed more completely in the next section, not only for the data from the 12-month assessment, but also for the sessions of the early part of the experiment.

Item-by-Item Contingency Analyses Across Sections

The design of our experiment allowed us to examine the consistency of K.C.'s performance with respect to individual target words across sessions. The basic question was this: Given that K.C. did (or did not) produce a certain target word in a given session, how likely was he to produce (or not produce) it again in some other session, in response to either the same or different cues?

To obtain quantitative answers to this question, we subjected the data from different pairs of sessions to an item-by-item contingency analysis. In the contingency analysis, all target words were cross-classified as produced or not produced in each of the two sessions. The relation between the performance in the two sessions—association, dependency, reliability, stability, or degree of session-to-session fluctuation—was expressed in terms of Yule's Q (Yule, 1900; see also Hayman & Tulving, 1989a; Nelson, 1984). The Q measure can assume values between -1.0 and 1.0. The statistical significance of its deviation from zero (stochastic independence of the two tests), as well as differences between any two Q values, can be calculated (Hayman & Tulving, 1989a).[3]

The results of the contingency analyses yield potentially useful information about K.C.'s performance that is not available in the records of individual sessions or in the comparison of his overall performance in different sessions. We report these data selectively and separately for the main part of the experiment and the 12-month assessment.

With 22 sessions in the main part of the experiment, we had 231 pairs of sessions, and we did in fact calculate the Q value for all 231 pairs. But we report here only the results of those analyses that are of either methodological or theoretical interest. These comparisons concern pairs of sessions that used (a) identical cues, (b) different fragment cues, and (c) fragment cues in one session and conceptual cues in the other. In a separate section, we report the results of the contingency analyses of the data from the 12-month assessment.

Identical cues. The results of the contingency analyses for all possible pairs of sessions in which identical cues were used in the main part of the experiment are listed in Table 6. The data show uniformly high Q values for pairs of sessions in which the same cues were used, regardless of the type of cue,

[3] Hayman and Tulving's (1989a, p. 231) Equation 5, which describes the formula for testing the significance of difference between two 2×2 tables, is incorrect. The log transformations of odds ratios in the formula should in fact be natural logarithm transformations. Thus, the correct formula is as follows: $\chi^2 = (\ln C_1 - \ln C_2)^2/[V(C_1) + V(C_2)]$.

Table 5
K.C.'s Performance After a Retention Interval of 12 Months: Proportion of Old and New Targets Produced and Adjusted Scores

Cue/test	Old targets	New targets	Adjusted scores
Fragment			
1	.58	.34	.36
2	.66	.31	.51
3	.69	.28	.57
Sentence frame			
1	.28	.00	.28
2	.39	.00	.39
3	.39	.03	.37

Note. Adjusted score = (old targets − new targets)/(1.00 − new targets).

and regardless of the length of the temporal interval (and the number of interpolated sessions) separating the sessions compared. High Q values were observed for the compared sessions in which perceptual priming was tested (fragment cues), for the sessions in which semantic learning was tested (picture and sentence cues), and for the sessions in which the cues were mixed. Thus, these data demonstrate that K.C.'s performance throughout the experiment tended to be quite stable from session to session or that the measure we used to assess the knowledge that K.C. had acquired in our experiment was quite reliable.

Each Q value shown in Table 6 also includes an estimate of its 95% confidence interval, as suggested by Upton (1978). All Q values in Table 6 fall within the confidence interval from unity, and none is within the confidence interval from zero.

Stochastic independence. We next report the outcomes of item-by-item comparisons of K.C.'s performance in sessions with different cues for the same targets. Two such sets of data are summarized: (a) tests in which different fragment cues were used, and (b) tests in which perceptual versus conceptual cues were used.

The relevant data for different fragment cues are summarized in Table 7. All 16 possible comparisons are shown. The Q values are clustered around zero. All but one of the Q values are within the 95% confidence interval from zero, and the single exception falls outside the interval toward −1. These data suggest that any two tests in which different fragment cues were used were stochastically independent.

The design of our experiment allowed us to compare K.C.'s performance, on an item-by-item basis, between sessions in which different classes of cues were used. For instance, in Session 10 K.C. was tested with the sentence frames alone (conceptual cues), and in Session 15 he was tested with the original fragment cues alone (perceptual cues). The Q value designating the degree of dependency between these two tests turned out to be −.21 (shown in Table 8). Table 8 contains data from all 25 comparisons of performance with perceptual and conceptual cues. All Q values shown in Table 8 are uniformly low, clustering around zero; all are within the 95% confidence interval from zero.

Thus, the data recorded in Table 8 show that K.C.'s performance in tests with perceptual cues was stochastically independent of his performance in tests with conceptual cues: Whether he could produce a given target word in response to its graphemic fragment had no bearing on his production of the same target word in response to its conceptual cues in a different session, and vice versa. We would like to offer this finding of stochastic independence as one of the major empirical conclusions of the research reported here.

Twelve-month retention data. In Table 9, a summary is presented of the results of contingency analyses done on the data from the three tests of the 12-month retention assessment and on the data from two representative earlier sessions, one in which only old fragment cues were used (Session 19), and one in which (auditory) sentence-frame cues were used (Session 22). The Q values obtained in these analyses are quite similar to those from the earlier part of the experiment. The Q values were high and positive when identical cues were used in the two tests being correlated, regardless of the nature of the cue (fragments or sentences), and they were low, hovering around zero, when the two tests being correlated involved different types of cues (fragments vs. sentences). The positive correlations between the three tests of the 12-month assessment, on the one hand, and the selected earlier sessions, on the other hand, were somewhat lower than the correlations among the three tests themselves and also were lower than the corresponding data summarized in Table 6, suggesting that the long retention interval has some deleterious effect on the consistency of responding with individual items, even if, as in the case of fragment cues, there was no pronounced loss in the overall level of performance as such.

General Discussion

In this extensive exploratory experiment, K.C., an amnesic subject who has no functional episodic memory, was taught a long list of three-word sentences, each presented in the context of a picture. The final words of sentences were the target words whose learning and retention by K.C. was observed and measured. These target words were tested with

Table 6
Contingency Analyses of Data From Pairs of Sessions in Which the Same Classes of Cues were Used: Q Values of the Dependency Between Two Tests

Cues	Sessions	Delay (days)	Q	CI
OF	7–15	60	.91	.11
	7–19	80	.96	.07
	15–19	20	.95	.07
NF	16–20	21	.76	.24
PSe	9–12	21	.81	.20
Se	10–13	21	.86	.16
	10–22	77	.89	.15
	13–22	56	.86	.16
PSeOF	11–14	21	.97	.07
PSeNF	17–21	22	.95	.06
Mean		40	.89	

Note. CI = 95% confidence interval; OF = old fragment; NF = new fragment; P = picture; Se = sentence frame.

Table 7
Contingency Analyses of Data From Pairs of Sessions in Which Complementary Fragment Cues Were Used: Q Values of the Dependency Between Two Tests

Cues	Sessions	Delay (days)	*Q*	CI
OF vs. NF	7–16	63	−.25	.48
	7–20	84	−.17	.50
	15–16	3	−.16	.51
	15–20	24	−.07	.53
	19–16	17	−.55	.39
	19–20	4	−.34	.48
PSeOF vs. NF	11–16	28	.22	.71
	14–16	7	.21	.85
	11–20	49	−.34	.63
	14–20	28	.58	.73
OF vs. PSeNF	7–17	67	−.20	.70
	7–21	91	.00	.74
	15–17	7	.18	.67
	15–21	31	.39	.66
	19–17	13	−.30	.75
	19–21	11	−.13	.80
Mean		33	−.06	

Note. CI = 95% confidence interval; OF = old fragment; NF = new fragment; P = picture; Se = sentence frame.

perceptual cues (word fragments), with conceptual cues (other words of the sentences and the pictures), or with both classes of cues. The major findings were as follows: (a) K.C. showed perceptual priming effects that were retained with little loss over 12 months; (b) K.C. exhibited semantic learning, producing many target words to conceptual cues alone, and retained a good deal of the learned information over 12 months; and (c) the target words that K.C. was capable of completing in the perceptual priming tests were stochastically independent of the target words that he was capable of producing in semantic tests. We discuss these findings in turn and then consider their implications for broader issues, such as the nature of amnesia and the relation between amnesia and multiple forms of memory.

Perceptual Priming

K.C.'s perceptual priming in tests with word fragments seems to be no worse than that of control subjects. This finding accords well with previous findings that amnesics show normal or near-normal performance in a variety of priming tasks (e.g., Graf et al., 1984; Shimamura, 1986; Warrington & Weiskrantz, 1970, 1974). But the long-lasting strength of these effects in K.C. exceeds anything that has been reported in the literature, either for amnesics (e.g., Graf et al., 1984; Shimamura, 1986; Squire et al., 1987) or even for normal learners (e.g., Jacoby, 1983a; Musen & Treisman, 1990; Salasoo, Shiffrin, & Feustel, 1985; Sloman, Hayman, Ohta, Law, & Tulving, 1987; Tulving, Schacter, & Stark, 1982). For instance, in one experiment (Sloman et al., 1987, Experiment 2), university students who served as subjects saw a list of 100 words on a single study trial and were then tested for fragment completion at intervals varying in length up to 71 weeks. Immediately after study, the mean relative priming effect, as defined earlier, was .31; after 71 weeks it was .12. For K.C., in the third test of the 12-month retention assessment the comparable figure was .57 (Table 5).

The long-lasting strength of the perceptual priming effects in K.C. is probably largely attributable to the kind of practice with fragment completion that he was given, namely, six study and test trials spaced at weekly intervals, followed by numerous subsequent tests. In previous experiments with amnesics, the extent of initial study typically has been limited to a couple of massed study trials (e.g., Graf et al., 1984; Squire et al., 1987; Warrington & Weiskrantz, 1974).

Perceptual priming effects are assumed to reflect the effects of data-driven processes (e.g., Jacoby, 1983b; Roediger, 1990b; Roediger et al., 1989) or the operations of the quasi-memory (QM) system (Hayman & Tulving, 1989a, 1989b) or the PRS system (Schacter, 1990; Tulving & Schacter, 1990). These processes or systems appear to be preserved in amnesia. The magnitude and longevity of the effects, in amnesics as in normal subjects, seem to depend on the conditions of the experiment.

Semantic Learning

More interesting than the perceptual priming exhibited by K.C. are the results of the semantic learning tests. K.C. was

Table 8
Contingency Analyses of Data From Pairs of Sessions in Which Different Classes of Cues (Perceptual Versus Conceptual) Were Used: Q Values of the Dependency Between Two Tests

Cues	Sessions	Delay (days)	*Q*	CI
OF vs. Se	7–10	28	.12	.50
	7–13	49	−.05	.51
	7–22	105	−.10	.51
	15–10	32	−.21	.50
	15–13	11	.02	.52
	15–22	45	.07	.53
	19–10	52	.09	.54
	19–13	31	−.12	.53
	19–22	25	−.11	.55
Mean		42	−.03	
NF vs. Se	16–10	35	−.03	.50
	16–13	14	−.14	.49
	16–22	42	.13	.50
	20–10	56	−.36	.48
	20–13	35	−.21	.48
	20–22	21	−.06	.51
Mean		34	−.11	
OF vs. PSe	7–9	21	−.31	.46
	7–12	42	.02	.51
	15–9	39	.02	.52
	15–12	18	.34	.54
	19–9	59	.03	.54
	19–12	38	.06	.54
Mean		36	.03	
NF vs. PSe	16–9	42	−.14	.25
	16–12	21	.28	.47
	20–9	63	.18	.49
	20–12	42	.10	.50
Mean		42	.11	

Note. CI = 95% confidence interval; OF = old fragment; NF = new fragment; P = picture; Se = sentence frame.

Table 9
Contingency Analyses of Data From the Three 12-Month Assessment Tests and From Sessions 19 and 22: Q Values of the Dependency Between Two Tests

Sessions compared	*Q*	CI
Fragments vs. fragments		
Test 1–Test 2	.83	.19
Test 1–Test 3	.98	.05
Test 2–Test 3	.92	.10
Test 1–Session 19	.66	.33
Test 2–Session 19	.86	.17
Test 3–Session 19	.69	.30
Sentence frames vs. sentence frames		
Test 1–Test 2	.94	.09
Test 1–Test 3	.98	.05
Test 2–Test 3	.96	.06
Test 1–Session 22	.79	.29
Test 2–Session 22	.74	.28
Test 3–Session 22	.74	.28
Fragments vs. sentence frames[a]		
Test 1–Test 1	.25	.53
Test 1–Test 2	−.06	.50
Test 1–Test 3	.07	.51
Test 1–Session 22	−.13	.50
Test 2–Test 1	.03	.58
Test 2–Test 2	−.20	.50
Test 2–Test 3	−.06	.52
Test 2–Session 22	−.14	.52
Test 3–Test 1	−.07	.58
Test 3–Test 2	−.18	.52
Test 3–Test 3	−.18	.52
Test 3–Session 22	−.32	.50
Session 19–Test 1	−.29	.53
Session 19–Test 2	−.09	.54
Session 19–Test 3	−.24	.51
Session 19–Session 22	−.11	.54

Note. Fragment cues were used in Session 19, and auditory sentence-frame cues were used in Session 22. CI = 95% confidence interval.
[a] Responses to fragment cues from the session designated on the left were correlated with responses to sentence-frame cues from the session designated on the right.

capable of producing a large proportion of old target words to conceptual cues alone, in the absence of any perceptual information about the target. This newly learned semantic information was largely intact 12 months later.

The fact that in Session 22, when K.C. was tested with auditorily presented sentence frames, he performed at a level comparable to those of earlier visually presented equivalent tests strongly suggests that his performance in that test was in fact driven by the semantic information contained in the cues, rather than by the perceptual information in the visually presented sentence frames. Perceptual priming effects usually are (Blaxton, 1989; Jacoby & Dallas, 1981; Roediger & Blaxton, 1987a), whereas conceptual priming effects are not (Blaxton, 1989) sensitive to shifts in the sensory modality of the cues from study to test.

The semantic learning that K.C. demonstrated is remarkable, given his total inability to recollect any events from his life, but it is not unprecedented. New semantic learning in amnesic subjects and its retention over shorter intervals of time has been reported in experiments on source amnesia (Schacter et al., 1984; Shimamura & Squire, 1987; 1991). Retention of newly learned semantic information over longer intervals has been reported in a number of previous studies. In studies by Glisky and her colleagues (Glisky et al., 1986a, 1986b; Glisky & Schacter, 1988), amnesic subjects were taught new computer-related terminology and programming knowledge. Although the amnesics acquired the information at a much slower pace than did the normal subjects, retention tests given as much as 9 months after training showed little forgetting by either group. K.C. was one of the subjects in all three studies. In Glisky and Schacter's (1988) report, K.C.'s data are shown in Table 3 under the subject initials of C.H. In another study by Glisky and Schacter (1989), H.D., another severely impaired amnesic patient, learned over 250 novel facts necessary for the job for which she was being trained. An analysis of long-term retention of 50 learned facts revealed negligible forgetting over a delay of 5 months. A third example is the report by McAndrews et al. (1987), who found that, following one to five repetitions of the material, two amnesics, one of whom was K.C., showed good retention over an interval of 7 days, despite total lack of recollection of the study episode. Finally, in the studies of Mattis and Kovner (1984; Kovner et al., 1983), amnesic subjects retained large numbers of words perfectly over intervals of up to 7 weeks.

All these studies show good agreement in revealing that (a) amnesics can learn new factual information, despite the inability of many to recollect the learning episodes, (b) such new semantic learning is slow and laborious in comparison with that of normal learners, and (c) once the new information has been acquired, its long-term retention is excellent, being comparable to that of normal learners. The long-lasting consequences of K.C.'s semantic learning fit well into this general picture.

From K.C.'s own point of view, his newly acquired knowledge represented ordinary facts of the world. When we questioned him, he thought that many other people would know that "RAYS softened ASPHALT" (one of his learned sentences) as well as they would know that *dogs chase cats.* As far as we could tell, there was no reason to believe that what he had learned were free fragments (Schacter & Tulving, 1982) or free radicals (Tulving, 1983).

Stochastic Independence

The third major finding of our study was that of stochastic independence between perceptual priming and semantic learning. No such findings have been reported before, either with normal or amnesic subjects.

Contingency analyses of outcomes of successive episodic memory tests typically show positive dependency between the tests. If the retrieval cues in the tests are informationally correlated, the dependency is very high; if the cues are informationally independent, the dependency between the tests is moderately positive. Usually a high degree of positive dependency is found even between such tests as recognition and free recall (e.g., Wallace, 1978), which are known to exhibit functional dissociations in other analyses (e.g., Kintsch, 1970; McCormack, 1972).

In striking contrast to these highly reliable dependency relations in explicit memory tests, contingency analyses of successive tests, at least one of which is a test of perceptual priming, have consistently revealed stochastic independence. The first such findings were reported by Jacoby and Witherspoon (1982) and Tulving et al. (1982), and numerous subsequent experiments have replicated and extended them (e.g., Eich, 1984; Hayman & Tulving, 1989a, 1989b; Light, Singh, & Capps, 1986; Mitchell & Brown, 1988; Musen & Treisman, 1990; Schacter et al., 1990; Snodgrass & Feenan, 1990; Tulving, 1985; Witherspoon & Moscovitch, 1989). It is not the case that priming tests are inherently unreliable: When two successive tests of priming employ identical or highly overlapping cues, the tests show high degrees of positive dependency (Hayman & Tulving, 1989a, 1989b; Witherspoon and Moscovitch, 1989). Rather, the stochastic independence found with priming tests in situations in which the cues on one test are informationally unrelated to the cues on the other test suggests that the processes underlying episodic memory and perceptual priming are fundamentally different. (For details of the discussion concerning contingency analyses in explicit and implicit memory, see Flexser & Tulving, 1978; Hayman & Tulving, 1989b; Tulving, 1985).

We interpret the finding of stochastic independence in the present study as suggesting that perceptual priming and semantic learning are subserved by different memory systems. By itself, the stochastic independence does not necessarily imply this conclusion. Stochastic independence would also be consistent with the hypothesis that both forms of learning are subserved by the same implicit memory system that subserves perceptual priming, such as PRS (Schacter, 1990; Tulving & Schacter, 1990; see also Hayman & Tulving, 1989b, and Witherspoon & Moscovitch, 1989). However, the additional finding that semantic learning in K.C. was unaffected by the modality shift from study to test rules out this alternative hypothesis: The system that subserves semantic learning is unlikely to be PRS because PRS is known to be modality specific. In other words, if semantic learning shown by K.C. were mediated by PRS, as we assume perceptual priming is, or even if it were attributable to data-driven processes that underlie perceptual priming (e.g., Roediger, 1990b), testing the visually based semantic learning in the auditory modality should have considerably reduced K.C.'s performance. There was not even a trace of any reduction in the outcome of the auditory test in Session 22.

The fact of essentially perfect cross-modality transfer in semantic learning, combined with stochastic independence between such learning and perceptual priming, suggests then that K.C.'s semantic learning is based on a system other than that subserving perceptual priming. Because K.C.'s semantic learning also cannot be based on the episodic system, we are left with the hypothesis that his semantic learning is based on his semantic memory. If so, K.C. is a person with a totally dysfunctional episodic memory and at least a partially preserved semantic memory.

Implications of the Findings

The findings of this study have some implications for the status of empirical facts of perceptual priming and semantic learning in amnesia, as well as for the theoretical issue of the relations among different forms of memory, or different memory systems. Above everything else, our findings rule out certain generalized conclusions that have been offered previously. First, our results make it clear that perceptual priming effects in amnesia need not be short-lived, as has been claimed (e.g., Squire et al., 1987). Second, our results make it clear that even densely amnesic subjects can acquire, and retain over rather long intervals of time, new semantic information, contrary to the conventional clinical wisdom discussed in the introduction of this article and contrary to claims sometimes made by experimental students of amnesia (e.g., Baddeley, 1984; Squire, 1986; Squire & Cohen, 1984). Third, and more broadly, our results imply that unqualified generalizations concerning what amnesic subjects can or cannot do are of little value and are probably as unjustifiable in descriptions of pathological memory as they are in normal memory. Fourth, our findings imply that research efforts in the future might be more profitably addressed to questions having to do with the conditions and variables that influence such things as the longevity of priming effects or the effectiveness of semantic learning rather than to less fruitful questions, such as whether perceptual priming is short-lived or long-lived or whether amnesic subjects can or cannot acquire new semantic knowledge.

Factors Affecting Semantic Learning in Amnesia

Having tested only K.C. and no other amnesic subjects, we cannot say to what extent the results we obtained are unique to K.C. and to what extent they would be generalizable to other amnesics. Furthermore, it might be argued that K.C. is not a typical amnesic, inasmuch as a part of his disorder may be a consequence of frontal-lobe damage superimposed on whatever other damage has caused his conventional amnesia (Squire, 1987). If true, any generalizations we draw would be limited by K.C.'s special status among severely memory-impaired individuals. However, because K.C.'s anterograde amnesia, assessed by currently conventional clinical and psychometric methods, is rather similar to that of many other densely amnesic subjects described in the literature, we are inclined to think that the kind of memory performance he exhibited is not unique. The fact that he was capable of learning and retaining new semantic knowledge over a long time probably reflects the conditions of our study, especially the materials and procedures we used, rather than his uniqueness. This assumption receives support from two sources. The first source lies in the other studies that have demonstrated long-lasting semantic learning in amnesia, already summarized in this discussion. The second is the observation that K.C. failed to exhibit any implicit memory for new associations in Graf and Schacter's (1985) experiment, nor did he exhibit any context effects in Sessions 1 through 4 in our study, yet he demonstrated both strong perceptual priming in

Sessions 1 through 7 and semantic learning effects in Sessions 9 through 14 in the present experiment. This pattern points to the relevance of the specific materials and procedures used.

In the remainder of this section we focus on two additional conditions of learning that we believe to be especially relevant. These are (a) the meaningfulness of the to-be-learned material and (b) the presence or absence of interference, in the form of response competition.

Meaningfulness. Factual information is meaningful to the extent that it represents something the subject already knows, or to the extent that the to-be-learned relation is consistent with existing concepts. Meaningfulness can be operationally defined and measured in terms of normative ratings of particular sets of materials. The role played by the meaningfulness of materials is well known in the literature on normal learning and memory (e.g., Underwood & Schulz, 1960), and meaningfulness seems to be implicated by previous studies with amnesic subjects (e.g., Cutting, 1978; Kovner et al., 1983; McAndrews et al., 1987; Shimamura & Squire, 1987). The amnesic young girl (described by Wood et al., 1982, and Wood, Brown, & Felton, 1989) who made satisfactory progress through the grades at school also seems to fit into the category of meaningful learning of semantic knowledge in amnesia. The relevance of meaningfulness is buttressed by the reported failure of amnesic patients to learn nonmeaningful or semantically unrelated materials (e.g., Cutting, 1978; Rozin, 1976; Squire & Shimamura, 1986; Warrington & Weiskrantz, 1982, Experiment 3; Winocur & Weiskrantz, 1976).

K.C. was one of the severely amnesic subjects in Graf and Schacter's (1985) study who, on a reanalysis of the data and in a subsequent replication experiment (Schacter & Graf, 1986b), did not show any semantic context effects. The fact that K.C. exhibited semantic learning in our experiment, but not in Graf and Schacter's (1985) experiment, may be attributable not only to differences in procedure but also to the meaningfulness of the materials. Even though K.C. had never seen any of the sentences that we used before, and even though the association between the sentence frame and the target word was new in the sense of not having been encountered before, as well as not being predictable on the basis of semantic knowledge alone, they made good sense to K.C. The materials used by Graf and Schacter (1985), as well as those used in a similar experiment by Shimamura and Squire (1989), consisted of unrelated word pairs, such as *window*—REASON. The semantic encoding of these word pairs at study may have been insufficient to render the relation between them meaningful.

The meaningfulness hypothesis may also account for the observations that amnesic subjects can learn rule-based information and rule-governed paired associates. Such rule-based information includes the learning of the Fibonacci rule (Kinsbourne & Wood, 1975) and rhyming pairs of words (Warrington & Weiskrantz, 1982; Winocur & Weiskrantz, 1976).

Thus, it looks as if the meaningfulness of materials may be an important determinant of new semantic learning in amnesia. It is not yet known whether amnesic subjects can learn completely meaningless associations under more optimal conditions than those used in the past.

Interference. The second factor that seems to be relevant to the success of semantic learning by amnesics is the degree of interference involved in learning a given task. By interference we mean the prior existence or acquisition of competing responses to a given stimulus "on-line" (in the course of trial-by-trial learning).

The most direct evidence for the role of interference comes from an experiment with K.C. that we conducted in parallel with the one reported here (Hayman & Macdonald, 1990). K.C. learned to interpret ambiguous phrases in terms of disambiguating words that accompanied the phrases (e.g., *a talkative featherbrain*—PARAKEET; *a servant in name only*—BRIDESMAID). The study list consisted of 96 such phrase–word pairs. The learning of information of this kind can be thought of as the learning of new (meaningful) paired associates, or as the acquisition of new semantic knowledge. The role of interference was examined by manipulating the presence and absence of interfering responses to the phrases, both before the experiment began and during learning. The results showed that K.C. learned and retained best (.84) those phrase–word pairs that (a) had no incorrect or competing word responses, as revealed by a pretest of the phrases used in the experiment, and (b) were not tested during learning. His worst performance (.30) was with phrase–word pairs that (a) had original competing associations and (b) were tested in the course of learning.

In normal subjects, on-line tests of associations are known to have large facilitative effects on subsequent retention (e.g., Estes, 1960; Runquist, 1986). Similar facilitative effects have been obtained with older adults whose retention of material is impaired in comparison with younger adults (Rabinowitz & Craik, 1986). But in K.C., and possibly in other amnesics, on-line tests have the opposite effect, probably because they engender incorrect responses which then compete with the correct responses. In the present study, the on-line testing of the material in the first six (study and test) sessions always involved the presentation of the word fragment that uniquely specified the target. This procedure largely precluded interfering responses to the conceptual cues, thereby facilitating learning.

A second line of evidence relevant to the interference hypothesis comes from previous research in which several amnesic patients, including K.C., were taught new computer-related vocabulary (Glisky et al., 1986b). In that study, the so-called method of vanishing cues was used. The testing of to-be-learned words by that method is functionally similar to the testing of targets with word fragments: In both situations the perceptual cue, either the n initial letters of the word or the word fragment, constrains responding with words other than the desired target, thereby reducing interference through response competition.

The interference hypothesis may also explain why Gabrieli et al.'s (1983, 1988) amnesic subjects failed to learn the meanings of unknown words. Gabrieli and his colleagues attempted to teach H.M. and a small group of other amnesic patients the meaning of English words that they did not know before, words such as *hegira*, *quotidian*, and *welkin*. The results of this experiment were completely negative: None of the amnesic patients showed any progress in learning the meaning of the 10 new words when tested with several methods. It is possible that the negative results of Gabrieli et al. (1983, 1988), at variance with the positive results of Glisky et al. (1986b), were at least to some extent attributable to the particular procedure that Gabrieli and his coworkers used in training their subjects. In their procedure, on every learning trial, the subjects had to select the correct response to a definition or sentence frame from the whole set of the to-be-learned words. The selection procedure for any given target word continued until that target word was selected by the subject, at which point it was eliminated from the choice set for the remainder of that trial. This procedure engenders a great deal of incorrect responding, allowing interference to be built up in the course of learning.[4]

The fact that an amnesic subject appears to have much greater difficulty than a normal subject in overcoming the effect of competing responses in associative learning may reflect the absence of the amnesic's conscious, episodic recollection of what happened where and when (Kinsbourne & Winocur, 1980), or it may reflect the absence of imaginal memory (Wilkinson & Poulos, 1984). In other words, sensitivity to interference or response competition reflected in semantic learning may be a direct consequence of a faulty episodic memory system. The episodic system allows the individual to discriminate among items of information in terms of the temporal–spatial coordinates of their previous appearance, thereby facilitating the acquisition of otherwise confusable general knowledge.

In summarizing this section, then, we would like to suggest that two important determinants of semantic learning by amnesic subjects such as K.C. are the meaningfulness of the to-be-learned material, defined in relation to the subject's existing semantic knowledge, and the minimization of competing associations. Both factors of course are also highly relevant in normal memory, but their importance may be accentuated in amnesia.

Nature of Amnesia

Let us now turn to the issue of anterograde amnesia, and examine it in light of our findings. We do so from the perspective of memory systems. Various memory systems have been postulated and discussed by a number of writers (e.g. Butters, Salmon, Heindel, & Granholm, 1988; Cermak, 1984; Cohen, 1984; DeRenzi, Liotti, & Nichelli, 1987; Halgren & Smith, 1987; Johnson, 1983, 1990; Kesner & DiMattia, 1984; Kinsbourne, 1989; Kinsbourne & Wood, 1975; Lewis, 1984; Martin & Fedio, 1983; Nissen, Knopman, & Schacter, 1987; Sherry & Schacter, 1987; Shimamura, 1986; Squire, 1986, 1987; Warrington, 1976, 1979; Weingartner, Grafman, Boutelle, Kaye, & Martin, 1983; Weiskrantz, 1987, 1989; Wilkinson & Poulos, 1987; Wood, 1987; Wood et al., 1989). The evidence accumulated to date suggests the existence of at least five major systems: procedural, PRS, short-term, semantic, and episodic memory (Roediger, 1990a; Schacter, 1990; Tulving & Schacter, 1990; Tulving & Schacter, in press; Weiskrantz, 1987, 1989).

It is widely agreed that amnesic patients typically are unimpaired on tasks that are heavily dependent on procedural memory, PRS, and short-term memory systems (Schacter, 1987b; Shimamura, 1986; Squire, 1987; Weiskrantz, 1987). There is also broad agreement that amnesic patients are impaired in postmorbid episodic memory. Indeed, the single most pervasive and telltale symptom of the amnesic syndrome is the inability of the amnesic patient to remember any personal experiences in ongoing activity beyond the period covered by short-term memory (Rozin, 1976). However, the status of semantic memory and its involvement in amnesia is not clear. One theory of anterograde amnesia holds that episodic and semantic memory, as subsystems of declarative memory, are both impaired in amnesia (e.g., Cohen, 1984; Cohen & Squire, 1980; Squire, 1987). Other theories hold that episodic memory is impaired, whereas semantic memory is largely intact in anterograde amnesia (Kinsbourne & Wood, 1975; Parkin, 1982; Shallice, 1988; Wood et al., 1982). If one attempts to come to theoretical grips with both anterograde and retrograde amnesia, the picture becomes even more complicated (Shimamura, 1989; Warrington & Weiskrantz, 1982).

The fact that K.C., in the absence of episodic memory, can learn new semantic knowledge agrees with a version of the episodic versus semantic theory of anterograde amnesia that is similar to but also different from other versions of the basic idea (Kinsbourne & Wood, 1975, 1982; Parkin, 1982; Rozin, 1976; Shallice, 1988). In our version of the theory, we assume that the episodic system is embedded within, or represents a unique extension of, the semantic system (Tulving, 1984, 1985, 1987). Although it possesses the distinctive capability of registering, storing, and making accessible for retrieval information about happenings in the individual's past, a capability not possessed by the semantic system, acquisition of episodic information is highly dependent on the semantic system. Thus, the relation between episodic and semantic memory is asymmetrical: Semantic memory is necessary for certain operations of episodic memory, but episodic memory is not necessary for semantic memory. A severely impaired semantic memory system would inevitably produce an impairment in the operations of episodic memory, whereas a dysfunctional episodic memory system need not have any deleterious effect on the operations of the semantic system (Tulving, 1985, 1987).

A direct consequence of this kind of relation between the episodic and semantic systems is variability in the patterns of memory impairment resulting from brain damage. In some cases the damage to the semantic system may be so severe

[4] In an informal study, we used the procedure described by Gabrieli, Cohen, and Corkin (1988) to try to teach K.C. the meanings of the same words that Gabrieli et al. used. We gave K.C. 5 trials each on definitions and synonyms and 10 trials on sentences. He showed no progress whatsoever across the learning trials, and the number of errors he made per trial in each of the three parts of the method was almost identical with the data reported for H.M. by Gabrieli et al. (1988). Because of these initial findings, we did not continue with this study: It looked as if our findings with K.C. would turn out to be very similar to those reported by Gabrieli and his colleagues.

that the patient, in addition to remembering no personal happenings beyond a few minutes, exhibits a total or near-total inability to acquire any new semantic information. In such cases, one can speak of amnesia as a breakdown of declarative memory (e.g., Baddeley, 1984; Cohen, 1984; Squire, 1986; Squire, Shimamura, & Amaral, 1989). The famous patient H.M. (Corkin, 1984; Milner, Corkin, & Teuber, 1968) may well fall in this category, although the final judgment will have to await tests of his semantic learning ability conducted under more optimal conditions. In other cases, the patient's semantic memory capabilities are largely preserved, although the episodic system may be profoundly impaired. The young girl (described by Wood et al., 1982, and Wood et al., 1989) who became amnesic following a bout with herpes simplex encephalitis but nevertheless continued to make satisfactory progress in school falls into this category of anterograde amnesia. Between these two extremes, which can be defined in terms of the extent of the damage to the semantic system (in addition to the obligatory damage to the episodic system), lie other possible patterns of impairment, including that of K.C.

The difference between the efficiency of learning new semantic information by amnesics and normal subjects may reflect nothing more nor less than the amnesics' impaired and the normal subjects' unimpaired semantic memory system. This is the position advocated by Squire and his colleagues when they assert that amnesia is an impairment of declarative memory that includes both facts and events (e.g., Shimamura & Squire, 1988; Squire & Cohen, 1984).

But the difference could also arise by virtue of the contribution that the normal subjects' unimpaired episodic memory system makes to new semantic learning. Once information has been recorded in both the semantic and episodic systems, performance on tests of recently learned factual, associative, or semantic information can be supported by both systems. If one of the systems (episodic) is dysfunctional in amnesia, amnesics will do less well on tests of recent semantic learning *even if their semantic memory was completely intact.* This hypothesis is not readily testable in normal subjects because it is difficult to prevent them from relying on their ability to remember past learning episodes, and happenings in it, when they are tested for their knowledge of recently learned information.[5]

Regardless of the validity of these ideas, which should be tested in future research, simple comparisons of new semantic learning by amnesic subjects and nonamnesic controls cannot tell us very much about the extent to which the semantic system, or its capability of acquiring new information, is impaired or preserved in amnesia. The finding that amnesic subjects, in experiments on source amnesia (e.g., Schacter et al., 1984; Shimamura & Squire, 1987, 1991) or in other comparable studies (e.g., Glisky et al., 1986a, 1986b; Glisky & Schacter, 1988; McAndrews et al., 1987; Shimamura & Squire, 1988), learn and retain new semantic knowledge less well than control subjects must be attributed, to an unknown extent, to the control subjects' intact episodic memory.

This logic for comparing the task performance of amnesics and normal learners has been articulated in previous research, although it tends to be ignored at times. Milner et al. (1968) suggested that the superior performance of the control subjects over H.M. in learning an incomplete-pictures task could have been attributed to the control subjects' verbal memory for the names of to-be-identified pictures, the kind of memory that H.M. does not possess. More recently the same argument has been made in the discussion of comparisons of tests of perceptual priming between amnesics and controls (e.g., Schacter, Delaney, & Merikle, 1990): Even if PRS, the system that subserves perceptual priming, is intact in the amnesic subjects tested in a particular experiment, normal controls can perform at a higher level because they can make use of their intact episodic memory when performing the task. Earlier in this article, we used the same line of reasoning to interpret the finding that K.C.'s priming effects in the first few sessions were lower than those of the control subjects in the conditions in which the picture that had accompanied the target word at study was present at testing, and thus could have reminded control subjects of the study episode.

The version of the episodic versus semantic hypothesis of amnesia we are advocating can account for the fact that patients with dense anterograde amnesia can acquire new semantic information, albeit slowly and laboriously, under appropriate conditions. It also provides a possibly useful criterion for assessing individual differences among severely memory-impaired individuals: Given a complete dysfunction of their episodic memory, patients may differ in the extent to which their semantic memory system functions in acquisition and retrieval. At the very least, our theory points to the necessity of more careful analyses in comparisons of normal subjects' and amnesics' semantic learning.

Conclusion

The conclusions we draw from our study are based on the following observations: (a) K.C. has no functional episodic memory; (b) under the conditions of our study he was found capable of learning new facts and retaining them over long intervals of time; (c) this learning occurred independently of perceptual priming, and it transferred readily across sensory modalities; and (d) from his own introspective point of view, K.C. believes that the facts that he knows, without knowing why he knows them, are no different from other known facts that can be stated as brief propositions.

[5] There is some evidence that adding certain kinds of new information to semantic memory is a slow and time-consuming process even in normal subjects. In an ingenious study, Dagenbach, Horst, and Carr (1990) tested semantic-memory changes in university students brought about by episodic study of unrelated words as paired associates. They measured these changes in the paradigm of semantic priming of lexical decisions (D. E. Meyer & Schvaneveldt, 1971; Neely, 1977), under conditions in which subjects could not strategically rely on conscious access to either episodic or semantic memory. The target word was primed by a short stimulus-onset-asynchrony presentation of a word that had been paired with the target in repeated previous study episodes. The results showed that even extensive study of pairs of unrelated words did not produce measurable semantic priming under these conditions, although similar extensive study did lead to semantic priming when the episodically paired words consisted of a completely unfamiliar word and its familiar synonym.

This picture suggests to us that the new semantic learning exhibited by K.C. is subserved by his partially or perhaps even wholly preserved semantic memory system. He learns new facts more slowly than normal individuals because (a) the brain damage that caused his amnesia may have impaired the functioning of his semantic memory as well, albeit less severely than his episodic memory, (b) a typical normal learner can rely on his or her episodic memory in learning new semantic information whereas K.C. cannot, (c) intact episodic memory may help the normal learner to overcome the effects of interference in the form of response competition, which plague K.C. because he cannot distinguish between past events in terms of their temporal differences, or (d) some combination of these and other, as yet little understood, reasons. Once K.C. has learned a new fact, however, he retains it as well as a normal individual.

References

Baddeley, A. D. (1984). Neuropsychological evidence and the semantic/episodic distinction. *Behavioral and Brain Sciences, 7,* 238–239.

Blaxton, T. A. (1989). Investigating dissociations among memory measures: Support for a transfer-appropriate processing framework. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 657–668.

Butters, N., Granholm, E., Salmon, D. P., Grant, I., & Wolfe, J. (1987). Episodic and semantic memory: A comparison of amnesic and demented patients. *Journal of Clinical and Experimental Neuropsychology, 9,* 479–497.

Butters, N., Salmon, D. P., Heindel, W., & Granholm, E. (1988). Episodic, semantic, and procedural memory: Some comparisons of Alzheimer and Huntington disease patients. In R. D. Terry (Ed.), *Aging and the brain* (pp. 63–87). New York: Raven Press.

Cermak, L. S. (1984). The episodic–semantic distinction in amnesia. In L. R. Squire & N. Butters (Eds.), *Neuropsychology of memory* (pp. 55–62). New York: Guilford Press.

Cermak, L. S., & O'Connor, M. (1983). The anterograde and retrograde retrieval ability of a patient with amnesia due to encephalitis. *Neuropsychologia, 21,* 213–234.

Cohen, N. J. (1984). Preserved learning capacity in amnesia: Evidence for multiple memory systems. In L. R. Squire & N. Butters (Eds.), *The neuropsychology of memory* (pp. 83–103). New York: Guilford Press.

Cohen, N. J., & Squire, L. R. (1980). Preserved learning and retention of pattern analyzing skill in amnesia: Dissociation of knowing how and knowing that. *Science, 210,* 207–209.

Corkin, S. (1984). Lasting consequences of bilateral medial temporal lobectomy: Clinical course and experimental findings in H.M. *Seminars in Neurology, 4,* 249–259.

Crovitz, H. F., Harvey, M. T., & McClanahan, S. (1981). Hidden memory: A rapid method for the study of amnesia using perceptual learning. *Cortex, 17,* 273–278.

Cutting, J. (1978). A cognitive approach to Korsakoff's syndrome. *Cortex, 14,* 485–495.

Dagenbach, D., Horst, S., & Carr, T. H. (1990). Adding new information to semantic memory: How much learning is enough to produce automatic priming? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 581–591.

Damasio, H., & Damasio, A. R. (1989). *Lesion analysis in neuropsychology.* New York: Oxford University Press.

DeRenzi, E., Liotti, M., & Nichelli, P. (1987). Semantic amnesia with preservation of autobiographic memory. A case report. *Cortex, 23,* 575–597.

Eich, E. (1984). Memory for unattended events: Remembering with and without awareness. *Memory & Cognition, 12,* 105–111.

Estes, W. K. (1960). Learning theory and the new "mental chemistry." *Psychological Review, 67,* 207–223.

Flexser, A. J., & Tulving, E. (1978). Retrieval independence in recognition and recall. *Psychological Review, 88,* 327–339.

Gabrieli, J. D. E., Cohen, N. J., & Corkin, S. (1983). Acquisition of semantic and lexical knowledge in amnesia. *Society for Neuroscience Abstracts, 9,* 28.

Gabrieli, J. D. E., Cohen, N. J., & Corkin, S. (1988). The impaired learning of semantic knowledge following bilateral medial temporal-lobe resection. *Brain and Cognition, 7,* 157–177.

Gardner, H., Boller, F., Moreines, J., & Butters, N. (1973). Retrieving information from Korsakoff patients: Effects of categorical cues and reference to the task. *Cortex, 9,* 165–175.

Glisky, E. L., & Schacter, D. L. (1988). Long-term retention of computer learning by patients with memory disorders. *Neuropsychologia, 26,* 173–178.

Glisky, E. L., & Schacter, D. L. (1989). Extending the limits of complex learning in organic amnesia: Computer training in a vocational domain. *Neuropsychologia, 27,* 107–120.

Glisky, E. L., Schacter, D. L., & Tulving, E. (1986a). Computer learning by memory-impaired patients: Acquisition and retention of complex knowledge. *Neuropsychologia, 24,* 313–328.

Glisky, E. L., Schacter, D. L., & Tulving, E. (1986b). Learning and retention of computer-related vocabulary in memory-impaired patients: Method of vanishing cues. *Journal of Clinical and Experimental Neuropsychology, 8,* 292–312.

Graf, P., & Schacter, D. L. (1985). Implicit and explicit memory for new associations in normal and amnesic subjects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 501–518.

Graf, P., Shimamura, A. P., & Squire, L. R. (1985). Priming across modalities and priming across category levels: Extending the domain of preserved function in amnesia. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 386–396.

Graf, P., Squire, L. R., & Mandler, G. (1984). The information that amnesic patients do not forget. *Journal of Experimental Psychology: Learning, Memory and Cognition, 10,* 164–178.

Halgren, E., & Smith, M. E. (1987). Cognitive evoked potentials as modulatory processes in human memory formation and retrieval. *Human Neurobiology, 6,* 129–139.

Hamann, S. B. (1990). Level-of-processing effects in conceptually driven implicit tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 970–977.

Hayman, C. A. G., & Macdonald, C. A. (1990, May). *Benefits of error-free learning in amnesia.* Paper presented at the 51st Annual Convention of the Canadian Psychological Association, Ottawa, Ontario.

Hayman, C. A. G., & Tulving, E. (1989a). Contingent dissociation between recognition and fragment completion: The method of triangulation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 228–240.

Hayman, C. A. G., & Tulving, E. (1989b). Is priming in fragment completion based on a "traceless" memory system? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 941–956.

Hirshman, E., Snodgrass, J. G., Mindes, J., & Feenan, K. (1990). Conceptual priming in fragment completion. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 634–647.

Jacoby, L. L. (1983a). Perceptual enhancement: Persistent effects of an experience. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 21–38.

Jacoby, L. L. (1983b). Remembering the data: Analyzing interactive processes in reading. *Journal of Verbal Learning and Verbal Behavior, 22,* 485–508.

Jacoby, L. L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 110,* 306–340.

Jacoby, L. L., & Witherspoon, D. (1982). Remembering without awareness. *Canadian Journal of Psychology, 32,* 300–324.

Johnson, M. K. (1983). A multiple-entry modular memory system. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research theory* (Vol. 17, pp. 81–123). San Diego, CA: Academic Press.

Johnson, M. K. (1990). Functional forms of human memory. In J. L. McGaugh, N. M. Weinberger, & G. Lynch (Eds.), *Brain organization and memory: Cells, systems, and circuits* (pp. 106–134). New York: Oxford University Press.

Kesner, R. P., & DiMattia, B. V. (1984). Posterior parietal association cortex and hippocampus: Equivalency of mnemonic function in animals and humans. In L. R. Squire & N. Butters (Eds.), *The neuropsychology of memory* (pp. 385–398). New York: Guilford Press.

Kinsbourne, M. (1989). The boundaries of episodic remembering: Comments on the second section. In H. L. Roediger III, and F. I. M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honour of Endel Tulving* (pp. 179–194). Hillsdale, NJ: Erlbaum.

Kinsbourne, M., & Winocur, G. (1980). Response competition and interference effects in paired-associate learning by Korsakoff amnesics. *Neuropsychologia, 18,* 541–548.

Kinsbourne, M., & Wood, F. (1975). Short-term memory processes and the amnesic syndrome. In D. Deutsch & J. A. Deutsch (Eds.), *Short-term memory* (pp. 258–291). San Diego, CA: Academic Press.

Kinsbourne, M., & Wood, F. (1982). Theoretical considerations regarding the episodic-semantic memory distinction. In L. S. Cermak (Ed.), *Human memory and amnesia* (pp. 194–217). Hillsdale, NJ: Erlbaum.

Kintsch, W. (1970). Models for free recall and recognition. In D. A. Norman (Ed.), *Models of human memory* (pp. 331–373). San Diego, CA: Academic Press.

Kovner, R., Mattis, S., & Goldmeier, E. (1983). A technique for promoting robust free recall in chronic organic amnesia. *Journal of Clinical Neuropsychology, 5,* 65–71.

Lewis, R. S. (1984). Variation on a theme: Are the elements of episodic memory dissociable? *Behavioral and Brain Sciences, 9,* 567–568.

Lezak, M. D. (1983). *Neuropsychological assessment.* New York: Oxford University Press.

Light, L. L., Singh, A., & Capps, J. L. (1986). Dissociation of memory and awareness in older adults. *Journal of Clinical and Experimental Neuropsychology, 8,* 62–74.

Martin, A., & Fedio, P. (1983). Word production and comprehension in Alzheimer's disease: The breakdown of semantic knowledge. *Brain and Language, 19,* 124–141.

Mattis, S., & Kovner, R. (1984). Amnesia is as amnesia does: Toward another definition of the anterograde amnesias. In L. R. Squire & N. Butters (Eds.), *Neuropsychology of memory* (pp. 115–121). New York: Guilford Press.

Mayes, A. W. (1988). *Human organic memory disorders.* Cambridge, England: Cambridge University Press.

Mayes, A. W., Pickering, A., & Fairbairn, A. (1987) Amnesic sensitivity to proactive interference: Its relationship to priming and the causes of amnesia. *Neuropsychologia, 25,* 211–220.

McAndrews, M. P., Glisky, E. L., & Schacter, D. L. (1987). When priming persists: Long-lasting implicit memory for a single episode in amnesic patients. *Neuropsychologia, 25,* 497–506.

McCormack, P. D. (1972). Recognition memory: How complex a retrieval system? *Canadian Journal of Psychology, 26,* 19–41.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90,* 227–234.

Meyer, V., & Yates, A. J. (1955). Intellectual changes following temporal lobectomy for psychomotor epilepsy. *Journal of Neurology, Neurosurgery, and Psychiatry, 18,* 44–52.

Milner, B., Corkin, S., & Teuber, H. L. (1968). Further analysis of the hippocampal amnesic syndrome: 14 year follow-up study of H.M. *Neuropsychologia, 6,* 215–234.

Mitchell, D. B., & Brown, A. S. (1988). Persistent repetition priming in picture naming and its dissociation from recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 213–222.

Moscovitch, M., Winocur, G., & McLachlan, D. (1986). Memory as assessed by recognition and reading time in normal and memory impaired people with Alzheimer's disease and other neurological disorders. *Journal of Experimental Psychology: General, 115,* 331–347.

Musen, G., & Treisman, A. (1990). Implicit and explicit memory for visual patterns. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 127–137.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106,* 226–254.

Nelson, T. O. (1984). A comparison of current measures of the accuracy of feeling-of-knowing predictions. *Psychological Bulletin, 95,* 109–133.

Nilsson, L. G., Law, J., & Tulving, E. (1988). Recognition failure of recallable unique names: Evidence for an empirical law of memory and learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 266–277.

Nissen, M. J., Knopman, D. S., & Schacter, D. L. (1987). Neurochemical dissociation of memory systems. *Neurology, 37,* 789–794.

Parkin, A. J. (1982). Residual learning capability in organic amnesia. *Cortex, 18,* 417–440.

Parkin, A. J. (1988). *Memory and amnesia.* Oxford, England: Basil Blackwell.

Rabinowitz, J. C., & Craik, F. I. M. (1986). Prior retrieval effects in young and old adults. *Journal of Gerontology, 41,* 368–375.

Richardson-Klavehn, A., & Bjork, R. A. (1988). Measures of memory. *Annual Review of Psychology, 39,* 475–543.

Roediger, H. L., III. (1990a). Implicit memory: A commentary. *Bulletin of the Psychonomic Society, 28,* 373–380.

Roediger, H. L., III. (1990b). Implicit memory: Retention without remembering. *American Psychologist, 45,* 1043–1056.

Roediger, H. L., III, & Blaxton, T. A. (1987a). Effects of varying modality, surface features, and retention interval on priming in word fragment completion. *Memory and Cognition, 15,* 379–388.

Roediger, H. L., III, & Blaxton, T. A. (1987b). Retrieval modes produce dissociations in memory for surface information. In D. S. Gorfein & R. R. Hoffman (Eds.), *Memory and cognitive processes: The Ebbinghaus Centennial Conference* (pp. 349–379). Hillsdale, NJ: Erlbaum.

Roediger, H. L., III, & Weldon, M. S. (1987). Reversing the picture superiority effect. In M. A. McDaniel & M. Pressley (Eds.), *Imagery and related mnemonic processes: Theories, individual differences, and applications* (pp. 151–174). New York: Springer-Verlag.

Roediger, H. L., III, Weldon, M. S., & Challis, B. H. (1989). Explaining dissociations between implicit and explicit measures of retention: A processing account. In H. L. Roediger III & F. I. M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honour of Endel Tulving* (pp. 3–42). Hillsdale, NJ: Erlbaum.

Rozin, P. (1976). The psychobiological approach to human memory. In M. R. Rosenzweig & E. L. Bennett (Eds.), *Neural mechanisms of learning and memory* (pp. 3–46). Cambridge, MA: MIT Press.

Runquist, W. N. (1986). The effect of testing on the forgetting of related and unrelated associates. *Canadian Journal of Psychology, 40,* 65–76.

Salasoo, A., Shiffrin, R., & Feustel, T. (1985). Building permanent memory codes: Codification and repetition effects in word identification. *Journal of Experimental Psychology: General, 114,* 50–77.

Schacter, D. L. (1985). Priming of old and new knowledge in amnesic patients and normal subjects. *Annals of the New York Academy of Sciences, 444,* 41–53.

Schacter, D. L. (1987a). Implicit expressions of memory in organic amnesia: Learning of new facts and associations. *Human Neurobiology, 6,* 107–118.

Schacter, D. L. (1987b). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 501–518.

Schacter, D. L. (1990). Perceptual representation systems and implicit memory: Toward a resolution of the multiple memory systems debate. *Annals of the New York Academy of Sciences, 608,* 543–571.

Schacter, D. L., Cooper, L. A., & Delaney, S. M. (1990). Implicit memory for unfamiliar objects depends on access to structural descriptions. *Journal of Experimental Psychology: General, 119,* 5–24.

Schacter, D. L., Delaney, S. M., & Merikle, E. P. (1990). Priming of nonverbal information and the nature of implicit memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (pp. 83–123). San Diego, CA: Academic Press.

Schacter, D. L., & Graf, P. (1986a). Effects of elaborative processing on implicit and explicit memory for new associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 432–444.

Schacter, D. L., & Graf, P. (1986b). Preserved learning in amnesic patients: Perspectives from research on direct priming. *Journal of Clinical and Experimental Neuropsychology, 6,* 727–743.

Schacter, D. L., & Graf, P. (1989). Modality specificity of implicit memory for new associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 3–12.

Schacter, D. L., Harbluk, J., & McLachlan, D. (1984). Retrieval without recollection: An experimental analysis of source amnesia. *Journal of Verbal Learning and Verbal Behavior, 23,* 593–611.

Schacter, D. L., & Tulving, E. (1982). Memory, amnesia, and the episodic/semantic distinction. In R. L. Isaacson & N. E. Spear (Eds.), *Expression of knowledge* (pp. 33–65). New York: Plenum Press.

Scoville, W. B., & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery, and Psychiatry, 20,* 11–21.

Shallice, T. (1988). *From neuropsychology to mental structure.* Cambridge, England: Cambridge University Press.

Sherry, D. F., & Schacter, D. L. (1987). The evolution of multiple memory systems. *Psychological Review, 94,* 439–454.

Shimamura, A. P. (1986). Priming effects in amnesia: Evidence for a dissociable memory function. *Quarterly Journal of Experimental Psychology, 38A,* 619–644.

Shimamura, A. P. (1989). Disorders of memory: the cognitive science perspective. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology* (pp. 35–73). Amsterdam: Elsevier.

Shimamura, A. P., & Squire, L. R. (1984). Paired-associate learning and priming effects in amnesia: A neuropsychological study. *Journal of Experimental Psychology: General, 113,* 556–570.

Shimamura, A. P., & Squire, L. R. (1987). A neuropsychological study of fact memory and source amnesia. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 464–473.

Shimamura, A. P., & Squire, L. R. (1988). Long-term memory in amnesia: Cued recall, recognition memory, and confidence ratings. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 763–770.

Shimamura, A. P., & Squire, L. R. (1989). Impaired priming of new associations in amnesia. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 721–728.

Shimamura, A. P., & Squire, L. R. (1991). The relationship between fact and source memory: Findings from amnesic patients and normal subjects. *Psychobiology, 19,* 1–10.

Sloman, S. A., Hayman, C. A. G., Ohta, N., Law, J., & Tulving, E. (1987). Forgetting in primed fragment completion. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 223–239.

Snodgrass, J. G. (1989). Sources of learning in the picture fragment completion task. In S. Lewandowsky, J. C. Dunn, & K. Kirsner (Eds.), *Implicit memory: Theoretical issues* (pp. 259–282). Hillsdale, NJ: Erlbaum.

Snodgrass, J. G., & Feenan, K. (1990). Priming effects in picture fragment completion: Support for the perceptual closure hypothesis. *Journal of Experimental Psychology: General, 119,* 276–296.

Squire, L. R. (1986). Mechanisms of memory. *Science, 232,* 1612–1619.

Squire, L. R. (1987). *Memory and brain.* New York: Oxford University Press.

Squire, L. R., & Cohen, N. J. (1984). Human memory and amnesia. In J. L. McGaugh, G. Lynch, & N. M. Weinberger (Eds.), *The neurobiology of learning and memory* (pp. 3–64). New York: Guilford Press.

Squire, L. R., & Shimamura, A. P. (1986). Characterizing amnesic patients for neurobehavioral study. *Behavioral Neuroscience, 100,* 866–877.

Squire, L., Shimamura, A. P., & Amaral, D. G. (1989). Memory and the hippocampus. In J. Byrne & W. Berrys (Eds.), *Neural models of plasticity* (pp. 208–239). San Diego, CA: Academic Press.

Squire, L. R., Shimamura, A. P., & Graf, P. (1987). Strength and duration of priming effects in normal subjects and amnesic patients. *Neuropsychologia, 25,* 195–210.

Sweet, W. H., Talland, G. A., & Ervin, F. R. (1959). Loss of recent memory following section of the fornix. *Transactions of the American Neurological Association, 84,* 76–82.

Tulving, E. (1983). *Elements of episodic memory.* Oxford, England: Clarendon Press.

Tulving, E. (1984). Relations among components and processes of memory. *Behavioral and Brain Sciences, 7,* 257–268.

Tulving, E. (1985). How many memory systems are there? *American Psychologist, 40,* 385–398.

Tulving, E. (1987). Multiple memory systems and consciousness. *Human Neurobiology, 6,* 67–80.

Tulving, E. (1989). Remembering and knowing the past. *American Scientist, 77,* 361–367.

Tulving, E., & Gold, C. (1963). Stimulus information and contextual information as determinants of tachistoscopic recognition of words. *Journal of Experimental Psychology, 66,* 319–327.

Tulving, E., Mandler, G., & Baumal, R. (1964). Interaction of two sources of information in tachistoscopic word recognition. *Canadian Journal of Psychology, 18,* 62–71.

Tulving, E., & Schacter, D. L. (1990). Priming and human memory systems. *Science, 247,* 301–306.

Tulving, E., & Schacter, D. L. (in press). Priming and memory systems. In G. Adelman & B. H. Smith (Eds.), *Neuroscience year: Supplement 2 to the Encyclopedia of Neuroscience.* Cambridge, MA: Birkhauser Boston.

Tulving, E., Schacter, D. L., McLachlan, D. R., & Moscovitch, M. (1988). Priming of semantic autobiographical knowledge: A case

study of retrograde amnesia. *Brain and Cognition, 8,* 3–20.
Tulving, E., Schacter, D. L., & Stark, H. A. (1982). Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8,* 336–342.
Underwood, B. J., & Schulz, R. W. (1960). *Meaningfulness and verbal learning.* Philadelphia: Lippincott.
Upton, G. J. G. (1978). *The analysis of cross-tabulated data.* New York: Wiley.
Wallace, W. P. (1978). Recognition failure of recallable words and recognizable words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 4,* 441–452.
Warrington, E. K. (1976). Memory for facts and memory for events. *British Journal of Clinical Psychology, 25,* 1–12.
Warrington, E. K. (1979). Neuropsychological evidence for multiple memory systems. *Brain and mind: Ciba Foundation Symposium* (Vol. 69, pp. 153–166). Amsterdam: Excerpta Medica.
Warrington, E. K. (1984). *Recognition memory test.* Windsor, England: National Foundation for Educational Research and Nelson.
Warrington, E. K., & Weiskrantz, L. (1968). New method of testing long-term retention with special reference to amnesic patients. *Nature, 217,* 972–974.
Warrington, E. K., & Weiskrantz, L. (1970). Amnesic syndrome: Consolidation or retrieval? *Nature, 228,* 628–630.
Warrington, E. K., & Weiskrantz, L. (1974). The effect of prior learning on subsequent retention in amnesic patients. *Neuropsychologia, 12,* 419–428.
Warrington, E. K., & Weiskrantz, L. (1978). Further analysis of the prior learning effect in amnesic patients. *Neuropsychologia, 16,* 169–177.
Warrington, E. K., & Weiskrantz, L. (1982). Amnesia: A disconnection syndrome. *Neuropsychologia, 20,* 233–249.
Wechsler, D. (1987). *Wechsler Memory Scale—Revised.* New York: The Psychological Corporation.
Weingartner, H., Grafman, J., Boutelle, W., Kaye, W., & Martin, P. (1983). Forms of memory failure. *Science, 221,* 380–382.
Weiskrantz, L. (1987). Neuroanatomy of memory and amnesia: A case for multiple memory systems. *Human Neurobiology, 6,* 93–105.
Weiskrantz, L. (1989). Remembering dissociations. In H. L. Roediger III & F. I. M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honor of Endel Tulving* (pp. 101–120). Hillsdale, NJ: Erlbaum.
Weldon, M. S., Roediger, H. L., III, & Challis, B. H. (1989). The properties of retrieval cues constrain the picture superiority effect. *Memory & Cognition, 17,* 95–105.
Wilkinson, D. A., & Poulos, C. X. (1984). A process theory of remembering: Its application to Korsakoff amnesia and a critique of context and episodic-semantic theories. In L. R. Squire & N. Butters (Eds.), *The neuropsychology of memory* (pp. 67–82). New York: Guilford Press.
Wilkinson, D. A., & Poulos, C. X. (1987). The chronic effects of alcohol on memory: A contrast between a unitary and dual-system approach. In M. Galanter (Ed.), *Recent developments in alcoholism* (Vol. 5, pp. 5–26). New York: Plenum.
Winocur, G., & Weiskrantz, L. (1976). An investigation of paired-associate learning in amnesic patients. *Neuropsychologia, 14,* 97–110.
Witherspoon, D., & Moscovitch, M. (1989). Stochastic independence between two implicit memory tests. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 22–30.
Wood, F. B. (1987). Focal and diffuse memory activation assessed by localized indicators of CNS metabolism: The semantic–episodic memory distinction. *Human Neurobiology, 6,* 141–151.
Wood, F. B., Brown, I. S., & Felton, R. H. (1989). Long-term follow-up of a childhood amnesic syndrome. *Brain and Cognition, 10,* 76–86.
Wood, F. B., Ebert, V., & Kinsbourne, M. (1982). The episodic-semantic memory distinction in memory and amnesia: Clinical and experimental observations. In L. S. Cermak (Ed.), *Human memory and amnesia* (pp. 167–194). Hillsdale, NJ: Erlbaum.
Yule, G. U. (1900). On the association of attributes in statistics. *Philosophical Transactions of the Royal Society, London, Series A, 194,* 257–319.

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