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# The Role of Repetition and Associative Interference in New Semantic Learning in Amnesia: A Case Experiment

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## Abstract

■ The question of whether globally amnesic subjects can learn new semantic (factual) information is controversial. Some students of amnesia believe that they can, others that they cannot. In this article we report an extensive experiment conducted with the amnesic patient K.C. in which we examined the role of repetition and associative interference in his learning of new semantic information. In the course of 8 study sessions distributed over 4 weeks, we taught K.C. novel, amusing definitions of 96 target words (e.g., "a talkative featherbrain—PARAKEET"). We varied systematically the degree of both pre-experimental and intraexperimental associative interference, as well as the amount of study. The results of the experiment showed that

K.C. can learn new semantic knowledge, and retain it over a period as long as 30 months indistinguishably from control subjects. The results further showed that the efficacy of such learning depends critically on both repetition of the material and the absence, or minimization, of pre-experimental and intraexperimental associative interference. These findings suggest that the extent to which at least some amnesic patients can acquire and retain new semantic knowledge depends on the conditions under which learning occurs, and that unqualified statements regarding the deficiency or absence of such learning in amnesia are not justified. ■

## INTRODUCTION

It is a well known and widely accepted clinical and experimental fact that amnesic patients are severely impaired in learning new factual, or semantic, information. Thus, for instance, Drachman and Ardit (1966) found that amnesic subjects were incapable of learning a string of digits longer than 10 presented on successive study and recall trials. Brooks and Baddeley (1976) found little progress by postencephalitic and Korsakoff patients in learning and relearning a list of 10 unrelated paired associates. Gabrieli, Cohen, and Corkin (1983, 1988) found that H.M. and other amnesics were incapable of learning the meanings of 10 rare English words, despite a large number of practice trials. Similar observations have been reported by many others (e.g., Cutting, 1978; Meyer & Yates, 1955; Rozin, 1976; Scoville & Milner, 1957; Squire & Shimamura, 1986; Sweet, Talland, & Ervin, 1959). This learning deficit is so prevalent that it is widely regarded as one of the primary features of the "core" amnesic syndrome (Rozin, 1976; Talland, 1965).

Amnesic patients' inability to learn new factual or semantic information, however, is not total. Both clinical

observations and more formal tests have shown that H.M. has acquired some new knowledge postmorbidly (Corkin, 1984; Marslen-Wilson & Teuber, 1975; Milner, Corkin, & Teuber, 1968). Studies of other amnesic patients have also revealed some acquisition of new semantic knowledge. The tasks used in these studies have included the learning of specified target words embedded in 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), specified target words as parts of meaningful sentences (Shimamura & Squire, 1988), new computer-related vocabulary (Glisky, Schacter, & Tulving, 1986b; Glisky & Schacter, 1988), computer commands as components of simple programs (Glisky & Schacter, 1988; Glisky, Schacter, & Tulving, 1986a), one-word semantic interpretations of ambiguous descriptions of situations and events (McAndrews, Glisky, & Schacter, 1987), and production of words to cues consisting of the initial letters of words (Wilson, 1992).

Three features characterize the learning of new factual or semantic information by amnesic subjects.

First, the learning of new semantic information by amnesic patients is typically slow and inefficient when compared with that of nonamnesic control subjects. Exceptional cases, in which amnesic patients have been shown to learn some semantic material as well as their control subjects (e.g., Cutting, 1978; Warrington & Weiskrantz, 1982; Winocur & Weiskrantz, 1976), may be attributed to the nature of the materials (related, or rule-governed paired associates) that do not require truly *new* learning, and may be more akin to priming.

Second, the learning and retention of the new semantic information usually occurs despite the absence of the amnesic patients' ability to remember the learning episode or episodes, that is, the inability to explicitly recollect the source of the newly acquired information. This phenomenon of "source amnesia" (Schacter et al., 1984; Shimamura & Squire, 1987) means that the new semantic learning by amnesics is classified as "implicit memory," distinguishing it from "explicit memory" revealed in tests in which the subjects consciously recollect (recall or recognize) events from a particular study episode (Graf & Schacter, 1985; Schacter, 1987a).

Third, after learning the new semantic information, amnesic patients typically retain it very well: existing literature suggests that their forgetting rates, even over intervals measured up to weeks and months, are frequently indistinguishable from those of the controls (e.g., Freed, Corkin, & Cohen, 1987; Glisky et al., 1986a, 1986b; Glisky & Schacter, 1988, 1989; Huppert & Piercy, 1979; Kovner et al., 1983; Mattis & Kovner 1984; McAndrews et al., 1987; Tulving, Hayman, & Macdonald, 1991).

Thus, extant evidence is consistent in revealing that (1) amnesics can learn new factual information, (2) such learning occurs despite the inability of the subjects to recollect the learning episodes, (3) this "implicit" semantic learning is slow and laborious, in comparison with normal learners, and (4) once the new information has been acquired, its long-term retention is excellent, being comparable to that of normal learners.

Given these facts concerning new semantic learning in amnesia, the question arises as to the factors and variables that determine the efficacy of such learning. Two different kinds of proposals, which are not mutually exclusive, have been made in this respect. One is that the differences in the efficacy of new semantic learning in amnesia are to be attributed to the severity of amnesia, as well as to different etiologies or the exact nature of cognitive impairments of the patients (Shimamura & Squire, 1989). Another proposal is to the effect that differences in the efficacy of new semantic learning depend on the type of material and the particular conditions under which learning occurs (Tulving et al., 1991). This latter suggestion was prompted by the finding that K.C., a densely amnesic patient, is capable of learning a great deal of purely semantic information under special conditions. These special conditions included extensive practice (repetition) under conditions where opportu-

nities for making errors in the course of learning (sources of interference) were minimized.

The role of repetition in learning by amnesics has not been the focus of particular interest in the literature. It is generally accepted, however, that repetition in situations in which amnesics do exhibit learning has the same facilitative effect as it does in learning by nonamnesic subjects.

The role of interference, on the other hand, has been studied systematically by experimental and theoretical students of amnesia (e.g., Cermak & Butters, 1972; Cermak, Butters, & Moreines, 1974; Mayes, Pickering, & Fairbairn, 1987; Warrington & Weiskrantz, 1973, 1974; Winocur & Weiskrantz, 1976). The findings have corroborated earlier clinical impressions that amnesics seem to be highly sensitive to interference of various kinds. A typical experimental demonstration is that following the learning of the first list in the AB,AC paradigm, amnesics show more negative transfer in the learning of the second list (e.g., Kinsbourne & Winocur, 1980; Mayes et al., 1987; Warrington & Weiskrantz 1974, 1978; Winocur & Weiskrantz, 1976) as well as impaired retention of the first list (e.g., Winocur & Weiskrantz, 1976).

In the present experiment we evaluated the role of repetition and associative interference in new semantic learning by the amnesic subject K.C. Associative interference refers to the hypothetical processes underlying *negative transfer* in situations modeled by the AB,AC paradigm: prior learning, or existence, of an A-B association interferes with the acquisition of an A-C association (Martin, 1971). Semantic learning refers to acquisition of "declarative" or "propositional" information about the world (Lockhart, Craik, & Jacoby, 1976). Semantic learning differs from other forms of learning, such as simple conditioning and learning of skills (procedural memory), short-term memory, and perceptual priming (Tulving & Schacter, 1992; Weiskrantz, 1987). It also differs from "episodic" remembering of personal happenings (Tulving, 1983; Tulving et al., 1991). By "new" semantic learning we mean learning of factual information that is not known to the subject before learning and that could not be arrived at by guessing or the use of some rule or strategy.

Thus the purpose of the experiment reported in this article was to seek systematic evidence regarding the role of two variables—repetition and associative interference—in determining the efficacy of new semantic learning of a severely amnesic subject.

## CASE HISTORY

The single amnesic patient of our study, K.C., has been previously described in two reports, one that was concerned with his retrograde amnesia (Tulving, Schacter, McLachlan, & Moscovitch, 1988) and another that dealt with his preserved capability of perceptual priming and semantic learning (Tulving et al., 1991). In addition, he

has participated in a number of other experiments done at Toronto.

K.C. was born in 1951. At age 16 he received a blow to the head that resulted in admission to the Montreal Neurological Institute where he remained under observation for 3 days. He was discharged on phenytoin and phenobarbital, and remained on these anticonvulsants for 1 year. He had no seizures, but did not re-enter school for 1 year. At age 24 he was involved in a traffic accident, in which he sustained a fractured mandible, but did not lose consciousness. Neither of these head injuries appeared to have deleterious effects on K.C.'s intellectual functioning. He was described as a normal, active, outgoing, and gregarious person. After graduating from high-school, he enrolled in a 3-year course in business administration at a community college, graduating at age 25. In the spring of 1978, at age 27, he became employed at B.E., an engineering company, where his job consisted of two activities: driving a delivery and pick-up truck and conducting quality-control measurements on one of the company's products.

The accident responsible for K.C.'s present condition occurred in October 1981, at age 30. While riding his motorcycle home from work at B.E. he went off the road. No other people or vehicles were involved in the accident. He remained unconscious for approximately 72 hr, when a subdural hematoma was removed from the left cranium. He then became stuporous, but responded to commands. At approximately the seventh post-traumatic day he appeared to recognize his mother. He remained in an intensive care unit for 4 weeks. He was transferred to a rehabilitation hospital 6 weeks after the accident. At the time he exhibited a severe right hemiplegia. He was discharged home in July 1982, where he remained in the care of his parents.

Neurological examination was conducted in December 1986. It revealed an alert, cooperative individual who responded appropriately to all questions. The most striking feature was a marked apathy, flattening of affect, and general indifference to his surroundings. Significant neurological signs included bilateral anosmia, a right homonymous hemianopia with macular sparing, and bilateral optic disc pallor. The eye movements were full in the horizontal and vertical planes, and no nystagmus was evoked. The left pupil measured 6 mm and responded poorly to light and accommodation, whereas the right pupil measured 4 mm and responded more briskly to light and accommodation. The lower cranial nerves were intact.

In the motor system there was ulnar deviation in the right hand, and in the foot lateral deviation of the great toe with marked restriction of movement of the small bones of the foot. The power was intact in upper and lower limbs, and there was slight increase in tone at the elbow but no supinator spasticity. His coordination for fine finger movements and finger-nose testing were intact. No tremor was noted.

Sensation was intact to pin prick, cold, light touch, and position sense. There was no inattention elicited, and two-point discrimination was equal on both sides of the body. In the finger tips, the threshold for two-point discrimination was approximately 2–3 mm. He was able to discriminate between fine and coarse sandpaper in both hands, and dermatographia was intact bilaterally.

Right hyper-reflexia was present in upper and lower limbs. The palmomental reflex was more pronounced on the right; the pout and snout reflexes were brisk. He exhibited a hemiplegic gait.

Computerized X-ray tomographic (CT) and magnetic resonance (MR) scans show extensive lesions in the left hemisphere, and some damage in the right hemisphere. Figure 1 shows the damage identified by the MR scan, localized on templates prepared according to the methods described by Damasio and Damasio (1989). Lesions can be seen in the superior frontal-parietal, medial temporal, medial occipital-temporal-parietal, and occipital regions. These areas include cortical association, limbic, and white-matter structures. There is also a small lesion observable in the right medial temporal region and superior medial parietal region. In addition, there is indi-

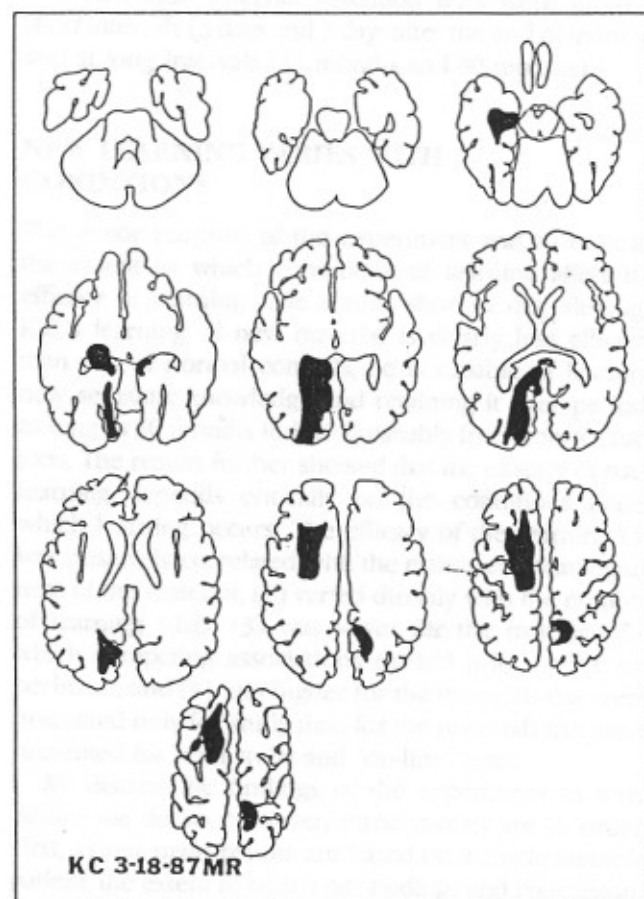


Figure 1. Regions of K.C.'s brain damage estimated from magnetic resonance (MR) scans. The left hemisphere is shown on the left, the right hemisphere on the right. (Templates courtesy Dr. Paul Eslinger.)

cation of abnormality in the region of the left retrosplenial cortex. Positron emission tomography was performed. It revealed that glucose utilization was essentially normal in the regions of the left hemisphere which did not exhibit damage as shown by the CT scan.

Repeated neuropsychological testing has revealed that K.C.'s cognitive functioning, with the exception of long-term memory, is reasonably intact. His IQ as determined by the Wechsler Adult Intelligence Scale—Revised (WAIS-R) 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, but on the Benton Word Fluency (FAS) 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 is normal. His short-term memory is normal: he can recall 8 digits forward and 5 backward, and gets 9 items correct on both forward and backward visual memory span tests of the Wechsler Memory Scale—Revised (WMS-R). His thought processes are normal; there is no confusion or disorganization of any kind. He does not confabulate. Other aspects of his intellectual functioning have been summarized in Tulving et al. (1988).

K.C.'s long-term memory performance is severely impaired. His scores on the WMS-R are as follows: Attention and concentration 99, Verbal memory 70, Visual memory 76, General memory 67, and Delayed Recall < 50. This latter score is below the published norms. His scores are equally impaired on the Warrington Recognition Test (Warrington, 1984), fluctuating around 25/50 for both words and faces, indicating chance performance.

There has been little change in K.C.'s status over the last several years. His anterograde and retrograde amnesia is profound. He does not remember a single event or happening that he himself has witnessed or in which he himself has participated, from any period of his life (Tulving et al., 1988, 1991), regardless of the method of testing or the specificity of cues and prompts that are used in the attempts to elicit recollections. In this sense his episodic memory (Tulving, 1983, 1987) is completely dysfunctional. Since 1991 he has held a part-time clerical job at a public utility company in Toronto, although, when he is not at work, he knows only that he has a job. He can name the company but cannot describe what his work consists of.

## EXPERIMENT

In the course of 8 study sessions distributed over 4 weeks, K.C. was taught novel, amusing definitions of 96 familiar *target* words (e.g., "an underpaid textile worker—SILKWORM," "mates live in, employees outside—PRISON," or "performs a daily massage—TOOTH-BRUSH"). The task can also be thought as one of learning to interpret ambiguous phrases by assigning disambi-

guating terms to them. The degree of both pre-experimental and intraexperimental associative interference, as well as the amount of study, was systematically varied. K.C. learned different sets of these materials, over 8 or 16 distributed learning trials, under conditions that varied with respect to the extent to which competing responses occurred. He was tested for his learned knowledge days after learning, as well as after many months.

Four independent variables were manipulated in the experiment:

1. *High or low* pre-experimental interference, defined in terms of K.C. pre-experimental responses to the definitions.
2. Training procedure: Items (definitions plus target words) were presented for *study only* or for both *study and test* during the training sessions. (We assumed, and obtained data in support of the assumption, that the study-and-test method engenders more "on-line" associative interference during training than does the study-only procedure.)
3. Presentation frequency: Items were presented for study, or for study-and-test, either *once* or *twice* in each training session.
4. Retention interval: Retention tests were given at *short* intervals (3 days and 7 days after the end of training) and at *long* intervals (14 months and 30 months).

## NEW LEARNING VARIES WITH CONDITIONS

The major purpose of the experiment was to evaluate the extent to which conditions of learning affect the efficacy of learning. The results showed that although K.C.'s learning of new material is clearly less efficient than that of normal controls, he is capable of learning new semantic knowledge and retaining it over periods as long as 30 months indistinguishably from control subjects. The results further showed that the efficacy of such learning depends critically on the conditions under which learning occurs. The efficacy of the learning (1) was positively correlated with the estimated meaningfulness of the material, (2) varied directly with the number of learning trials, (3) was lower for the materials for which competing associations existed prior to the experiment, and (4) was higher for the materials that were presented only for study than for the materials that were presented for both study and "on-line" tests.

We discuss the findings of the experiment in turn. Before we do so, however, three caveats are in order. First, as our main results are based on a single amnesic patient, the extent to which our findings and conclusions are generalizable to other amnesic subjects is not known. It is possible, indeed highly probable, that different amnesic patients vary in their ability to learn new information. Second, as we used only one kind of material in

the learning, the generalizability of the findings to other materials, such as pairs of unrelated words, is also unknown. Third, our experiment did not allow us to determine to what extent the "new" semantic knowledge that K.C. learned in this experiment was similar to or different from the facts about and knowledge of the world that he had acquired before the onset of his amnesia, that is, to what extent the new learning was incorporated into K.C.'s semantic knowledge structures, and to what extent they represented only "free radicals" (Tulving, 1983). These and other related issues can be settled only through future research.

### The Role of 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 facilitative role played by the meaningfulness of materials is well known in the literature on normal learning and memory (e.g., Underwood & Schulz, 1960), and the available data point to the same relation in studies with amnesics (e.g., Cutting, 1978; Kovner et al., 1983; McAndrews et al., 1987; Shimamura & Squire, 1987; Squire & Shimamura, 1986; Warrington & Weiskrantz, 1982; Winocur & Weiskrantz, 1976).

The present results reinforce the hypothesis that an important condition of new semantic learning in amnesia is the consistency of the to-be-learned relation with existing concepts, or meaningfulness. In the present experiment, meaningfulness of individual items (phrase-target pairs) was rated by K.C. and the results showed the expected correlation between these ratings and the learning of items. These meaningfulness ratings, gathered at the beginning and at the end of the study trials, were positively associated with the frequency of correct responding, although only ratings from the end of the study trials were statistically reliable. The observation that ratings of meaning are predictive of learning is consistent with a form of declarative rather than procedural memory (cf. Squire, 1987). That is, the experimental presentations resulted in changes that affected K.C.'s ability to both solve a phrase-cue with a single word and to deliberately assess what was known about a phrase-target pair. In general, it can be stated that the ease with which new semantic learning was acquired by K.C. was correlated with the extent to which the to-be-learned relations were consistent, or not inconsistent, with pre-existing concepts.

### Variable Effects of Repetition

The results of our experiment confirm the relevance of repetition, and they add a new dimension to the known facts about its effects in learning by amnesics. The direct

comparison between the retention performance, in Sessions 9 and 10, with the materials presented once versus twice in Sessions 1 to 8, confirms the direct effect of repetition: when the data are averaged over other conditions, K.C. produced 48% of the once-per-session targets and 71% of the twice-per-session targets.

The novel dimension of the results has to do with the nature of the effects of repetition. With the type of the learning task and the nature of the to-be-learned material held constant, the results show that the efficacy of trial-by-trial learning can depend greatly on the conditions of trial-by-trial practice. Calculations based on the data shown in Table 3 indicate that K.C. could produce, on the average, 42% of the target words following the study-and-test training procedure and 77% of the target words following the study-only procedure in Sessions 3 to 8. Because the frequency of presentation of the to-be-learned materials was identical in the two conditions, it follows that the effect of repetition depends on the nature of the learning task, specifically with the conditions of interference. We will discuss the matter further below.

Two conclusions regarding the effect of repetition can be drawn:

1. Although K.C. learns new factual information more slowly than subjects without memory impairment, this learning is facilitated by repetition.
2. The facilitative effects of repetition may vary greatly with other conditions of learning.

### The Role of Associative Interference

Our experiment was designed to assess the role of associative interference from two sources, pre-experimental and intraexperimental. Pre-experimental interference was manipulated in terms of the presence or absence of responses competing with the designated target responses. The retention data summarized in Table 3 show that the pre-experimental interference did have an effect on learning and retention performance. With the data averaged over the other conditions, K.C. produced 50% of the high-interference targets, which had pre-experimentally established competing responses, and 69% of the low-interference targets, which had no such competing responses.

Intraexperimental interference was manipulated indirectly, through the two training methods used. The study-and-test method allowed K.C. to make incorrect responses during the on-line tests, whereas in the study-only method such responses were precluded by design. K.C. did in fact make many incorrect responses in the retention tests in Sessions 9 and 10, especially when faced with the high-interference materials, as shown by the data summarized in Table 4. It is the overall pattern of these data that allows us to interpret the difference in performance between study-and-test and study-only

methods in terms of the interfering effects of competing responses.

The two sources of interference are additive. K.C.'s retention performance in Sessions 9 and 10, in the presence of both pre-experimental and intraexperimental interference (high-interference materials learned by the study-and-test method), with the data averaged over once-presented and twice-presented targets, was 29%, whereas in the absence of interference from either source (low-interference materials learned by the study-only method) his retention performance was 84%. This large difference is the most important finding of the experiment. It attests to the powerful role that associative interference plays in the learning of new semantic information by at least one amnesic patient.

The role of interference in learning and memory by subjects without memory impairments has been thoroughly studied and discussed (e.g., Martin, 1971; Postman, 1971; Runquist, 1975; Underwood & Postman, 1973). The concept of interference has also been invoked in the psychological interpretations of the memory deficits exhibited by amnesic patients (e.g., Cermak & Butters, 1972; Cermak et al., 1974; Mayes et al., 1987; Warrington & Weiskrantz, 1973, 1974; Winocur & Weiskrantz, 1976).

Our results add to the existing knowledge by directly implicating associative interference as an important determinant of new semantic learning in amnesia. They show that the variations in the magnitude of the effects of interference can be surprisingly large. The data shown in Table 2 (study-and-test condition for the high pre-experimental interference items presented once per session) show that up until the *eighth* training trial, K.C. had not produced a single correct response. If we had tested K.C.'s ability to learn new information only under those, rather typical, conditions, we would have had to conclude that he cannot learn new factual (declarative) information, and we would have pointed out that such failure occurred despite a rather large number of (distributed) learning trials. This conclusion would have been regarded as unremarkable and highly redundant with what is already known about amnesia. It is only because of the other conditions included in the experiment that the actual results are somewhat more remarkable. Against the near-zero performance in the condition just referred to, the data summarized in Table 3 show that K.C. was capable of producing 92% of the learned target words in another condition: low pre-experimental interference items presented twice per session for study only.

These results suggest that previously published statements concerning the impossibility of new semantic learning by amnesic patients, and the empirical grounds on which they have been based, are worth re-examination. At the very least it is clear that absolute statements about what amnesic subjects can or cannot learn are not

justifiable. Much depends on the conditions of learning. Repeated presentation of the to-be-learned material under conditions where associative interference is minimized seems to constitute a favorable condition of new semantic learning in amnesia.

In this connection it is interesting to note that the most popular method that has been used to study new "declarative" learning in amnesia—the anticipation method of paired associates—(e.g., Brooks & Baddeley, 1976; Shimamura & Squire, 1984; Squire & Shimamura, 1986) is far from optimal. The materials used are probably always loaded with hidden pre-experimental associative interference, and the study-and-test procedure inevitably begets a great deal of on-line interference. The difficulty that amnesic patients have had in learning paired-associates under these conditions fits well with the results observed in the least optimal conditions of the present experiment, as discussed above. The "standard gross impairment of verbal learning that is characteristic of globally amnesic patients" (Brooks & Baddeley, 1976, p. 113, emphasis added) may tell us as much, if not more, about the methods that the experimenters have used than about the inherent capabilities of amnesic subjects.

The widely cited results of an experiment by Gabrieli et al. (1983, 1988), in which they found that H.M. and other amnesics could not learn the meanings of 10 rare English words, such as HEGIRA, QUOTIDIAN, and WELKIN, despite a large number of practice trials, is worth special mention in the present context. The method that these experimenters used to teach their amnesic patients new semantic information was highly conducive to the making of large numbers of erroneous responses. In their procedure, on every learning trial, the patient was provided with a definition or a sentence frame, together with the whole set of 10 to-be-learned words. The subject's task was to select the correct response from the set, with guessing required. The selection procedure for any given target word continued until the correct target word was selected by the patient, at which point the procedure was repeated with the next definition and the set of remaining target words. This procedure engenders a great deal of incorrect responding, allowing interference to be built up in the course of learning. It is possible, therefore, that H.M. and other amnesic patients in the Gabrieli et al. (1983, 1988) experiments failed to exhibit any learning, because they fell victim to the forces of associative interference.

Why are amnesic patients extraordinarily sensitive to associative interference? This is an involved issue that we cannot discuss at any length here. We simply note that in light of the results we have reported here this important question gains even greater urgency. We also wish to reaffirm suggestions made earlier that amnesic subjects' sensitivity to interference may be a direct consequence of their lack of episodic memory (e.g., Kinsbourne, 1987; Baddeley, 1992; Tulving et al., 1991).

Normal individuals, who "possess" intact episodic memory, can differentiate between similar events, and between two competing responses to one and the same stimulus, on the basis of their ability to consciously recollect the temporal and spatial contexts of these events, and their direct involvement with them. Patients with brain damage, such as some amnesics, whose episodic memory is dysfunctional, cannot rely on this resource, and are therefore handicapped in updating and modifying previously acquired information (Kinsbourne, 1987; Kinsbourne & Winocur, 1980; Mayes et al., 1987; Parkin, 1982).

An interesting problem for future research is to identify the brain regions subserving an individual's ability to overcome associative interference and to update or modify previously acquired information. The role of the frontal lobes, in light of their hypothesized connection to episodic memory, holds out especial interest in this respect (Schacter, 1987b; Shimamura, Janowsky, & Squire, 1990; Warrington & Weiskrantz, 1982; Weiskrantz, 1987).

## METHOD AND RESULTS

### Background Information

The experiment was carried out in parallel with a number of other studies, involving 4 to 5 hr visits to the laboratory once or twice a week over many weeks. It consisted of five successive stages: (1) Pretest, (2) Initial study—two sessions, (3) Study-and-test training—six sessions, (4) Short-term (3-day and 7-day) retention tests—two sessions, and (5) Long-term (14-month and 30-month) retention tests—three sessions. The pretest was conducted 1 week before the first study session. The remaining sessions were conducted twice weekly for 6 weeks, with a 2-week hiatus between sessions 4 and 5. The results of the pretest were used to construct the sets of materials for the main study; the manipulation of the experimental variables of interest took place during study (and testing) during Stages 2 and 3; and the critical data of the experiments were yielded by the assessment of retention of the material in Stages 4 and 5.

Four control subjects underwent an abbreviated procedure, as they reached the ceiling of performance in only a few sessions. In what follows, we describe the method used, and the results obtained, with K.C. first, followed by the same coverage for the control subjects.

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 implicit knowledge of the material, as revealed through the production of appropriate responses to given cues.

### Materials and Task

The materials were selected from a pool of 288 items used by Tulving and Watkins (1977) and by Donnelly (1988). Each item consisted of a short phrase or statement that served as a description or definition of a noun. Examples are "a talkative featherbrain"—PARAKEET, "Marlon Brando's wife"—GODMOTHER, and "a servant in name only"—BRIDESMAID. We will refer to the phrase part of a complete item as the "phrase," "phrase cue," or "cue," and to the noun part of the item as the "target word" or "target."

The learning task set for K.C., and the control subjects, was to learn to produce the target word to the phrase cue. We refer to the task as one of semantic learning, although it can be described more specifically in various ways as learning of (1) new semantic definitions of the target words, or (2) new factual information about the concepts designated by the target words, or (3) new associations between the phrase cues and the target words.

### Pretest and Design

In the pretest, K.C. was shown 180 phrases randomly selected from the pool and asked to name a word that would fit the definition suggested by the phrase. He was given three practice phrases (e.g., "a surface disorder of youth") followed by the solution (ACNE) to illustrate the "kind of answer that other people had given." He was told that there were no right answers, and that he did not have to produce a response: if an appropriate word did come to mind, he should say it; if he could not think of one, he should say so. Individual phrases were presented for 15 sec, K.C.'s answers were recorded, but no target words were presented.

The results of the pretest allowed a selection of a total of 96 phrase-noun pairs to serve as experimental items. One half of these were items for which K.C. had not provided any response during the pretest—we refer to these as low (pre-experimental) interference items. The other 48 items were items from the pretest for which K.C. had provided a response that did *not* match the predetermined target word, that is, an "incorrect" response to the phrase cue—these items constituted high (pre-experimental) interference items. The occasional items for which K.C. produced the "correct" experimentally designated target words were eliminated.

Four independent variables were manipulated in the experiment:

1. Degree of pre-experimental interference: *High* or *low*, operationally defined in terms of the results of the pretest as explained above.
2. Training procedure: The material was presented for *study only* or for both *study and test* during the training sessions.

3. Presentation frequency: The material was presented for study, or for study-and-test, either *once* or *twice* in each training session.

4. Retention interval: Retention tests were given at *short* intervals (3 days and 7 days after the end of training) and at *long* intervals (14 months and 30 months).

The two levels of each of the first three of these independent variables were combined orthogonally to yield a  $2 \times 2 \times 2$  design: 2 levels of frequency of presentation during a training session (once or twice), combined with 2 levels of pre-experimental interference (high vs. low), and with 2 levels of type of training (study only vs. study-and-test). Short-term (3 and 7 days) and long-term (14 and 30 months) retention was assessed for all learned items in all tests.

To implement the design, each of the two 48-item interference sets (high and low) was randomly subdivided into four subsets of equal size. The resulting subsets were randomly assigned to one of eight factorial conditions of the experiment, one subset of 12 items per condition.

## Sessions 1 and 2

### Method

K.C. was given the same instructions and practice items as in the pretest. He was then presented with the 96 phrase-noun (cue-target) pairs for study and assessment of "meaningfulness," as follows. Each item was presented one at a time. A phrase would appear on the computer screen and after 15 sec, or immediately after K.C. had produced a response (whichever came first), the corresponding target word appeared below the phrase. Next the question, "Do you think you could have guessed the answer (Y/N)?" would appear below the phrase and solution. After K.C. had indicated whether or not he thought he could have guessed the answer, the first question was removed and replaced by the second question, "How many other people do you think might have guessed the answer (Very few, Some, Many)?" After K.C. had responded to the second question, the whole display was removed and the next phrase was shown. This cycle was repeated for all 96 phrase-target combinations, or 96 study-list items.

Following a delay of approximately 2.5 hr, during which K.C. was occupied with other tasks, 48 items in the set designated for presentation twice in a session were shown to K.C. again. The procedure was exactly the same as before.

This procedure was repeated in Session 2. Sessions 1 and 2 served (1) as an initial stage of training, (2) as an initial assessment of the extent of learning and retention, and (3) as a check on the pre-experimental existence of competing responses.

## Results

The results of Sessions 1 and 2 are summarized in Table 1. Each entry in Table 1 is based on a set of 24 items, as at this stage of the experiment there was no distinction between the two types of training.

The data in Table 1 show that (1) K.C. managed to learn very little under the conditions of Sessions 1 and 2, (2) he made numerous (erroneous) competing responses for the phrases in the High-Interference sets, and (3) he made practically no such erroneous responses in the Low-Interference sets.

## Training Sessions 3-8

### Method

In each of Sessions 3 to 8, K.C. was shown a total of 96 phrases for 15 sec each. The set of 48 once-presented ( $1\times$ ) items was shown first, followed by the set of 48 twice-presented ( $2\times$ ) items, or vice versa, the order of the sets alternating between sessions.

For 24 of the phrases in each set (the study-and-test items), K.C. was asked to name a word that fit the definition in the phrase. After 15 sec, or if K.C. provided a response, whichever came first, the target word appeared on the screen below the phrase cue. Whenever K.C. produced either an incorrect response or no response during the presentation of the phrase, the question "Do you think you would have guessed this answer?" appeared on the screen. After he had responded "yes" or "no," he was asked a second question, "How many other people do you think might have guessed the answer? Very few, some, or many?" Whenever K.C. produced the correct target to the phrase cue within 15 sec, only the second question was asked.

For the remaining 48 phrases (the study-only items), consisting of 24 items in each of two presentation-frequency sets, the target word was presented at the same time as the phrase cue, and K.C. was asked only the second question. Within each frequency set, the presentation order of phrases with or without solutions (target words) was randomly determined; however, the order of items within each set remained constant across sessions. Each session began with four practice phrases, two with solutions presented along with the phrases and two with solutions presented only after K.C. had time to come up with a solution on his own. He was asked the first and/or second questions according to the procedure outlined above.

Approximately 2.5 hr later, all 48 phrase cues in the  $2\times$  set were presented again. The procedure was identical with that used before.

## Results

A summary of the results of the testing in Sessions 3 to 8 is given in Table 2, which shows proportions of correct

**Table 1.** Proportions of Correct Targets and Competing Responses Produced by K.C. in Sessions 1 and 2

Session and Presentation	Correct Targets				Incorrect Responses			
	Presentation Frequency							
	2×		1×		2×		1×	
	Interference							
	High	Low	High	Low	High	Low	High	Low
Session 1								
First presentation	0.00	0.04	0.00	0.04	0.33	0.00	0.58	0.00
Second presentation	0.04	0.04	—	—	0.54	0.00	—	—
Session 2								
First presentation	0.04	0.00	0.00	0.08	0.50	0.00	1.00	0.00
Second presentation	0.08	0.00	—	—	0.62	0.04	—	—

**Table 2.** Proportions of Correct Targets and Incorrect Responses Produced for the Study-and-Test Items in Sessions 3 to 8

Session and Presentation	Correct Targets				Incorrect Responses			
	Presentation Frequency							
	2×		1×		2×		1×	
	Interference							
	High	Low	High	Low	High	Low	High	Low
Session 3								
First presentation	0.08	0.25	0.00	0.08	0.75	0.08	0.83	0.25
Second presentation	0.08	0.17	—	—	0.67	0.00	—	—
Session 4								
First presentation	0.25	0.42	0.00	0.25	0.50	0.08	0.92	0.08
Second presentation	0.25	0.42	—	—	0.67	0.00	—	—
Session 5				0.08				
First presentation	0.08	0.25	0.00		0.75	0.00	0.67	0.33
Second presentation	0.25	0.42	—	—	0.50	0.00	—	—
Session 6								
First presentation	0.25	0.42	0.00	0.17	0.58	0.08	0.83	0.08
Second presentation	0.33	0.42	—	—	0.58	0.00	—	—
Session 7								
First presentation	0.50	0.50	0.00	0.17	0.42	0.00	0.92	0.17
Second presentation	0.50	0.50	—	—	0.33	0.08	—	—
Session 8								
First presentation	0.50	0.58	0.17	0.33	0.42	0.08	0.75	0.17
Second presentation	0.50	0.58	—	—	0.33	0.00	—	—
Mean	0.30	0.41	0.03	0.18	0.54	0.03	0.82	0.18

target productions and incorrect responses for High- and Low-Interference items and for the two presentation frequencies. These data represent only items in the study-and-test condition, because the items in the study-only condition were only presented for study and not tested in any way during Sessions 3 to 8.

Five features of these summary data should be noted. First, there was a gradual improvement in K.C.'s performance over the sessions: correct target production increased more-or-less regularly from Session 3 to Session 8. Second, this improvement was noticeably greater for the 2× items than for the 1× items. Third, K.C. produced more low-interference items than high-interference items (mean proportions of 0.25 and 0.16, respectively). Fourth, K.C. produced large proportions of incorrect responses to high-interference phrase cues and relatively few such responses to low-interference phrase cues (mean proportions of 0.68 and 0.10, respectively). Fifth, the trend of the data over Sessions 3 to 8 suggests that in the high-interference 2× set of items correct targets gradually replaced the incorrect responses, as the total frequency of responses remained at an essentially constant high level throughout.

## Sessions 9 and 10

### Method

Session 9 was held 3 days after Session 8. Its purpose was to assess the acquisition and retention of all the materials studied in Sessions 1 to 8, including the items in the study-only condition that had not been tested in Sessions 3 to 8. The procedure was identical with that used in Sessions 1 and 2, except that all 96 phrases were presented only once. K.C.'s responses to the 96 phrase cues were recorded. The procedure was repeated in Session 10 (7-day retention test) in order to estimate the reliability of the 3-day retention data.

### Results

A summary of the results of Sessions 9 and 10 is presented in Table 3 (correct target words) and Table 4 (incorrect responses). The patterns of data for Sessions 9 and 10 for both target and incorrect response production were very similar, attesting to the reliability and stability of the results. We therefore combined these data for further analyses, with 24 observations in each condition. An additional measure of the stability of these data is the high positive dependency observed for correct target word production in Sessions 9 and 10 [ $Q = .893$ ,  $\chi^2(1) = 30.0$ ,  $N = 96$ ]. (For discussion of the  $Q$  measure of association, see Hayman & Tulving, 1989.)

First, the data in Table 3 show a superiority in the learning and retention of twice-presented items (mean = 0.71) over the once-presented items (mean = 0.48). This difference was highly significant ( $z = 3.25$ ,  $N = 96$ ,  $p < 0.001$ ). (All significance levels reported are for two-tailed

tests, except where noted otherwise.) The difference was larger for the study-and-test items (means of 0.58 and 0.25 for twice- and once-presented items,  $z = 3.41$ ,  $N = 48$ ,  $p < 0.001$ ) than for the study-only items (means of 0.83 and 0.71 for twice- and once-presented items,  $z = 1.35$ ,  $N = 48$ ,  $p < 0.09$  one-tailed). Thus, this finding speaks to the issue of repetition: K.C.'s learning and retention of the material improved with repetition.

Second, K.C. learned and retained more low-interference (mean = 0.69) items than high-interference items (mean = 0.50). This difference was present in all four individual comparisons, and was significant ( $z = 2.62$ ,  $N = 96$ ,  $p < 0.01$ ). This finding suggests that pre-experimental interference is an important determinant of learning of new associations: a new association is more difficult to learn if an old one already exists.

Third, there was a large effect of the method of study. K.C.'s performance in the study-only condition (mean = 0.77) was higher than in the study-and-test condition (mean = 0.42). This difference was present in all four individual comparisons, and was highly significant ( $z = 5.27$ ,  $N = 96$ ,  $p < 0.001$ ).

A comparison of the data in Tables 3 and 4 reveals that, in general, K.C.'s overt production of incorrect responses was negatively correlated with the production of correct responses ( $r = -0.84$ ,  $p < 0.01$ ,  $df = 6$ ). However, the production of incorrect responses was largely confined to the high-interference items (mean = 0.46). The low-interference items (mean = 0.07) were close to the floor levels, and they showed no significant differences among conditions. For this reason, we consider only the high-interference items in the following analysis. The main finding for high-interference items is that the study-and-test procedure produced significantly more incorrect responses (mean = 0.67) than did the study-only condition (mean = 0.25;  $z = 4.40$ ,  $N = 48$ ,  $p < 0.001$ ). The production of incorrect responses only approached significance ( $z = 1.56$ ,  $N = 48$ ,  $p < 0.06$  one-tailed) and as expected was numerically larger in the once-presented condition (mean = 0.54) than in the twice-presented condition (mean = 0.38). This difference occurred primarily in the study-and-test condition (means = 0.54 and 0.79 for twice- and once-presented items,  $z = 1.75$ ,  $N = 24$ ,  $p < 0.05$  one-tailed) and was noticeably smaller in the study-only condition (means = 0.21 and 0.29 for twice- and once-presented items,  $z = 0.50$ ,  $p > 0.30$  one-tailed).

## Control subjects

### Method

The control subjects were given the same phrase-noun pairs in the same conditions as those presented to K.C. This procedure allowed a rough check to be made about the general memorability of phrase-noun pairs in the high- and low-pre-experimental interference conditions and in the study-and-test and study-only training condi-

**Table 3.** Summary of the Results of the 3-Day and 7-Day Retention Tests: Proportions of Correct Targets Produced by K.C. in Sessions 9 and 10

Session	Study-and-Test				Study Only			
	Presentation Frequency							
	2×		1×		2×		1×	
	Interference							
	High	Low	High	Low	High	Low	High	Low
Session 9	0.50	0.75	0.00	0.33	0.83	0.92	0.67	0.75
Session 10	0.42	0.67	0.25	0.42	0.67	0.92	0.67	0.75
Mean	0.46	0.71	0.12	0.38	0.75	0.92	0.67	0.75

**Table 4.** Summary of the Results of the 3-Day and 7-Day Retention Test: Proportions of Incorrect Responses Produced by K.C. in Sessions 9 and 10

Session	Study-and-Test				Study Only			
	Presentation Frequency							
	2×		1×		2×		1×	
	Interference							
	High	Low	High	Low	High	Low	High	Low
Session 9	0.50	0.00	0.83	0.17	0.17	0.00	0.25	0.08
Session 10	0.58	0.08	0.75	0.17	0.25	0.00	0.33	0.08
Mean	0.54	0.04	0.79	0.17	0.21	0.00	0.29	0.08
Mean Targets	0.46	0.71	0.12	0.38	0.75	0.92	0.67	0.75
Mean Incorrect	0.54	0.04	0.79	0.17	0.21	0.00	0.29	0.08

tions. The same pattern of results between pre-experimental interference items for control subjects and K.C. would suggest a general effect of item difficulty rather than a specific effect of proactive interference. The same pattern of results between training conditions for control subjects and for K.C. would suggest a common effect of learning or of item difficulty rather than a problem in learning specific to amnesia.

### Results

There were no main effects of either pre-experimental interference (means = 0.83 and 0.84 for high- and low-interference items, respectively) or of training procedure (means = 0.83 and 0.85 for study-and-test and study-only items, respectively). There was, however, a significant effect of presentation frequency (means = 0.90 and 0.78 for twice- and once-presented items, respectively). Because the effect of two versus one presentation per trial was numerically the weakest of the three variables af-

fecting K.C.'s performance, the presence of an effect of presentation frequency for the controls rules out ceiling effects as an explanation of the absence of either training procedure or interference effects. In summary, the pattern of responses produced by control subjects was different from that produced by K.C., presumably reflecting the absence of interference effects on learning that influenced K.C.'s performance.

### The 14-Month and 30-Month Retention Tests

#### Method

Three delayed tests were given to K.C., one 14 months after Session 10, and two further tests, separated by 1 week, 30 months after Session 10. In each of these tests, the procedure was identical with that used in Sessions 9 and 10. K.C.'s performance in the 14-month test was similar (although somewhat higher) to that in the 30-month test. The three control subjects were tested individually, in a single session, 18 months after they had

studied the material. The procedure was the same as that used with K.C., except that the control subjects were reminded of the learning that had taken place 18 months earlier, and their instructions were for (cued) recall, with guessing encouraged, of the target items studied on that occasion. During the retention interval neither K.C. nor any of the three control subjects was exposed to the material again, with the exception of K.C.'s performance in the 14-month test, which may have influenced his performance at 30 months.

## Results

The results of the immediate and delayed tests for K.C. and for the three control subjects are presented in Table 5 and showed more-or-less comparable retention of the material. That is, the absolute level of correct targets in the delayed tests produced by K.C. (means = 0.30 and 0.18 for 14- and 30-month) was as good as or better than that produced by the control subjects (mean averaged over 3 subjects = 0.17). Such a result may appear remarkable, inasmuch as in the immediate test of retention (1 week following learning) the control subjects' performance (mean = 0.84) was clearly superior to K.C.'s (mean = 0.59), and inasmuch as control subjects were in a position at least to rely on their intact episodic memory in performing the task. The data in Table 5 can be used to estimate savings (the ratio of delayed to immediate performance). The savings were actually larger for K.C. (51% and 31% for 14- and 30-month delays, respectively) than for the control subjects (20%). The meaning of this difference, however, is not entirely

clear. It could be a function of differences in retroactive interference (e.g., Mayes et al., 1987), or in the degree of original learning (e.g., Slamecka & McElree, 1983; Underwood, 1964). The relevant observation is that, on the basis of the data, there is no reason to conclude that K.C.'s rate of forgetting was greater than that of the control subjects.

There are two additional points of interest in the pattern of savings observed for K.C. that together imply that the effects of interference on learning are different from the effects of interference on forgetting. First, the existence of a pre-experimental response had similar effects for savings and for learning. The estimated savings for phrase-target pairs that had a pre-experimental response (42% and 15% for 14- and 30-month delay, respectively) were noticeably smaller than the savings estimated for phrase-target pairs that did not have a pre-experimental response (57% and 41% for 14- and 30-month delay, respectively). This implies that the associative interference that inhibited learning in this condition also increased the rate of forgetting. Second, the presence or absence of on-line testing had opposite effects for savings and for learning. The estimated savings for tested responses (60% and 38% for 14- and 30-month delays) were numerically larger than savings for study-only responses (46% and 26% for 14- and 30-month delays). This result implies that intraexperimental interference from test trials during study had different effects on learning and on forgetting. In sum, the amount and pattern of interference observed with K.C. at learning, as estimated from Sessions 9 and 10, were not predictive of the amount and pattern of savings observed in the

**Table 5.** Summary of the Results of the Immediate and Delayed Retention Tests: Proportions of Correct Targets Produced by K.C. and Control Subjects in the Immediate and Delayed Tests<sup>a</sup>

	<i>Study-and-Test</i>				<i>Study Only</i>				<i>Mean</i>
	<i>Presentation Frequency</i>								
	<i>2×</i>		<i>1×</i>		<i>2×</i>		<i>1×</i>		
	<i>Interference</i>								
	<i>High</i>	<i>Low</i>	<i>High</i>	<i>Low</i>	<i>High</i>	<i>Low</i>	<i>High</i>	<i>Low</i>	
K.C.									
Immediate	0.46	0.71	0.12	0.38	0.75	0.92	0.67	0.75	0.59
Delayed 14 months	0.17	0.33	0.17	0.33	0.17	0.42	0.33	0.50	0.30
Delayed 30 months	0.08	0.38	0.00	0.17	0.13	0.29	0.08	0.29	0.18
Average of 3 Control subjects									
Immediate	0.89	0.92	0.72	0.78	0.89	0.89	0.83	0.78	0.84
Delayed 18 months	0.22	0.27	0.04	0.10	0.17	0.25	0.14	0.10	0.17

<sup>a</sup>The immediate test performance for K.C. is the average of 3- and 7-day tests and for the Control subjects is a single 7-day test. The delayed 30-month test performance for K.C. is an average of two tests at 30 months following learning and for the Control subjects it is an average of two tests at 18 months following learning.

delayed tests. Although intraexperimental interference had a larger absolute effect on learning (0.44 vs. 0.77 for study-and-tested and study-only pairs, respectively) than did pre-experimental interference (0.50 vs. 0.69 for pre-test response and no response, respectively), only pre-experimental interference significantly affected the amount of forgetting.

### Meaningfulness and Learning

Throughout the experiment, items were not only presented for study (and test) to K.C., they were also rated by him as to their meaningfulness. Every time a complete item (phrase cue and target word) was presented to K.C., he was also asked to estimate how many "other people" might produce the target word to the phrase cue when asked to do so. We assumed that those items for which K.C. provided rating of "some" or "many" were more meaningful to him than those items for which he provided the rating of "none."

To evaluate the role of meaningfulness on learning of the definitions, we divided the total set of 96 items into two subsets: 60 "less" meaningful items for which K.C. had provided no, or only one, rating of "some" or "many" other people in Sessions 3 to 8, and 36 "more" meaningful items for which he had provided at least two such ratings during those sessions. We then contrasted the production of the targets averaged over the 3-day and 7-day retention sessions (Sessions 9 and 10) in terms of the "less" and "more" meaningful division. The results of this analysis are summarized in Table 6.

The data in Table 6 show that the production of targets was uniformly higher for the items estimated as being more meaningful than those estimated as being less meaningful. When the data were pooled over all eight conditions shown in Table 6, the target production of low-meaningful items was 0.58, whereas that of high-meaningful items was 0.86. To evaluate the statistical significance of this relation a  $3 \times 2$  table was constructed

comparing the frequency correct on Sessions 9 and 10 (none, one, or two) with the preceding estimate of meaningfulness (less or more). The data were collapsed over the different study conditions because of the small number of observations in some conditions. The Pearson  $\chi^2$  test statistic for this table was 8.18 ( $df = 2, p < 0.02$ ), indicating a significant dependence between the conditions, where responses for phrase-target pairs that received a high rating were more likely to be produced correctly. The contingency coefficient for the table was 0.28.

The dependence observed between ratings of meaningfulness at study and correct responses at test could reflect one of two underlying relations. Pre-experimental meaningfulness could have determined both the rating and the ease of learning, or the experimental learning could have determined both the ratings and the frequency correct. To evaluate these explanations an additional analysis was performed comparing the frequency correct on Sessions 9 and 10 with ratings obtained from Sessions 1 and 2. It was hypothesized that if pre-experimental meaningfulness was responsible for the previous dependence, then this comparison should also show dependence. However, if experimental learning was responsible, then little dependence should be seen because ratings from Sessions 1 and 2 were obtained before much experimental learning had occurred (e.g., see Table 1). In this comparison there were 53 less meaningful items, which received no "some" or "many" ratings, and 43 more meaningful items, which received one or two such ratings. The test statistic for this  $2 \times 3$  table failed to reach significance [ $\chi^2(2) = 2.22, p > 0.3$ ; the contingency coefficient for the table was 0.15]. Thus although phrase-target pairs receiving a more meaningful rating at the beginning of the experimental sessions tended to be positively related to frequency correct at test in Sessions 9 and 10, they were not reliably related to test performance. Indeed, of the 48 phrase-target pairs that K.C. produced correctly on both Sessions 9 and 10,

**Table 6.** Proportions of Correct Target Words Produced by K.C. in Sessions 9 and 10, as a Function of Estimated Meaningfulness of the Items<sup>a</sup>

Session and Presentation	Study-and-Test				Study Only			
	Presentation Frequency							
	2×		1×		2×		1×	
	Interference							
	High	Low	High	Low	High	Low	High	Low
Lower	0.44	0.63	0.00	0.32	0.67	0.88	0.50	0.63
Higher	0.50	1.00	0.25	1.00	0.83	1.00	0.78	1.00
Mean	0.46	0.71	0.13	0.34	0.75	0.92	0.67	0.75

<sup>a</sup>See text for explanation.

only half or 24 had been rated as meaningful in Session 1 or 2. Thus, although an effect of pre-experimental meaningfulness on ratings and frequency correct should not be ruled out, it appears more likely that experimental exposure enhanced the meaningfulness of the phrase-target relation.

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