INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600

Implicit and explicit cognitive functioning in hippocampal amnesia

by

William Winter

A dissertation submitted to the Doctoral Faculty in Psychology
in partial fulfillment of the requirements for the degree of Doctor of Philosophy
The City University of New York

1995

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

This manuscript has been read and accepted by the Doctoral Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy

7/23/05

Date

Chair of the Examining Committee

8/[illegible]/05

Date

Executive Officer

David Owen

Rhianon Allen

Arthur Reber

Supervisory Committee

The City University of New York

Abstract

IMPLICIT AND EXPLICIT COGNITIVE FUNCTIONING IN HIPPOCAMPAL AMNESIA

by

William Winter

Advisor: Arthur S. Reber

The research reported here constitutes a cognitive neuropsychological profile of an adult male (M.S.) who became severely amnesic following a major hypoxic episode occurring at the age of eight. Recent MRI studies have confirmed the presence of a bilateral atrophy of the hippocampal formation which does not involve surrounding cortical tissue. Across ten evaluations, this subject demonstrated a general preservation of implicit cognitive functioning despite clear explicit deficits. This assessment was complicated, however, by anomalous results on certain evaluations. For example, M.S. showed relatively slow acquisition of a "perceptual/motor skill" task (the computer game Tetris). In another series of evaluations, M.S. showed evidence of an unexpectedly low rate of priming in word-stem completion, but showed a robust effect on another task ("fame-priming") which does not involve responses to partial letter sequences. This result, when combined with several other sources of evidence described herein suggest the possibility of an "acquired dyslexic" condition which may be a consequence of his hypoxic injury. The slowed rate of learning on Tetris is viewed as a function of depressed motoric response, and to subtle but significant demands upon long-term explicit memory through repeated testings. It was also concluded, based upon the results of several of these evaluations and related observations, that M.S. possesses a significant residual ability to form memories of the explicit or declarative type, but that these memories can only formed after repeated exposures to target material. Moreover, it is suggested that the amnesia suffered by this subject is less severe than that of the noted case H.M., whose mid-temporal lobe neuropathology is more extensive, and includes structures whose importance to memory are not yet fully understood. Other evaluations reported here include artificial grammar learning, an assessment of release from proactive interference, vocabulary acquisition, an evaluation of source memory, and the Tower of Hanoi puzzle. Results are discussed in terms of current theories related to the implicit and explicit, semantic and episodic, and declarative versus nondeclarative classification systems.

Acknowledgement

It is difficult to find words that will adequately and yet concisely express my deep appreciation to the several people who made this effort possible. Thanks to my lab mates Andrew Hsiao, Max Locke, and Lou Manza for their unflagging willingness to help me out and deal with my numerous questions. Thanks to the members of my committee, Rhianon Allen, Minna Broman, Neil Macmillan, David Owen, and Arthur Reber for the long hours they put in wrestling with the style, syntax and substance of this work. I am deeply grateful for their generosity of time and attention. Many thanks to Rhianon Allen for teaching me the Woodcock-Johnson, conducting several of the subtests, doing the summary stats, and for being so patient. Special thanks to Neil Macmillan who first got me interested in this stuff, took me seriously and introduced me to my mentor Arthur Reber. I owe an incalculable debt of gratitude to Minna Broman for her trust in me, for introducing me to M.S., and for working so hard to get me started in the field. Undying thanks to Debbie Tangen for making life fun, and for having the good sense to raise a remarkable son named Jesse. Thanks of course, to my long-suffering and loving mother.

A deep and unique sense of gratitude is reserved for Arthur Reber. He gave me a desk in his lab and showed me how to use the computer. For more than six years now he has encouraged, prodded, cajoled, menaced, praised, promoted and recommended me, all in due measure. Most of all he has believed in me, and I can't thank him enough for that. He's Aces all the way.

This dissertation is dedicated to M.S., who is a brave and good man.

Table of Contents

List of Tables

List of Figures

Consider the following proposition: The amnesic disorder presents a window through which cognitive researchers may glimpse certain functional aspects of memory that are otherwise hidden from view. While this statement maybe somewhat hyperbolic, the notion that the performance of amnesic subjects may provide a unique source of information about learning and memory has been a prime motivation for this line of research. Moreover, it is clear that this approach to the investigation of memory has been unequivocally successful. Amnesia research has contributed substantially to the development of the contemporary scientific understanding of learning and memory. Foundational concepts such as working memory, long-term memory, implicit and explicit learning and memory, have all been greatly influenced by amnesia research.

An understanding of the importance of amnesia research in cognitive psychology requires a familiarity with the nature of the disorder. The following section provides an overview of the cognitive and neuropsychological characteristics of the amnesic syndrome.

The Amnesic Syndrome

A Characterization of the Deficit

The term amnesia refers to a relatively circumscribed memory impairment that spares general cognitive and intellectual functioning. Typically, the amnesic is described as having a basic preservation of motoric, perceptual, linguistic, and logical ability. There is virtually normal capacity to manipulate and process information within the bounds of immediate attention. In contrast, the ability to form new long term (anterograde) memories for facts and events, and to retrieve relatively recent pre-trauma (retrograde) memories of the same kind, is severely compromised. The memorial deficit present in amnesia is exemplified by impaired performance on tasks that require direct recall or recognition for words, numbers, names, objects, faces, spatial layouts, facts, events, etc. (cf. Cermak, 1982; Hirst, 1982; Scoville & Milner, 1957; Squire, 1987, 1992). The term *explicit* memory, or a similar term, *declarative* memory, have been used to describe the sort of memorial functioning that is impaired in amnesia (cf. Graf & Schacter, 1985; Reber, 1992; Schacter, 1987, 1990). Explicit or declarative memory can be contrasted to a kind of memorial representation which appears to be unaffected by the amnestic condition, often termed *implicit* (or *non-declarative*) memory (Graf, Squire & Mandler, 1984; Reber, 1989, 1992, 1993; Squire 1992). Unlike explicit memory, implicit memory is a form of representation in which contents are not directly recalled or recognized. The contents of implicit memory are inferred to be present by their indirect, but measurable, effects upon behavior. For example, an amnesic patient may acquire skillful performance at a certain task, but may be unable to recall any of the training sessions in which the skill was acquired. Thus an explicit memory for the learning sessions may be compromised, while the implicitly represented aptitude for the task is not. The dissociation between compromised explicit and preserved implicit functioning in amnesics is one of the hallmark findings of amnesia research, and constitutes one of the major forms of evidence for the existence of separate memory systems. Many of the important studies that are relevant to the issue of separate memory systems will be reviewed in a later section.

Etiologies of Amnesia and Loci of Lesions The question of the causes of amnesia can be discussed on two levels: on the level of etiology *per se*, as in the nature of the precipitating trauma (i.e., viral encephalitis, anoxia, closed head injury, tumors, vascular malformations, nutritional deficiency), and on the level of the locus of anatomical lesions. While individual etiologies tend to produce characteristic lesions, there is still considerable variability as to their location and extent (Corkin, Cohen, Sullivan, Klegg, Rosen, & Ackerman, 1985; Victor, Adams, & Collins, 1989). These differences can be taken as accounting for the variability in performance on behavioral measures and the severity of impairment found within etiological classification (Corkin, et al. 1985; Squire, 1992).

As to the locus of critical anatomic lesions, there is a considerable convergence of opinion as to which anatomical locations are most directly responsible for normal memorial functioning. Structures in the medial temporal lobe, including the hippocampal formation and associated cortex, comprise one major grouping (Scoville & Milner, 1957; Zola-Morgan & Squire, 1993). The diencephalon, most particularly midline thalamic nuclei, form another (Squire, 1987, 1992; Victor, et al. 1989), and the basal forebrain region may constitute a third (Alexander & Freedman 1984; Damasio, Eslinger, Damasio, Van Hoesen, & Cornell 1985; but see Zola-Morgan & Squire, 1993). The role of the basal forebrain has been implicated in memory loss resulting from rupture of aneurysms of the anterior communicating artery (see Corkin et al. 1985). The role of the diencephalon in amnesia has been documented primarily through the study of Korsakoff syndrome (Victor et al. 1989). The importance of the medial temporal lobe region for memory was conclusively established by Scoville and Milner (1957), and has since been intensively studied by numerous researchers (see Squire, 1992 and Squire & Zola-Morgan, 1991 for reviews).

On the other hand, there has been definite disagreement among researchers as to whether the various etiologies that may produce amnesia result in qualitatively different pathologies. Some researchers argue that the disorder presents a certain set of core characteristics that allow us to talk about a single amnesic syndrome regardless of etiology (Baddeley, 1982; Hirst, 1982; Victor, et al. 1989), while others contend that behavioral differences between groups prevent us from describing amnesia as a unitary syndrome (Moscovitch, 1982, Squire, 1982; Squire & Shimamura, 1986). Corkin et al. (1985) tested groups of various etiologies (i.e., amnesia due to ruptured aneurysm of the anterior communicating artery, encephalitis, anoxia, Korsakoff's, closed head injury, and medial temporal lobe resection) on several memory measures and found quantitative, but not qualitative differences. Thus while there were group differences in terms of the severity of impairment, there were no differences in terms of the kinds of impairments observed. Amnesics of all varieties demonstrated a similar pattern of deficits on the same measures of memory. While these findings are provocative, the authors acknowledged that the low number of subjects in each group in the study requires us to view these findings as tentative.

The issue of whether amnesia represents one or many syndromes may in fact be a question of emphasis and orientation. Researchers who argue for a unitary disorder emphasize the essential nature of the memory impairment itself, i.e. the standard syndrome of a deficit in forming memories for verbal and nonverbal information which otherwise spares linguistic and intellectual capabilities. Those who propose multiple syndromes point to the fact that this core characteristic tends to be manifested within a variable set of accompanying symptoms, depending on etiology.

The most frequently cited example in this connection are those specific symptoms frequently observed in Korsakoff's patients (Butters, 1984; Moscovitch, 1982; Shimamura, Janowsky & Squire, 1990; Squire, 1982;). These include an impaired sense for the temporal order of events and a failure to show normal release from proactive interference following a shift of taxonomic category (Moscovitch, 1982; Squire, 1982; Shimamura & Squire, 1986). These impairments are commonly observed in Korsakoff pathology and are largely absent in other amnesic populations. Additional deficits that are sometimes attributed to Korsakoff amnesics, such as a generalized confusional state and a tendency to confabulation, dissipate as the disease progresses from the acute Wernicke phase to the chronic, more stable, Korsakoff stage (Victor, et al. 1989).

The specialized qualities of the Korsakoff pathology may be due to the fact that some of the brain areas typically lesioned, e.g. the dorso-medial nucleus of the thalamus, project directly to frontal lobe sites which in turn, sustain neuronal necrosis. Moscovitch (1982) demonstrated that the failure to release from proactive interference noted in Korsakoff's patients was also seen in frontal lobe patients who were *not* amnesic. Accordingly, it is not unreasonable to view Korsakoff pathology as a core amnesic syndrome that is modified in its behavioral characteristics by an overlay of frontal lobe pathology. Whether amnesia is viewed as one or many syndromes, it is clear that the ancillary characteristics that attend certain etiologies present something of a problem for researchers attempting to identify the nature of preserved functioning in amnesics. For example, in a given experimental evaluation of heterogeneously grouped subjects, it may be unclear as to whether the observed deficits in mean performance stem directly from memory dysfunction or from some other source, such as failures in attention or perceptual organization on behalf of some of the subjects. Grouping according to etiology, on the other hand, not only introduces difficulties for the generalization of results, but does not solve the problem of variability of performance owing to differences in site and extent of lesions. Other factors, such as coexisting pathologies, effects of medication, and age of onset may also be of importance. Examples of how these issues have come into play in particular experiments will be discussed in following sections.

Evaluations of Learning and Memory in Amnesia

Simple Motor Learning and Conditioning in Amnesics

The case of H.M. The contemporary era of research into preserved learning in amnesia may be said to have initiated with the studies of motor-skill learning in the amnesic patient H.M. Originally described by Scoville (1954) and Scoville and Milner

(1957). H.M. underwent bilateral resection of the medial temporal lobes in 1953 in an attempt to relieve an epileptic condition that was unresponsive to available medication. The structures excised included the amygdala, the anterior two-thirds of the hippocampus and surrounding cortical tissue. While a significant improvement in the epileptic condition was produced, and while general intellectual functions returned to, and even exceeded their preoperative status, an unanticipated consequence of the surgery was a profound amnestic condition. Scoville and Milner (1957) described his condition as having "...a complete loss of memory for events subsequent to bilateral medial temporal lobe resection... with a partial retrograde amnesia for the three years leading up to his operation; but early memories are seemingly normal and there is no impairment of personality or general intelligence" (p. 17)[1].

In the years that followed, Milner and her colleagues (Corkin, 1968; Milner, et al. 1968) summarized a series of studies that provided evidence for some residual learning capacity in even such a profound amnesia as that suffered by H.M. Initially, H.M. was reported to show steady improvement in a mirror drawing task over three days of multiple trials. This task requires the subject to trace accurately between the doubled outlines of a simple star-shaped figure that is reflected in a mirror; neither the drawing hand or the figure itself can be seen by the subject except in mirror reflected form. While control subjects were apparently not run in this task, it is clear that H.M. did display a marked improvement in his performance across sessions, as evidenced by

---

[1] The estimate of H.M.'s retrograde amnesia has been revised to include the span of 11 years preceding his surgery; see Corkin (1984).

reduced time and error scores. This improvement occurred despite the fact that he indicated no awareness of having repeated the task across daily sessions.

Rotary pursuit, bimanual tracking, and related tasks. H.M.'s modest success in mirror tracing invited further testing on some additional simple motor skill tasks, including rotary pursuit, bimanual tracking, and a sequence tapping task (Corkin, 1968). These simple tasks were designed to specifically assess the acquisition and retention of basic motor skills. The rotary pursuit task requires the subject to keep a hand held stylus upon a metal disk as it revolves on a turntable at the rate of 45 revolutions per minute. On the bimanual tracking task, the subject is seated in front of a horizontally positioned cylinder upon which two asymmetrical lines have been printed. Employing a stylus in each hand, the subject must maintain contact with the two lines as the cylinder rotates. In the tapping task, the numerals 1 through 4 have been printed out of sequence on to quadrant sections of two metal circles, one numeral per quadrant. In both unimanual and bimanual conditions, the subject must repeatedly tap a stylus to the quadrants in the correct numerical sequence, as quickly as possible.

It is of more than passing interest to note that H.M.'s performance on these tasks demonstrated marked impairments relative to that of the control subjects. While the trial to trial improvement gained by H.M. demonstrated a modest acquisition of proficiency, he did not perform as well as normals in either rotary pursuit or bimanual tracking, achieving an equivalent level of performance only in the tapping task. H.M.'s scores were inferior to the normal controls on every session of testing in each of the former tasks; there is a clear qualitative difference in the slope and height of the learning curves. Furthermore, most of H.M.'s improvement on the rotary pursuit task can be accounted for by an increasing ability to move quickly back on target after he has moved away. Unlike the normals, he showed little improvement in his ability to consistently keep the stylus on the target. It is clear from this report that H.M. demonstrated genuine impairments on these simple motor-based tasks.

Corkin suggested that this sub-normal performance may be due less to a memorial or cognitive deficit than to a generalized reduced efficiency in tasks that require normal reaction time. This point was affirmed by H.M.'s impaired performance in a task that measured simple reaction times to a light or tone. Corkin further noted that H.M. has a generally slow rate of spontaneous activity and movement, and also cited evidence from Penfield and Milner (1958), and Arrigoni and DeRenzi (1964) which showed a correlation between elevated reaction times and cortical lesions. More recently (Corkin, 1984), a CT scan disclosed an atrophy of the cerebellum that may be secondary to long-term Dilantin treatment, suggesting that his impaired motoric performance may be causally connected to a long-standing requirement for anti-convulsant medication.

The rotary pursuit task was employed with greater success by Brooks and Baddeley (1976) in a study with amnesics whose conditions were apparently not complicated by the supplementary pathology shown by H.M. This group, which consisted of two post-encephalitic and three Korsakoff patients, showed completely normal learning as compared to controls on this task. Cermak, Lewis, Butters and Goodglass (1973) tested rotary pursuit with a group of nine Korsakoff patients over two consecutive days, showing learning and retention comparable to the alcoholic control group and only slightly inferior performance to the normal controls. The fact that the non-Korsakoff alcoholics performed more like the patient than the normal group suggests that some diminution in performance may be due directly to the effects of alcoholism. Butters (1984) reported that post mortem examination of several Korsakoff patients revealed a generalized cortical atrophy that was correlated with amount of alcohol abuse. This additional pathology may be reasonably suspected as having a detrimental effect upon performance on a variety of experimental tasks.

Simple conditioning. Studies with amnesics that have explored simple conditioning have often involved classical conditioning paradigms. In 1962, an attempt to demonstrate a classically conditioned response in H.M. had to be aborted when he failed to produce the expected galvanic skin reaction to electric shock, even at intensity levels that normal control subjects experienced as painful (Milner, et al. 1968). Initially this somewhat surprising finding was attributed to the fact that H.M.'s resection included the amygdala, a structure implicated in emotionally valenced learning (Ledoux, 1987). Subsequently, Corkin (1984) suggested that this lack of responsiveness might be due to the cerebellar atrophy mentioned above.

Talland (1965) did succeed in producing a classically conditioned eyeblink response in eleven of fifteen Korsakoff patients by pairing puffs of air applied to the eye with the sound of a buzzer. These subjects, who were trained on a random mixture of 30 reinforced and 30 unreinforced trials, acquired the response to a preset criterion that was comparable to the normal controls. Talland reported, however, that the amnesics showed a steeper extinction curve than the normal controls.

Weiskrantz and Warrington (1979) also demonstrated the acquisition of the conditioned eyeblink response in two amnesic subjects, one Korsakoff's, the other probably post-encephalitic. Trained on a continuous reinforcement schedule with varying intervals between the CS and UCS, both showed clear acquisition of the response with retention over testing sessions. The results differed from the earlier Talland study in that the subjects did not show evidence of extinction at the end of the testing procedure. This difference is difficult to evaluate given the lack of trial by trial data from the Talland study, and the small *n* employed by Warrington and Weiskrantz. In this later study, post-experimental interviews were conducted with the patients showing that although the amnesics reliably displayed the conditioned response, they could recall very little about the actual testing sessions, even when shown the training apparatus. More recently Daum, Channon and Canavar (1989) produced the conditioned eyeblink response in a larger group of amnesics who likewise demonstrated little recollection for the training sessions.

As a whole, these studies provide satisfying evidence that this form of conditioning can be produced in amnesics. However, it is worth noting that none of these studies, with the exception of Talland (1965), simultaneously tested normal controls, leaving some doubt as to whether this form of conditioning is acquired by amnesics in an entirely normal fashion.

Maze Learning. H.M. was tested on a 28 choice-point visual maze (Milner, 1965) and also on a 10 choice-point tactile maze (Corkin, 1965), showing poor performance on both versions. On the visual maze, he showed virtually no learning after 215 trials. Similarly, he was unable to learn the correct sequence of turns in the tactile maze, showing some savings, however, in his time to completion scores over 80 trials. In a later study (Milner, et al. 1968) H.M. was tested on greatly reduced versions of these mazes. The visual maze was initially reduced from 28 choice-point to eight choice-points. When H.M. failed to show learning here, the maze was shortened yet again to four choice-points. H.M. finally reached the criterion of three successive errorless runs after 155 trials, showing some savings (but never errorless performance) in retesting on 1, 5, 8, and 14 days later. On the tactile maze, H.M. did show a significant improvement in reduction of error scores (number of turns in to a blind alley), but he never solved the maze to the criterion of three consecutive errorless runs.

The pattern of results obtained with H.M. is in basic correspondence to that found in some other maze learning studies. Talland (1965) and Cermak, et al. (1973) reported that their Korsakoff subjects could not acquire a six choice-point tactile maze. Similarly, the post-encephalitic patient S.S. tested by Cermak (1976) could not learn an eight choice-point visual maze. The Korsakoff patients in Cermak, et al. (1976) were eventually able to acquire and retain a simplified four point maze, and interestingly, patient S.S. was able to solve the eight point maze after mastering two four point components and applying this knowledge to the reconstituted full-scale version. The greater success demonstrated by amnesic patients on the shorter mazes is probably due to the reduced demands of these mazes on explicit memory. The task can be learned, albeit after many trials, as long as it is short enough to be completed without a significant contribution of a long-term explicit store; the more comfortably the number of choice points fits within immediate memory, the more likely it is to be learned by the amnesic subject (Corkin, 1965; Milner, 1965).

In a seeming contradiction to this point, Brooks and Baddeley (1976) reported that their mixed group of Korsakoff and post-encephalitic amnesics managed to show definite learning and nearly normal retention across delay on the adult version of the Porteus maze, a maze of considerably greater length than those discussed above. Equally impressive was the performance of the post-encephalitic patient M.K. (Starr & Phillips, 1970) who learned several tactile mazes some as complex as 13 choice-points. The authors note that this subject seemed particularly motivated in his performance, stating that he enjoyed this task more than any other in the study. Moreover, this was the only task for which he retained an explicit memory from session to session.

Section summary. It is a commonly held belief in psychology that H.M. demonstrated genuinely normal performance on early motor learning evaluations. As detailed above, this belief is not supported by the facts as presented in the literature. Ironically, this misunderstanding has not proved to be a critical factor in our understanding of the relationship of amnesia to motor-skill acquisition; essentially normal performance on these simple tasks has been produced in studies using other amnesic subjects. That basic motor-skill learning is largely unaffected by severe deficits in explicit memorial functioning constitutes something of a foundational fact in amnesia research. The lesson to be derived from the performance of H.M. is probably that, in the evaluation of brain damaged individuals on tasks related to learning and memory, it is necessary to keep a sharp eye out for co-existing pathologies, such as motoric impairments, which can produce artifactual results.

Another factor concerning H.M's performance that is usually overlooked is his clearly abnormal motivational and affective condition. As reported in Corkin (1984), he is described as complacent and amotivational to a truly remarkable degree. For example, as the author notes, if he is asked to sit in a particular place, he will stay there indefinitely without complaint. While the attendants at the home in which he resides report that H.M. eats well at meals, they also recount that he never spontaneously asks for food or drink, and never complains about, or volunteers information about, his well-being or physical condition. If the attending nurses suspect that he is in some discomfort, they must question him with a list of possible ailments until they hit upon the right one; he will not simply come out and state what is wrong with him, i.e. that he has a headache or a stomachache. Additionally, H.M. apparently displays no indications of desire for sexual expression. While it is possible that this symptomology predates his surgery (some abnormal sexual motivation is common in temporal lobe epilepsy; see Blumer & Walker, 1975 as cited in Kolb & Whishaw, 1985), it would seem that an affective condition as radically aberrant as this would have been previously documented.

The description offered of H.M. suggests a person who is in some way disconnected from normal autonomic promptings related to hunger, thirst, sexual gratification and pain. As related above, H.M. does not even show a normal response to as noxious a stimulus as painful electric shock. The facts as related here would seem to call into question the original assessment (Milner, et al. 1968; Scoville & Milner, 1957) that H.M.'s post-surgical deficit was limited to memory and did not extend to personality factors. On the contrary, it seems appropriate to suggest that H.M.'s deficits extend far beyond an impairment of explicit long-term memory. Moreover, it would seem likely that H.M.'s profoundly amotivational condition has had a significant impact upon his ability to address the requirements of performance based measures, and that this would create genuine difficulties for the specific assessment of his memorial characteristics. It is therefore likely that while H.M. has been, and remains, the most celebrated example of an amnesic in the literature, he may not present the best, or most pristine example of the disorder.

Perceptual learning and Priming

Warrington and Weiskrantz (1968) utilized the Gollin incomplete pictures test (Gollin, 1960) in a study designed to assess perceptual learning in amnesia. The stimuli consist of 20 sets of five line drawings of familiar objects. The five drawings in each set portray a familiar object in graduated degrees of pictorial completeness. The subjects are first presented with the most fragmentary drawings of all the objects; the procedure continues with increasingly complete pictures until all the objects have all been identified. The subjects are tested again after 24 and 48 hour delays. Perceptual learning on this task is assessed by the amount of savings in the number of pictures required to identify the object. This study also included a verbal analog of this task in which graphically degraded words were presented in increasingly complete form in the same manner as the pictorial stimuli. For both of these conditions, the amnesics showed clear evidence of savings across delay, but their performance was at no point equal to that of the control group. The Gollin pictures were also administered to H.M. (Milner, et al. 1968), who demonstrated normal performance in the original presentation, but clearly below normal performance with little savings after a one hour delay. More recently, a completely normal performance on the Gollin pictures was reported by Ostergaard (1987) for the childhood-onset anoxic/amnesic, C.C.

An interesting demonstration of intact perceptual-motor learning was reported by Nissen and Bullemer (1987), in which Korsakoff amnesics and controls gradually displayed sensitivity to a repeating visual pattern of computer administered stimuli. Specifically, reaction times to the stimulus display decreased steadily when the sequences presented a repeating pattern, but increased markedly when the sequences were randomly ordered. This "learning" of the pattern on the part of the amnesics occurred despite the fact that none of the subjects in this group noticed the presence of a pattern in the display.

In a study designed specifically to assess perceptual, or as they termed it, "pattern analyzing" skills, Cohen and Squire (1980) taught amnesics and controls to read English words that were presented in mirror reflected form. Learning was defined as the decrease in time required to read word triads over repeated presentations. The amnesics and matched controls were shown five blocks of 10 word-triads for three consecutive days, and also on a fourth day, approximately three months later. Half of the word triads were repeated in every block of trials, and half were unique to a specific block, and were thus nonrepeated. The amnesic subjects demonstrated learning of the mirror reading skill at a normal rate. However, the learning curve for the repeated word triads was markedly steeper for the normal controls, indicating a facilitation in reading time provided by repeated exposure. Amnesics benefitted significantly less from reading the same words repeatedly, suggesting that while they could learn the skill or "procedures" supporting the mirror reading skill, they were not benefiting from an explicit recollection of previously encountered words. In fact, during post-experimental interview, none of the amnesics realized that any words had ever been repeated during the experiment. All subjects showed strong retention of the mirror reading skill upon retest 94 days later.

In a later study that examined the effect of partial information upon retrieval performance, Warrington and Weiskrantz (1974) showed that when supplied with information about word targets in the form of the first three letters of the word, performance by amnesic patients could be brought to levels equal to that of normal controls. The patients were clearly inferior to controls in a free recall condition for items on a word list, but showed no difference in performance when they were asked to complete word stems of the target items. This result was taken as an indication that amnesics are able to benefit from this partial information in that it serves to limit interference from other response alternatives.

This enhanced retrieval effect was found to be somewhat unreliable in studies that followed (Mayes, Meudall & Neary, 1978; Mortensen, 1980; Squire, Wetzel & Slater, 1978), suggesting that the partial information supplied to subjects may simplify the task to such a degree that it becomes insensitive to the actual differences between patients and controls.

The observed discrepancy in the results of these studies is now widely accepted as having been a function of the task instructions supplied to the subjects. Graf, Squire and Mandler (1984) demonstrated that amnesics performed the word stem completion task like the normal controls when the instructions were to complete each stem with the first word that came to mind. However, the amnesics exhibited impaired performance upon exactly the same task when they were directed to complete the stems with words from the previously presented list. This simple instructional manipulation was enough to highlight the difference in performance potential between the memory intact controls, who have access to explicit recall mechanisms, and the amnesics, who by and large are limited to the activity of implicit functioning. The instruction that the stems be completed with the first word to come to mind eliminated the advantage of explicit memory for the word list, resulting in equivalent performance for both groups in this condition.

The word-stem completion effect referred to here is, of course, one example of what is now known as *priming*. Since these early experiments, research on priming in both amnesics and normals has been pursued extensively and constitutes a major portion of the "implicit memory" literature. In addition to word-stem completion, other variants of priming paradigms include lexical decision (Scarborough, Cortese &

Scarborough, 1977), perceptual identification (Jacoby & Dallas, 1981), and paired associate completion tasks (Graf & Schacter, 1985). Preservation of priming in amnesia has been demonstrated in all of these major paradigms: lexical decision (Moscovitch, 1982), perceptual identification (Cermak, Talbot, Chandler, & Wolbarst, 1985; Haist, Musen, & Squire, 1991), and paired associate completion (Schacter, 1985; Shimamura & Squire, 1984). The common factor shared by all priming effects is a facilitation in the processing of a specific stimulus, or some property of that stimulus, subsequent to a previous exposure. Because priming is assessed after only one or two exposures to the target stimuli, it is viewed as a qualitatively different process than the learning of skills, or the forming of conditioned responses, which are characterized by gradual acquisition over repeated sessions. Consequently, priming, skill learning, and conditioning can be construed as different types of preserved memorial functioning in amnesia (Schacter, 1985; Squire, 1992).

Research on priming has pointed to a fundamental distinction between *perceptual* and *conceptual* (or *semantic*) forms of priming. Perceptual priming effects are seen as depending largely on the integrity of early stage perceptual processing systems. Schacter (1990) and Tulving and Schacter (1990) have proposed that perceptual priming is mediated by a perceptual representation system (PRS) that is independent of cognitive or semantic memory systems. This view is supported by the results of a recent PET scan study (Squire, Ojemann, Miezin, Petersen, Videen, & Raichle, as cited in Squire, 1992) which demonstrated relative metabolic changes (as compared to a baseline condition) in areas of the right visual extrastriate cortex during a word-stem completion task. The scan revealed a *reduction* in blood flow to this visual processing area, suggesting that less neural activity is required to reprocess a stimulus that has been recently presented.

Conceptual or *semantic* priming represents a class of priming effects that are thought to require the activation of semantic representations (Tulving & Schacter, 1990). Several studies that involved semantic priming demonstrated performance equivalent to normals in amnesics. In an early study, Gardner, Boller, Moreines and Butters (1973) presented amnesics and controls with lists of words in association with their respective categories (i.e. "the first word is a tree - it is *oak*"). The amnesics exhibited priming equal to controls when they were cued with the category name and asked to provide the first exemplars that came to mind. They were markedly impaired when instructed to respond with exemplars that had actually been presented on the learning list. Hamann (1990) likewise observed normal priming in amnesics in a study that paired category level terms and exemplars of that category (e.g. *fruit* - BANANA). Similar results have been obtained by Shimamura and Squire (1984) using paired associates of intra-category words (e.g. *table* - CHAIR), and by Schacter (1985), using idiomatically related words (i.e. *sour*-GRAPES).

One interpretation of priming has been that it is dependent upon the automatic activation of previously formed representations in memory (Mandler, 1980; Scarborough, et al. 1977). However, this interpretation has been countered by experiments which have shown priming after a single exposure to novel material (i.e., stimuli for which representations are not pre-existent) in normal subjects, and more recently, in amnesics. For example, Cermak, et al. (1985) demonstrated priming for orthographically correct nonwords in a perceptual identification paradigm. Diamond and Rozin (1984) also produced priming for nonwords in a cued recall test. Both of these studies found the priming effect in their normal subjects, but failed to find it for the amnesic subjects. However, in a recent study specifically designed to limit the use of explicit memory for the target words by normal subjects, Haist, Musen and Squire (1991) succeeded in demonstrating priming for non-words in amnesic subjects at levels equivalent to normals. Another priming effect involving novel verbal information that was demonstrated in both amnesics and normals was reported by Squire and McKee (1992). In this study, based on a paradigm first developed by Neely and Payne (1983), subjects first read a list containing the names of both famous and non-famous people. Immediately after, they were asked to judge each name on another list as to whether it was the name of a famous person. Both amnesic and control subjects were more likely to judge a name as being famous if that name had appeared on a previously viewed list, than if the name was being read for the first time. Because the non-famous names in the study list were previously unknown to the subjects, the enhanced fame judgments for these names was characterized as the priming of novel information.

Similar results have been obtained for non-verbal material. Gabrieli, Milberg, Keane and Corkin (1990) reported clear priming effects for novel line drawings in both H.M. and normal controls, an effect also reported by Musen and Treisman (1990) with amnesic patients and control subjects. Schacter, Cooper, Tharans and Rubens

(1991) demonstrated priming for drawings of novel objects in amnesics and controls. In all of these experiments, priming performance on the part of the amnesics was independent of recognition memory. Another type of nonverbal priming, similar in spirit to the well-known Kunst-Wilson and Zajonc (1980) study, was reported by Johnson, Kim and Risse (1985). In this study, amnesics showed a normally enhanced preference for (presumably novel) Korean melodies that were heard earlier in the experiment over similar melodies to which they had not been exposed.

While priming for novel information in amnesics has been demonstrated in perceptual priming paradigms, the issue is much less clear when it comes to priming for new semantic *associations*. The stimuli in the semantic priming experiments which have shown normal effects in amnesics have all involved ostensibly preexistent associative representations (i.e., *fruit*-BANANA; *table-CHAIR*).

An experiment reported in Graf and Schacter (1985) tested amnesics and normals for their ability to form novel paired associate representations. Specifically, subjects were presented with unrelated word pairs (such as *window*-REASON), and upon test were presented with the cue word and a three letter fragment (i.e., *window*-REA___), or some recombination of cue and target fragments. The important finding was that the amnesics were more likely to generate the correct fragment completion for the paired associates they had seen at study than for the recombined cue-fragment pairs. This result was taken as reflecting the successful formation of novel verbal associations. However, subsequent re-analysis of the data (as reported in Schacter & Graf, 1986) showed that the priming performance of the amnesic group was carried by mildly amnesic subjects, and was not present at all in the more severe amnesics. This finding suggested that the associations formed by the less severely impaired patients were accomplished with the aid of residual explicit memory processes.

A similar study by Shimamura and Squire (1989) also failed to find evidence of priming to new associations in amnesics. These authors suggested that the individual subjects who succeeded in the paired associate word completion task in Graf and Schacter (1985), apparently through the employment of explicit recall strategies, might more accurately be termed "memory impaired", as opposed to "amnesic". The indication of explicit functioning on the part of the amnesics in their study represented a methodological contamination of their experimental purpose. It is important to keep in mind that experimental cognitivists are primarily interested in studying hypothetical memory systems or processes, not a clinically defined disorder known as amnesia as it is manifest in particular individuals. Whether or not amnesics can exhibit priming in response to single exposures of newly associated stimuli depends critically upon the experimenter's operational definition of the amnesic condition, and the nature of the research hypothesis under evaluation.

<u>Section summary</u>. The normal performance of amnesics on tasks that can be described as "perceptual" in nature gives strong indication that fundamental perceptual processes remain uncompromised in amnesia. This point is buttressed by the fact that H.M., who showed clearly compromised performance on motor-skill tasks, shows normal immediate learning with the Gollin incomplete pictures, and also produces priming to novel nonverbal stimuli (Gabrieli, et al., 1990). In fact, while it is usually

assumed that motor skills are the most robustly preserved capability in amnesia, it could be argued that the perceptual domain has been most reliably demonstrated as functionally intact in amnesic patients. Like normals, amnesics have shown perceptual and conceptual priming in a wide variety of experimental contexts, including conditions in which novel stimuli, for which no preexistent representation was likely to exist, were employed as targets. A major exception has been in the case of novel verbal associations, in which priming on the part of amnesics appears to have required the contribution of residual declarative memorial processes.

Animal Models of Amnesia Research with animals has shown that lesions introduced to brain structures typically affected in human amnesia produces analogous memory deficits. The work towards an animal model of amnesia is based primarily on experiments with rats and monkeys and has yielded a sizable literature (for reviews see Eichenbaum, Cohen, Otto & Wibble, 1991; Olton, 1983; Zola-Morgan & Squire, 1990). It has only been within the past few years that the degree of correspondence between the animal and human studies has come to be appreciated. Early experiments that failed to produce memory deficits in animals employed tasks that tap capabilities now recognized to be largely intact in amnesia (Eichenbaum, et al, 1991; Squire, 1992). Tasks that require only the learning of a simple association over many trials, or that require no delay in response can be learned at a normal rate by hippocampally lesioned animals, whereas tasks that require more complex forms of learning across delays produce impaired learning. For example, Olton and Papas (1979) showed that hippocampally lesioned rats, over many trials, will show normal learning for the arms of a radial maze that have been consistently baited in the past, and will also learn to avoid the arms which have never been baited (the win-stay task). They are severely impaired in comparison to controls, however, if the task requires them to choose only those arms *not* chosen on previous trials (the win-shift task). This requirement demands reference to a representation of specific previous events, a function held to be mediated by the hippocampal system.

The experimental task just described is similar in principle to the *non-matching to sample task* (NMTS) developed by Mishkin and Delacour (1975). A seminal study by Mishkin (1978) demonstrated impaired performance on the NMTS task by monkeys whose operated lesions were designed to model the surgical excision sustained by H.M. Since that time, the NMTS has been used extensively in this line of research and has proven to be sensitive to the types of memory deficits that result from lesions to medial temporal lobe structures.

The task makes use of a series of highly discriminable common items such as plastic blocks, empty yogurt cups, etc.; these items constitute the pool of potential stimulus items, all of which are initially concealed behind a removable panel. After an initial pre-training period in which the animal learns that raisins are likely to be hidden beneath objects, the panel is lifted and the animal is presented with an object and allowed to displace it, finding the reward. The object is then retracted behind the panel, and either immediately or at a variable delay, two objects are presented simultaneously (with left-right positioning pseudorandomly counterbalanced). One of these objects is the same one that was previously displaced to gain the raisin, the other is new. Since the raisin is now always hidden beneath the new object, the animal is required to choose the object which was not previously reinforced. Like the win-shift paradigm, this manipulation guarantees that the animal cannot master the problem simply by forming a conditioned association to a particular object (or to a particular spatial position).

Zola-Morgan and Squire (1984, 1985) have developed a battery of similar discrimination tasks used to characterize the memory deficits sustained by monkeys with varying operated lesions. An interesting finding is that hippocampally lesioned monkeys perform as well as controls in simple *pattern* discrimination tasks (i.e., learning to discriminate between a square and a cross to gain a reward) but are clearly outperformed in simple *object* discrimination tasks (Zola-Morgan & Squire, 1984). The learning of the simple pattern discrimination task requires many trials on the part of both lesioned and control animals. In contrast, the object discrimination task is learned very quickly by controls, and is also learned by the lesioned animals but only after many trials. Zola-Morgan, et al. surmise that monkeys may learn about real (3-dimensional) objects in a way that enlists the participation of the hippocampal memory system; it may be that a discrete representation is formed for objects by the hippocampally intact animals, allowing rapid learning of the task. The pattern discrimination is learned in a protracted, incremental fashion by both groups, suggesting a reliance on the formation of a simple conditioned association which can be acquired by lesioned and intact animals. This same study reported fully preserved motor-skill learning for the lesioned monkeys.

Another important finding to emerge from lesioning studies with animals is a clarification of the function of the amygdala. While the amygdala was at one time assumed to perform memory functions similar to that of the hippocampus, prospective lesioning studies in animals suggest that the amygdala does not share this function. Several studies with rats and monkeys have shown that memory tasks upon which hippocampally lesioned animals show clear impairments are performed normally by animals with discrete lesions of the amygdala (Becker, Walker & Olton, 1980; Sutherland & McDonald, 1990; Squire, 1992; Zola-Morgan, Squire & Amaral, 1989). Partial or complete lesions of the amygdala were found, however, to produce emotionally disordered behavior, i.e. an abnormal tendency to approach or touch stimulus objects (Zola-Morgan, Squire, Alvarez-Royo, & Clower, 1991). This evidence suggests that amygdala is specifically involved with the formation of emotionally-based memories, i.e., the learning of conditioned fear responses, or the establishment of affective significance for previously neutral stimuli (Davis, 1986; Ledoux, 1987; Sutherland & McDonald, 1990), but that its functioning is not crucial to the learning of more affectively neutral "cognitive" memory tasks, such as the delayed non-matching to sample task (Zola-Morgan, et al., 1989).

Zola-Morgan, Squire, and Chen (1988) applied several of the tasks developed for mid-temporal lobe lesioned monkeys to human amnesic patients. The general finding was that human amnesics display the same patterns of deficits as demonstrated in lesioned monkeys, with the exception that lesioned monkeys are not impaired on the

24 hour concurrent discrimination task, while amnesic patients display a deficit relative to their controls. This discrepancy may be due to the application of a different mode of acquisition employed by monkeys in addressing this task.

Additionally, these studies have made the important demonstration of a strong positive correlation between size and extent of lesion to medial temporal lobe structures and severity of memory deficit. For example, monkeys whose lesions were intended to model the excision sustained by H.M. (thereby including the hippocampus, the amygdala, and surrounding cortical tissue) exhibited more severe deficits than monkeys whose lesions involved only the hippocampal formation and more limited surrounding cortical tissue. These monkeys, in turn, tended to be more impaired than those whose ischemically produced lesions were confined to the CA1 field of the hippocampus (Zola-Morgan, Squire, Rempel, Clower & Amaral, 1992). This hierarchy of impairments is mirrored by neuropsychological evidence from human patients. For example, H.M.'s radical surgery has resulted in deficits that are more severe than those exhibited by patient R.B., whose ischemically sustained lesions were limited to the hippocampal CA1 field (see Zola-Morgan, Squire & Amaral, 1986 for the case study of R.B.; see Squire, 1992 for a fuller treatment of the issue of comparative severity of amnesia).

<u>Complex Learning and Cognitive Skills</u>. The Tower of Hanoi puzzle is sometimes referred to as a "procedural" task (e.g. Beatty, Salmon, Bernstein, Martone, Lyon, & Butters, 1987), but may be more accurately described as a cognitively based problem-

solving task that includes a motoric component. Briefly, the puzzle involves the use of three vertical pegs mounted on a board. The left-most peg contains a stack of disks (usually five in number) which are graduated in size, with the largest disk on the bottom and the smallest on top. The goal of the task is to move the stack of size-ordered disks to another peg in the fewest moves possible. This must be done moving only one disk at a time, and without placing a larger disk upon a smaller one. The minimum moves to solution in the five disk version is 31. Cohen (1984) reported that H.M. and a heterogenous group of amnesics solved the Tower puzzle at a rate equivalent to normal controls (see also Cohen, Eichenbaum, DeAcedo & Corkin, 1985). This conclusion was qualified, however, when it was acknowledged that the success of the patients may have owed to occasional promptings supplied by the experimenters (Gabrieli, Keane & Corkin, 1987).

Butters and his colleagues (Butters, Wolfe, Martone, Granholm & Cermak, 1985) ran early stage Huntington's disease patients (EHD), as well as advanced stage patients (AHD), and seven amnesics: six with diencephalic lesions (five Korsakoff's patients, one with a medial diencephalic tumor), and the post-encephalitic patient S.S. Both the EHD and normal controls learned the task over repeated solutions (16 trials over two days) at similar rates. The diencephalic amnesics performed at a significantly worse rate (as measured by mean percentage of improvement) over the same number of trials. Butters, et al. state that the performance of S.S. fell below the 95% confidence band of the normal and EHD patients.

Using the same protocol and control subject data, Beatty, et al. (1987) tested the anoxic/hippocampal amnesic M.R.L. (identified as L.M. in several papers by Squire and colleagues, e.g., Squire and Shimamura, 1986; Press, Amaral & Squire 1989). Similarly to patient S.S. mentioned above, the performance of M.R.L. (percent improvement score = 39) also fell below the 95% confidence band of the control subjects.

Taken together, the results of these studies seem to weigh against the finding of normal performance by amnesics on the Tower of Hanoi. The question remains as to why, if problem solving and analytic skills are indeed preserved in amnesic patients, do they fail to demonstrate normal learning capability on this task.

Butters, et al. speculated that the frontal lobe pathology which often accompanies Korsakoff's syndrome, and which compromises planning, organizational and analytical skills, may account for the below normal performance of this group. However, this explanation does not account for the impaired performance of subjects who do not show signs of frontal lobe pathology, such as M.R.L., H.M., and others.

It is possible that the difficulty that the Tower of Hanoi task presents for amnesics is not a matter of problem solving capability, but more simply, a consequence of the demand placed upon explicit long-term memory. The amount of time required for a typical trial to solution (up to a couple of minutes) most certainly exceeds the bounds of short-term memory. Moreover, the critical moves in the puzzle's solution occur toward the middle of the task; memory for the choices made at these junctures is probably interfered with by choices occurring before and after. Thus any explicit knowledge of the puzzle's solution acquired by an amnesic during the course of a particular trial will most probably be unavailable for application in subsequent trials. In contrast, normal subjects would be able to benefit to a much greater extent from their explicit memory for previous choices made, and be able to modulate their performance on subsequent trials accordingly. They would be able to reapply explicitly recalled successful choices and avoid their previous mistakes. Amnesics are disadvantaged in this, and similar tasks in that they cannot recruit a similar explicit recall of their actions on previous trials.

Another study designed to assess cognitive skill learning in amnesia may have also highlighted the advantage conferred by the availability of explicit memory. Squire and Frambach (1991) implemented a computerized simulation of factory worker/productivity relationships first employed with normal subjects by Berry and Broadbent (1984). Starting out with 600 workers and a production level of 6,000 tons, the task required amnesics and controls to adjust the number of hired workers to achieve a target production level of 9000 tons. The productivity rates displayed by the computer were actually governed by an arbitrary formula unknown to the subjects. Over 30 trials, subjects entered the number of desired workers via keyboard and gained feedback as to the consequences of their selections.

In the first session, amnesics learned to control the production system at a rate equal to normal subjects. However, in a second session a month later, the controls continued to improve their scores while the amnesics showed absolutely no evidence of savings, producing a learning curve virtually identical to the first session. This result may reflect the ability of the normals to apply some explicit information acquired in the first session to their subsequent performance. While questionnaire responses indicated that neither amnesics or controls learned task-specific information, normal subjects had acquired explicit general strategy information which may have assisted their performance in the second round.

In contrast to the previous studies, amnesics have displayed normal learning on cognitive tasks which, it may be argued, place little or no demand upon explicit long-term memory. Musen, Shimamura and Squire (1990) demonstrated that after repeated readings of the same prose passages, amnesics showed normal savings in the time required for re-reading of the texts (although they were significantly impaired in a test of their memory for the content of those passages). A similar fluency of reading effect was reported by Musen and Squire (1991). Amnesics and controls read lists of different types: a list which contained 100 unique (non-repeating) words, a list of 100 repeating words (five words repeated 20 times), a list of 100 unique nonwords, and a list of repeating nonwords. Both groups of subjects read the lists of repeated items faster than the non-repeated items, the improvement occurring at the same rate within each list. In a second experiment with four new lists, rereading was delayed for 10 minutes; facilitation in reading time persisted across this delay for both patient and control groups. The amnesics were significantly impaired on recognition tests for the lists of words and non-words in both experiments.

Amnesic patients have also demonstrated a normal ability to correctly classify letter strings in the "artificial grammar" (AG) paradigm developed by Reber (see Reber 1989 for a review). The basic AG experiment has the following form: In an initial study phase, subjects are presented with a list of consonant letter strings and asked to memorize them. No information is provided that the sequences of letters are governed by a deep rule based system—"the artificial grammar". Subjects are then required to make classification judgments on a new list of letter strings, only 50% of which conform to the grammar common to the items initially studied. The reliable finding is that subjects are able to correctly classify the grammatical and ungrammatical letter strings at greater than chance levels despite a generalized lack of awareness about the underlying rule system, or about what principles were employed in guiding their decisions. Knowlton, Ramus and Squire (1992) and Knowlton and Squire (1994) found that amnesics performed as well as normal controls in making these classification judgments, and that this ability was not correlated with severity of amnesia or I.Q. However, in a separate explicit recognition test for study phase letter strings, the amnesics were significantly impaired in comparison to normals.

Subsequent experiments have also provided evidence that amnesics are capable of deriving category level information from studied exemplars. Knowlton, Gluck and Squire (1993) ran amnesics and normals in an experiment that required subjects to make predictions based upon the probabalistic relationship of observed cues to one of two possible outcomes. For example, subjects were given cues in the form of descriptions of physical symptoms and then were asked to make a "diagnosis", choosing between two fictious disease outcomes. In a second experiment, the same task was implemented using cues about weather conditions which were predictive of weather outcomes. Because the cues were only probabalistically related to the outcomes, and because the number of cues presented varied from trial to trial, the experimental demands emphasized the development of a knowledge base accumulated over multiple exposures. The results showed virtually identical learning curves for both normals and amnesics over the first 50 trials. There was however, a tendency for faster learning on the part of the normals on the remainder of the task. The authors interpret this pattern as an indication that category induction of this sort can, at least in its initial stages, be fully supported by implicit learning mechanisms. The enhanced performance of the control subjects in the latter stages may indicate that explicit knowledge of stimulus contingencies can be acquired by non-memory impaired individuals after many trials and advantageously applied to the relevant categorical judgments. Knowlton and Squire (1993) further approached the question of category learning by an adaptation of the classic Posner and Keele (1968, 1970) prototype abstraction experiment. Normal and amnesic subjects were unaware that the 40 dot patterns they were shown were actually highly distorted versions of an arbitrarily constructed "prototype" pattern. Then the subjects were informed that the patterns they had seen were all examples of the same pattern category, and were asked to judge novel dot patterns as to whether they also belonged to that same category. The results showed that amnesics and normals were not significantly different in the accuracy of their judgments and that both groups demonstrated the "prototype effect" as described in the original Posner and Keele studies. However, in a later test of the same design, the amnesics were significantly impaired in a recognition test for the patterns that were actually studied. The series of experiments reviewed in this section are strongly suggestive that category level representations for novel information can be acquired despite the explicit memorial deficits that typify amnesia. These demonstrations can be construed as offering an important theoretical advance to the extent that category abstraction can be viewed as a sophisticated form of cognitive functioning which is not completely dependent upon specific item associations or simple motoric or perceptual processes.

Summary

In the thirty or so years since the early evaluations of H.M., an extensive literature has grown up concerning the assessment of preserved learning in amnesia. The evidence suggests that a heterogenous collection of learning and memorial capabilities persist despite amnesia, which may be collectively referred to as *non-declarative* or *implicit* functions. These capabilities include those that support priming, skill-learning and simple conditioning. They are heterogenous in the sense that they appear to involve qualitatively different processes. For example, priming refers to a facilitation in processing after only one or two exposures to a target stimuli, while skills are learned gradually through many trials. Additionally, recent evidence suggests the preservation of skill learning in amnesia is not limited to simple motor, or even perceptual skills, but also includes relatively sophisticated cognitive processes such as those involved in the implicit learning of categories.

The Case Study of M.S.

The research presented here is a single case study of an amnesic patient. The patient is an adult male (M.S.), who at the age of eight, became amnesic secondary to an anoxic episode accompanied by epileptic seizure. An MRI of this subject, conducted in 1991, demonstrated bilateral atrophy of the hippocampal formation. A more recent MRI, performed in June of 1994, indicates that the atrophic lesion also involves the amygdala bilaterally (Rose & Broman, 1994).

Although the association between mid-temporal lobe damage and impairment of explicit long-term memory has been widely acknowledged since the report of H.M., the nature of an amnestic condition that would result from a more limited lesion than that sustained by H.M. has not been well documented. H.M.'s postoperative lesions involved not only the hippocampus and the amygdala, but also the surrounding perirhinal and parahippocampal cortices. While prospective research with rats and monkeys has indicated that the amygdala provides little, if any, contribution to basic (non-emotionally toned) memory functioning, recent evidence suggests that the perirhinal and parahippocampal cortices may be crucial to explicit long-term memory processes (Squire, 1992; Zola-Morgan & Squire, 1993; Zola-Morgan, et al. 1992). Thus our considerable knowledge concerning the nature of H.M.'s memory impairment that has accrued over these many years does not adequately inform us about the characteristics of a memory disorder that would result from damage limited essentially to the hippocampal formation. The available evidence suggests that such a lesion would result in an amnestic disorder that is less severe in kind than that of H.M.'s, but more severe than that demonstrated by someone such as patient R.B., whose ischemic lesion was confined to the CA1 sub-field of the hippocampus (Zola-Morgan et al. 1986).

Due at least in part to the relatively recent provenance of MRI technology, only a handful of other amnesic cases with similar discrete mid-temporal neuropathology have thus far been identified. The resultant lack of detailed and comprehensive information regarding the nature of hippocampal amnesia provides a compelling motivation for the intensive study of patient M.S. Another factor which contributes to the specialness of this case is the fact that his precipitating trauma occurred during childhood. The timing of the injury appears to have produced a complex of deficits related to language functioning and affective development which have not been associated with specific hippocampal injury in adults. Recorded cases of childhood onset amnesia are extremely rare; only two others have been described at full article length in the literature (Ostergaard, 1987; Wood, Brown & Felton, 1989). The research reported here, taken together with the reports by Broman and her colleagues (Broman, Kriengkrairut, McCarthy & Rose, 1991,; Rose & Broman, 1994) would constitute the most complete documentation of such a case to date.

The central focus of this case study is an experimental evaluation of the implicit and explicit learning capabilities of this amnesic patient. The overriding theoretical position assumed is that the performance of this subject on these evaluations will confirm and extend the previously described body of findings documenting the general preservation of implicit functions in the presence of severely compromised explicit capability. Statements of expectations regarding individual evaluations are separately described in their respective *Methods* sections.

The evaluations employed in this study are similar to, and in some cases virtually identical to, many of the now classic evaluations described in the *Introduction*. Among the measures included are evaluations involving visuo-spatial manipulation, perceptual/motor learning, priming, artificial grammar learning, vocabulary learning, etc.. The majority of these evaluations are in the form of within-subject experiments, in which case a variable of interest is manipulated across conditions, and the subject acts as his own control. In some cases, performance of this subject will be compared to previously published data, or to the performance of a provisional comparison group. As part of the attempt to characterize the memorial deficit that attends the particular lesion sustained by this subject, comparisons will be made to other amnesic patients, most particularly to H.M. Special attention will be given to the possible confounding effects produced by medication interactions and comorbid pathology. The importance of this case to current memory research, and its implications for further research, will also be considered.

Overview of Methodology.

Subjects

Amnesic patient. M.S., whose case was first presented in Broman, et al. (1991), was born May 6, 1962 and is at the time of this writing 32 years old. He was born to a secure middle class family from a stable, residential neighborhood of an outlying borough of New York City. He has two older siblings, both of whom are college educated and have gone on to achieve post-graduate professional training. His mother holds a Masters degree in education. His father is a retired small business owner.

Severely asthmatic from infancy, M.S. required extensive medical attention throughout childhood, and experienced numerous emergency room admissions in response to recurrent asthmatic attacks. An episode of status asthmaticus occurred in January of 1970, requiring intubation and placement on a mechanical respirator for three days. In the following months, it was determined that the severity of his condition warranted admission for residency in a special facility for asthmatic children in a city distant from home. In June of 1970, while under the care of this facility, M.S. experienced his first grand mal seizure. This episode was of uncertain etiology, lasted approximately four minutes, and apparently did not produce lasting neurological deficits. In December of that same year, while at home for a holiday visit, he experienced a second grand mal seizure. He was hospitalized in a condition of status epilepticus and respiratory arrest. He remained comatose for a protracted period, regaining full consciousness after three days. His immediate post recovery condition involved a generalized confusion, disorientation, and an inability to recognize family members. While these initial symptoms proved transitory, other conditions proved more persistent; these included frequent expressions of fearfulness, of the perception of being followed or pursued, of there being "someone behind him". A condition of affective/behavioral maladjustment persisted throughout his childhood, which included a pronounced emotional volatility and repeated attempts to run away from home. The combination of his asthmatic condition and emotional maladjustment created a substantial barrier to the continuation of his formal schooling. His enrollment in special education classes proved ultimately unsuccessful. He has been unable to complete his elementary school education. In his early twenties, episodes of violent emotionality became sufficiently severe as to require physical restraint and treatment with psychotropic drugs. While these disruptive behaviors have apparently resolved, and in fact, are currently no longer in evidence, he is clearly affectively immature. A chronic, stable, anterograde amnesia remains as a profound and debilitating cognitive deficit. M.S. still suffers from severe asthma and the effects of frequent low-level epileptic activity. He receives medication for both disorders (see Appendix A).

The detailed neuropsychological profile of M.S. presented by Broman, et al. (1991) reports a current WAIS-R Verbal I.Q. of 80, Performance IQ of 89, and a full-scale IQ value of 82, placing him in the low normal range. It is clear, however, from the data presented, that M.S. is severely handicapped on tasks requiring long-term retention of both verbal and spatial information; his delayed recall score on the WMS-R is less than 50. Moreover, the authors note that for many basic language skills, such as reading and word fluency, M.S. performs as if these capabilities were developmentally arrested at the time of his trauma. Other functions were marginally less compromised; basic mathematical skills appear to have achieved a fifth grade equivalence. Interestingly, conceptual language abilities, as assessed by tests of sentence comprehension, grammatical capability, and complex ideational material, have progressed to adult levels. His immediate attention, planning and organizational capacity is strong. Verbal and nonverbal logic and problem solving skills have also progressed to adult levels. This last point is exemplified by his strong performance (50-75%tile) on the Raven Matrices, an evaluation which loads heavily on nonverbal perceptual and logical skills. Broman, et al. offer the interpretation that the capabilities impaired in M.S. are those that are dependent upon long term memory for their normal development.

In addition to the test scores reported by Broman and her colleagues, more recent testing, including an administration of the WAIS-R and the Woodcock Johnson - Revised (WJ-R) Battery was performed. The WAIS-R was administered in 1993 by the author of this paper, and the WJ-R was administered in 1992 by Rhianon Allen of Long Island University and by the author. The results of the WAIS-R, and the summary scores of the WJ-R are reported in Table 1. A more complete listing of the neuropsychological data is presented in Appendix B.

Table 1.

Performance by M.S. on the WAIS-R and WJ-R

Wechsler Adult Intelligence Test- Revised

IQ Subtest	Score
Verbal	78
Performance	94
Full Scale	82

Table 1. (cont.)

WAIS-R Subtests

Verbal Subtests	Score	Performance Subtests	Score
Information	5	Picture Completion	11
Digit Span	8	Picture arrangement	8
Vocabulary	4	Block Design	13
Arithmetic	6	Object Assembly	10
Comprehension	6		
Similarities	8		

Woodcock Johnson - Revised: Summary Scores (1992)

Summary Category	Age Equivalent	Percentile Score
Broad Cognitive Ability	13.2	16th %tile
Long-Term Retrieval	5.2	3rd %tile
Short-Term Memory	14.3	35th %tile
Auditory Processing	9.0	18th %tile
Visual Processing	12.2	16th %tile
Comprehension-Knowledge	11.1	2nd % tile
Fluid Reasoning	11.8	24th % tile
Knowledge-Aptitude		25th % tile
Oral Language Aptitude		1st %tile
Basic Reading Skills	7.9	0.3 %tile

Comparison subjects. Evaluations of the performance of patient populations generally employ control subjects matched on such basic demographic variables as age, gender, and education. The subject of this case study presents unusual difficulties in this regard. An extreme view would hold that the appropriate control subjects for this individual would be a sample of adult male asthmatic epileptics who were separated from their families during early childhood and have not completed grammar school education. Even the less stringent criterion of an age and education matched control group would prove extremely difficult to assemble and maintain over the course of an extended study. The most tractable solution, given the present practical and financial considerations, would be to employ control subjects drawn from the Brooklyn College undergraduate subject pool. However, the comparison of the performance of M.S to that of a sample of college undergraduates raises fundamental methodological questions. While the employment of a such a group is not problematic as long as M.S. shows equivalence in performance, problems do arise where M.S.'s performance in either implicit or explicit tasks is not on par with that of the controls. The differential performance in such a case could be explained as a function of the general cognitive superiority of the students in the sample. In other words, it is possible that college students are critically different from M.S. along dimensions other than that of explicit memory. A reasonable alternative to this between-group approach is to structure the evaluations as a series of within-subject experiments, in which the patient acts as his own control. As noted above, this methodology is particularly well-suited to the evaluation of single-subject performance. With the exception of the first triad of tests as described below, the within-subject experimental design was employed throughout. In several studies, the performance of a subject group of college students was included to permit selected comparisons to the performance of M.S.

Materials. The evaluations employed in this study make use of two basic formats: paper and pencil and computerized administration. The computerized tests were all conducted upon the same hardware configuration: a 80386 Intel based computer operating at 25 megaHertz with a .31 dot pitch VGA color display. The specifics pertaining to individual evaluations will be fully described in a corresponding *Materials* section.

Evaluations of Perceptual and Perceptual/Motor Skills.

Mental Rotation Task (MRT)

Previous evaluations of M.S. have demonstrated strengths in certain tasks which involve relatively straightforward perceptual skills but do not place demands upon explicit long-term memory. His successful performance on the Raven Matrices and the Block Design subtest of the WAIS-R are cases in point. In a recent testing (June, 1994), M.S. scored 45/60 correct on the Raven's Matrices (65th percentile), and achieved a standard score of 13 on the Block Design subtest.

Another evaluation which can be said to involve similar perceptual skills is the Mental Rotation Test (Vandenburg & Kuse, 1978). This paper and pencil task presents as a target a line drawing of a complex three dimensional object in a particular spatial orientation. The subject is provided with an array of four additional objects which have been rotated spatially with respect to the original; two of these are structurally identical to the target object. Selection of the matched objects requires that the subject recognize the structural equivalence of the two objects despite their differing spatial orientations. A leading view regarding the cognitive operations supporting these judgments is that the mental representations of the test stimuli are manipulated until a match to the target is produced (Shephard & Meltzer, 1971).

The demands of this task appear to be well-suited to the known cognitive strengths of M.S. in that it is primarily based upon nonverbal perceptual operations and places no burden upon long-term explicit memory. Given his strong performances on normed evaluations such as the Raven Matrices, this test was administered with the expectation that M.S. would likewise demonstrate a proficiency comparable to that of a sample of college undergraduates who were administered this task as part of a course requirement.

Materials. The stimuli consist of line drawings of complex and arbitrarily shaped objects, taken from Vandenburg and Kuse, (1978). The test pamphlet consists of two 10 item sections, each item consisting of a target and its corresponding alternatives. The target and the four alternatives (two matches and two distractors per target) are printed on plain paper horizontally across the page. The target is printed on the extreme left of the page, the alternatives appear immediately to the right. An example of a target with corresponding choices is given in Figure 1.

A Sample Trial of the Mental Rotation Task

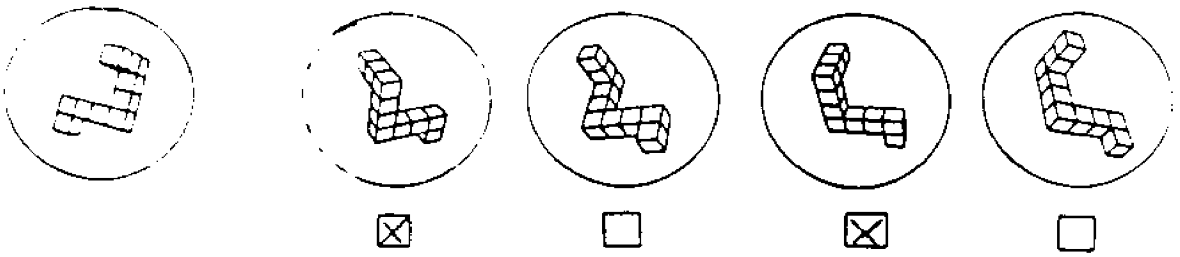
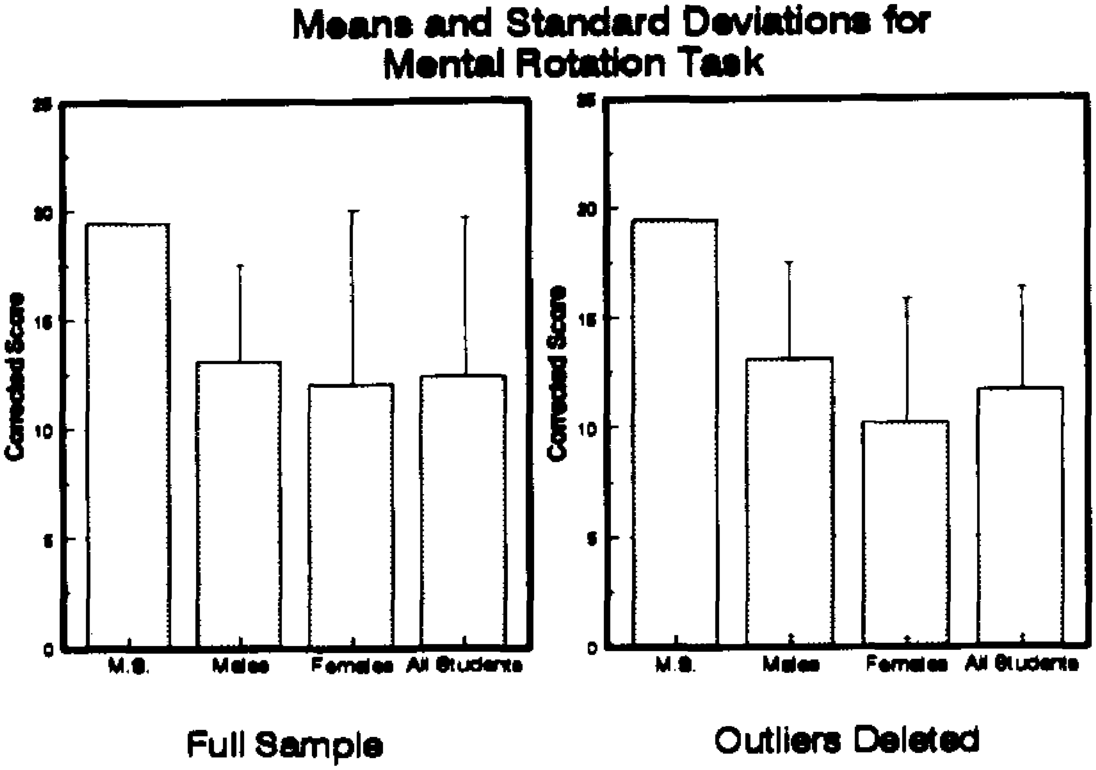


Figure 1. A sample trial of the Mental Rotation Task. The target is on the left, the four alternatives appear on the right. The correct matching items are marked in the boxes beneath the figures.

Procedure. The 10 item sections were completed one at a time. In each section, including the preliminary three item practice trial, the subject was encouraged to choose the two matching objects for each target as quickly and as accurately as possible. There was a time limit of three minutes for each section of 10 items. The score was defined as the total number of correct choices within the three minute time limit, summed across both sections, and corrected for guessing by subtracting half the number of incorrect choices.

Results and Discussion. M.S. was administered this test twice, once in July, 1992 (score = 17) and again in July, 1993 (score = 22). The score reported here for M.S. is the average of these two administrations. Given that this task is one in which a small, though reliable advantage for male subjects has been reported (e.g. Linn & Petersen, 1985; Vandenburg & Kuse, 1979), the data for the college students is reported separately by gender as well as for the combined group. The score for M.S. (averaged across the two administrations) as well as the mean scores for the students are shown in Figure 2.

The statistics for the student subjects shown in Fig. 2a are as follows: combined group (*n* = 52) *M* = 12.42, *SD* = 6.94; male subgroup (*n* = 18) *M* = 13.14, *SD* = 4.42; females alone (*n* = 34) *M* = 12.04, *SD* = 8.00. M.S.'s mean score of 19.5 is approximately one standard deviation above the mean of the combined subject group; only seven of the 52 comparison subjects achieved equivalent or superior scores. If the three highest scores (28.5, 31, and 32.5, all achieved by females) are discarded, (they are each in excess of three standard deviations above the mean of the remainder of the comparison group), the mean for these subjects is 11.69. Since the intention is to compare the performance of M.S. to "normal" and not "exceptional" data, Figure 2b displays a comparison to these revised means.


Means and Standard Deviations for Mental Rotation Task

Full Sample

Outliers Deleted

Figure 2. The figure on the left compares the performance of M.S. on the M.R.T. to a group of college undergraduates. The student data are displayed separately for males and females and also as a combined group. The figure on the right shows the results with data for three outlying students deleted from the set.

Here M.S.'s score is closer to 1.5 standard deviations above the student group mean. M.S.'s proficiency here supports the interpretation that there is a major area of nonverbal perceptual functioning which has been unimpaired by his brain injury. His performance on this task suggests that he is capable of forming, manipulating and comparing mental representations of depicted objects in a completely normal, if not superior, fashion. Moreover, his strong performance in this difficult timed task attests to his ability to sustain considerable attention and concentrated mental effort in an experimental situation.

Tetris

The well-known computer game Tetris (Mirrorsoft and Andromeda Software, Ltd. 1987) bears an interesting similarity to the Mental Rotation Test. Both involve two dimensional renderings of geometric objects which must be skillfully manipulated against a time constraint. A fundamental difference is that in the Mental Rotation Test the "manipulation" of the objects is entirely a cognitive process; Tetris requires the actual manipulation of these objects in space via computer keystroke. In this way it contains a perceptual-motoric component not present in the former test.

An attractive feature of this game is that proficiency requires the coordination of a fairly complex series of eye/hand motor responses. Perceptual/motor skills of this kind are acquired gradually and through repeated exposure, permitting the tracking of a learning curve over time. Another attractive feature of the game is that especially proficient performance can extend the length of playing time indefinitely. In principle, there is no upper limit to the number of points that can be scored, and hence little danger of ceiling effects.

The game of Tetris was employed here as a basic perceptual/motor skill evaluation, and it was reasoned that skilled performance on this task would be possible without a substantial contribution from explicit long-term memory. It was also assumed that Tetris was sufficiently similar to the Mental Rotation Task to allow M.S. to apply the same repertoire of apparently superior perceptual skills to this evaluation. Accordingly, it was expected that M.S. would show a learning curve over delayed sessions fully comparable to that of a comparison group of college students. The students selected for this group, like M.S., had no previous experience with this game. Normal learning by M.S. would parallel that reported for the childhood onset amnesic C.C. (Ostergaard, 1987) in a fighter jet simulation game, Thunderbirds (Urban Soft, 1980).

There appears to be no previously published study that has employed Tetris with amnesic patients.

Materials. The computer game Tetris is commercially available from Spectrum Holobyte, Inc. in a variety of formats. This study employs the MS-DOS version, implemented on the above noted hardware configuration. Beginner's level settings (0 level and 0 height) were used with all subjects.

Procedure. This game was administered entirely through the previously mentioned software. The subject received instructions as to the goal of the game, as to which keys were to be used, and as to the particular functions that they perform. The game requires a player to manipulate differently shaped objects as they appear to "fall" from the top of the computer screen. The task is to rotate or reposition the falling objects so that they are arranged as compactly as possible at the bottom of the screen. The placement of each object gains the player a certain number of points. The game is ended when the stack of objects reaches the top of the screen. This endgame can be delayed, however, by stacking the objects so that they fill a complete row across the screen, leaving no open spaces. This results in the removal of that row, providing more space for the stacking of objects, and hence more opportunity for point accumulation. The software automatically records the scores for each game.

Results and discussion. The performance of two student subjects, whose first session mean scores were more than four standard deviations above that of the other comparison subjects, were dropped from consideration. Questioning revealed that these subjects had frequently observed Tetris being played by others. The mean scores of M.S. and the remaining undergraduate subjects (*n* = 13) were compared across four sessions of testing, each session consisting of seven consecutive games. The sessions were separated by a one week interval. M.S. was also tested a number of additional times at various delays in the following two months (mean inter-session interval = 8.7 days).

Figure 3 displays the mean performance scores of M.S. and the comparison subjects across four weeks of testing, and for M.S. across seven additional sessions. It is clear that the initial performance of both patient and student subjects (Week 1) is closely matched (mean for M.S. = 370.43; students = 413.38, *SD* = 85.23). By the second week, the score for M.S. is actually numerically superior to that of the mean for the students (mean for M.S. = 508.17; students = 490.92, *SD* = 131.50). For the remaining two sessions, however, the performance curves show evidence of meaningful difference. While the curve of the comparison subjects shows a steady, strong, linear improvement, the performance of M.S. shows a much gentler, protracted function. Although it is true that at the end of Week 4 (the last week of comparison to the comparison group) he is not much more than one *SD* below the student group mean, it is clear that his initial parity with the students has eroded, and his learning curve has taken on a qualitatively different trajectory.

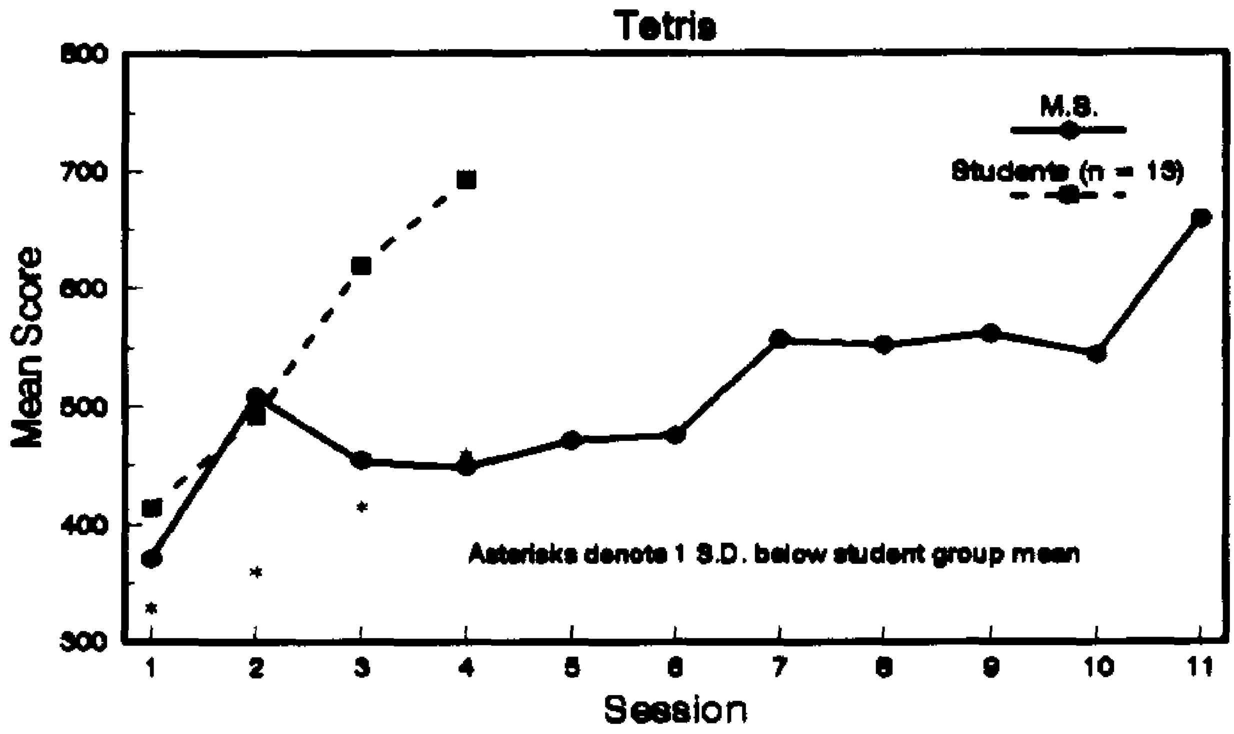


Figure 3. The performance of M.S. and 13 students on four consecutive weeks of testing. M.S. was also tracked for seven additional sessions which were conducted at various intervals over the following two months.

In contrast to his initial performance, he requires 11 weeks to approximate the mean student group performance of Week 4. Slopes for both performance curves were calculated by simple linear regression; for the students, b = 96.40; for M.S., b = 19.98. If it is assumed that these linear slope values validly characterize the empirical performance curves, and that the rate of learning shown by the comparison group over four weeks would remain stable, the data appear to demonstrate a genuinely depressed rate of learning on the part of M.S. In contrast with his performance on the Mental Rotation Task, in which M.S. scored higher than all but seven of 52 student subjects, 11 of 13 subjects outscored M.S. by the fourth week of testing in Tetris.

That M.S. is capable of fully normal performance upon first exposure to the task is shown by the data across the first two weeks. The detectable difference in performance emerges only after the third week of testing. The students were apparently deriving a measure of benefit from their repeated experience that M.S. simply did not, or at least not at the same rate. It is possible that these results indicate that an intact explicit memory for information gathered in previous sessions does indeed confer an appreciable benefit on subsequent performance on this task. In such a case, M.S. would be at an obvious disadvantage, and the observed discrepancy in learning rate could be generated by the contribution to performance supplied by the intact explicit memory of the students.

For example, it is possible that subjects develop strategies for the efficient stacking of objects within the course of a session, but only the student subjects, by virtue of their functional explicit memories, are able to fully retain and apply this information across weekly sessions. The more gradual rate of learning shown by M.S. may well reflect the savings conferred by an implicitly based acquisition of the task, supplemented, perhaps, by a degraded memory trace for some relevant explicit information gained on a session by session basis. The steeper learning curve shown by the normals could be interpreted as the additive result of intact implicit and explicit acquisition.

Another factor to be considered is that M.S.'s performance on this task may have suffered due to a generalized motoric slowness that impaired optimal operation of the keyboard. A subtle impairment of this sort might not be a factor in entry level play (hence the initial equivalence of scores), but might well affect his ability to improve upon the speed and coordination of complex keystroke sequences that proficient performance requires. Accordingly, the following evaluation was performed in order to assess the integrity of simple motor response functioning in this subject.

Simple Reaction Time Measure

As outlined in an earlier section, H.M. failed to show normal learning on simple motor tasks such as rotary pursuit and bimanual tracking (Corkin, 1968). That this impairment in performance might have been based in a motoric, rather than a memorial deficit, was suggested by H.M.'s inferior performance on a simple reaction time measure. Corkin (1968, 1984) offered that H.M.'s elevated reaction times may be rooted in any one, or some combination of factors. These include the possible effects of previously undetected cortical pathology, and the cerebellar atrophy originally revealed by CT scan, and more recently by MRI (Corkin, 1984, 1993).

The possibility must be raised that M.S. might also suffer from some motor skill impairment. The anoxic condition which was the putative cause of his brain damage, or the chronic epileptic activity from which he has suffered, may have produced as yet undetected damage to brain structures that are relevant to motor performance. There is also the fact that M.S. has been treated with a variety of powerful anti-convulsant drugs, as well as an assortment of asthma medications for more than 20 years. These have included, at various times and combinations, primidone (Mysoline), carbamazepine (Tegretol), and phenytoin (Dilantin) for the anti-convulsant group, and albuterol (Proventil), cromolyn sodium (Intal), Flunisolide (Aerobid) and methylprednisolone (Medrol) for the anti-asthmatics. Of these, the anti-convulsants primidone and phenytoin have been especially associated with ataxic symptomology and other cognitive/motoric side-affects (Bennet, 1992; Rall & Schleifer, 1990). Whether as a result of the epileptic condition itself, or as a side effect of medication (or both), deficiencies in motor response time in epileptics are commonly observed (Bennet, 1992). A simple visual reaction time test was conducted with M.S. in order to assess whether motoric sluggishness may be a factor in his performance. The visual modality was chosen in order to parallel the sensory demands of both the Mental Rotation Task and Tetris. The basic methodology employed in this procedure, in particular, the number of response trials required of the subjects, was selected to provide an approximate measure of comparison to the visual reaction time evaluation of H.M. as reported in Corkin (1968).

Materials. The test was administered via a 80386 Intel based computer operating at 25 megaHertz with a .31 dot pitch VGA color display. The target stimulus was a light cyan colored square, approximately 1 5/8" square, which is presented in the center of the screen at a randomly selected interval ranging from one to seven seconds. Subjects respond to the appearance of the stimulus by pressing the spacebar. The reaction time of the subjects' response was recorded by the computer and saved to a data file.

The computer and monitor employed in Tetris was utilized here in an attempt to simulate the basic demand characteristics of that evaluation. The reaction times were measured through the onboard clock of the computer. No special calibration of the timing mechanism or dedicated apparatus was employed. It is assumed however, that the operation of the computer clock and the calculation of RTs remained consistent across all subjects. Accordingly, the reaction times reported here are considered to be accurate in relative, but not necessarily in absolute terms.

Procedure. Each subject received a short practice session in order to gain familiarization with task requirements. The subjects were urged to respond as quickly as possible to the presentation of the colored square. This stimulus appears at the center of the screen at a randomly selected delay of one to seven seconds. The stimulus remains on the screen until the subject responds to its appearance by pressing the spacebar; the response time of the subject is recorded by the computer and the stimulus is removed from the screen. Reaction times were tested separately for left and right hands for each subject. The order of testing of hand was initially randomly determined, and thereafter alternated in sequence. Each subject was tested over three 100 trial sessions (50 trials per hand). The sessions were separated by a one week interval.

Results and discussion. Two student subjects were disqualified from inclusion in this test when an interview revealed a history of traumatic head injury. The reaction time data (in milliseconds) for the remaining student subjects and M.S. across three weekly sessions of testing (combining the data for both hands) is presented in Figure 4.

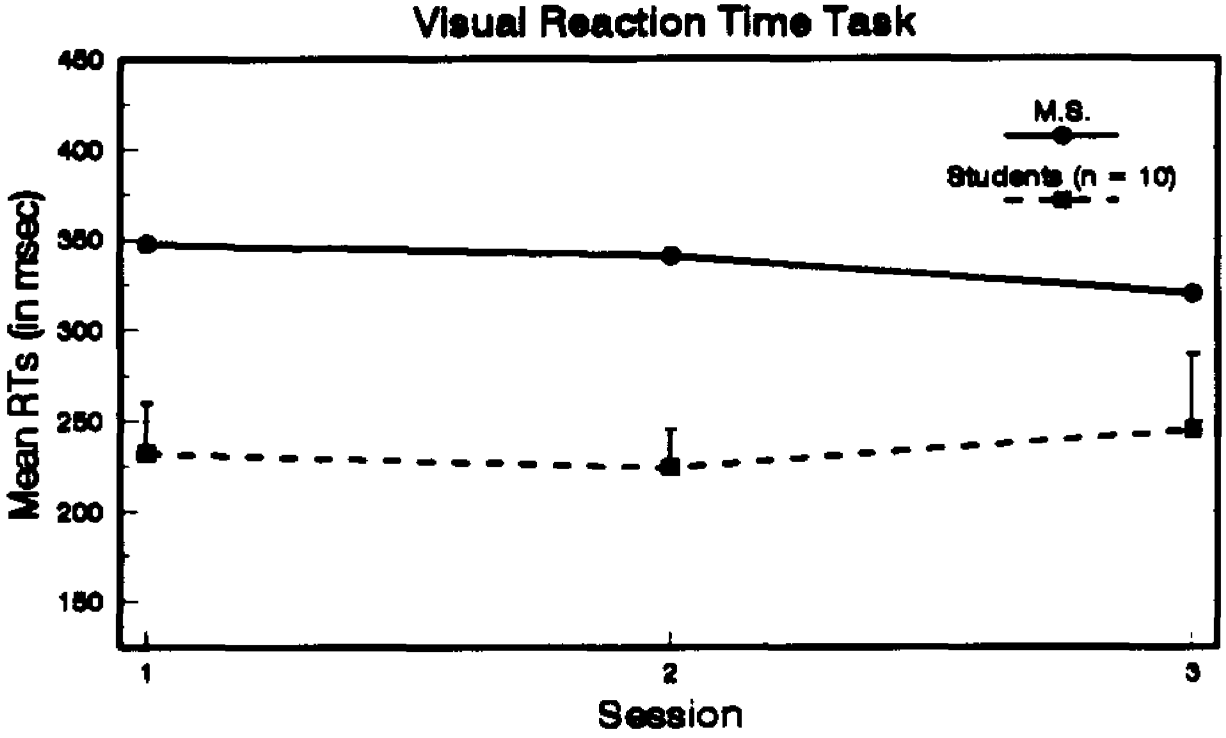


Figure 4. Mean visual reaction times (in milliseconds) for M.S. and 10 students on three weekly sessions. The data were averaged across hands for each subject. The error bars indicate one standard deviation above the mean for the student group.

The data clearly indicate markedly slower reaction times for M.S. relative to the student subjects. Unlike his initial equivalence of performance in Tetris, he is consistently slower throughout the period of testing. The magnitude of the disparity can be gauged by the fact that the means for M.S. for the first two sessions are more than four standard deviations beyond that of the students. The grand mean across all subjects in the comparison group is 234 *msec* (*SD* = 25.58) the same statistic for M.S is 336 *msec*, a full four standard deviations beyond the student group mean. Nevertheless, it is possible to detect a definite across session improvement trend on the part of M.S. Numerically, his mean for the third session shows a 28 *msec* (7.9%) improvement over his mean for the first session. By the third session his mean is only 1.79 *SD* beyond that of the students. This may be taken as an indication that the deficit in response time shown by M.S. can in fact be narrowed with practice. It is not readily apparent how best to account for this finding. Perhaps it is the case that there are several factors which contribute to the overall response slowness shown by M.S., some of which are remediable through practice.

H.M. and controls were tested in a single session for both visual and auditory reaction times (Corkin, 1968). Averaging across a total of eighty trials in the visual condition, H.M.'s mean *RT* of 279 *msec* substantially exceeded that of the control mean of 219 *msec* (range = 189 - 276), suggesting a pronounced and reliable difference in response time.

H.M.'s total decrement of 59.7 *msec* relative to the control group grand mean of that study is substantially smaller in magnitude than the 103 *msec* difference observed between M.S. and his comparison group. However, since these studies were conducted with a different measurement apparatus, and since the comparison subjects in this study were non-age matched college students, precise cross-study comparisons can not be made. It is clear nonetheless that both amnesic subjects were clearly and reliably slower when compared to their respective comparison groups.

Reaction times to visual stimuli were also measured in the context of the Chase Max game in which M.S. was tracked over several thousand trials. That evaluation is presented and discussed in a following section.

Section summary. The strong performance by M.S. in the timed Mental Rotation task demonstrates that he is capable of rapid and accurate judgments in the domain of nonverbal perceptual tasks. In fact, he outperformed most of the neurologically normal college students in the comparison sample. Nevertheless, this superiority vanishes when a somewhat more complicated perceptual task containing a motoric element is introduced. It is reasonable to assume that the demonstrated motoric slowness on the part of M.S. contributed to the flattened learning curve in Tetris. It is far from clear, however, that this was the only contributing factor. While it was initially assumed that the game of Tetris was representative of a fairly straightforward test of perceptual/motor skills, a closer consideration suggests that the game contains elements of planning and strategy which may require the participation of explicit memorial processes for a full benefit to be realized across sessions. It is also possible that M.S. was less sophisticated than the students in developing these strategies, as well as in retaining such information across sessions.

That some mixture of relatively poor strategic skills and motoric deficiency were cofactors in depressing his performance is supported by observations recorded during play on week 7:

> ...his performance seems to be compromised by slow reaction time and motoric awkwardness. He still hasn't made a good integration of the fast down and flip keys. He doesn't use them effectively, if at all ... he doesn't seem to understand how best to pack the blocks—he ends up with sprawling hole filled structures.

Although M.S. may have learned Tetris at a somewhat slower rate than normals, it is clear that he has indeed, over an extended period of time, developed an impressive skill in this task. In the several months subsequent to his formal evaluation, he has played Tetris extensively on his recently acquired personal computer. His manipulation of the keys is now rapid and fluid. He has learned how to use the flip and fast down keys with near virtuosic precision; he regularly achieves scores in the six to eight thousand range, which is impressive even when compared with the Week 4 student mean of less than 700. Thus while his performance in the testing sessions may be indicative of a somewhat depressed rate of learning, it is clear that the combined effects of his amnestic and motoric impairments do not impose identifiable asymptotic restrictions upon learning. In contrast, this appears to have been the case with H.M. in the rotary pursuit task; H.M. reached asymptotic performance after only four sessions.

M.S.'s demonstration of excellent performance in the similar Mental Rotation Task and his initial equivalence (Weeks 1 and 2) in Tetris suggest a fully normal basic ability in task relevant skills. It is suggested here that his depressed rate of learning over delayed sessions can be best explained as owing to the game's subtle demands upon explicit long-term memory, and to the interference with fluent and coordinated task performance caused by relatively slowed motoric responses.

Implicit Learning Tasks.

The Artificial Grammar (AG) Task

Implicit learning is a term coined by Reber (1967, 1989) to refer to a non-declarative mode of information acquisition, and was originally conceived in the context of a basic fact concerning natural language learning: that children achieve essential grammatical and linguistic competence without the benefit of systematic, explicit instruction regarding the rules of grammar. Implicit learning theory suggests that children extract information about grammatical structure as a result of their consistent exposure to structured speech in their local environments. It is not assumed, however, that learning of this kind takes place in a totally incidental manner; the process is conceived as a cognitive by-product of attention to relevant rule governed structures in the environment. Additionally, implicit learning is not considered to be a mechanism specific to language acquisition, *per se*, but, more generally, refers to an ability to derive information about rule structures in the environment in an unconscious, non-reflective way, whether these structures are properties of a natural language, of a system of cultural norms, or of complex economic entities. In short, implicit learning describes a generalized, non-domain specific inductive process that derives information about patterned relationships in the stimulus environment, and represents these relationships in an abstract and tacit form (Reber, 1989; Winter & Reber, 1994).

One of the major avenues of investigation of implicit learning has been through the use of "artificial grammars" (the AG task). A standard experiment of this kind involves a learning phase followed by a testing procedure. In the learning phase, subjects participating in a "simple memory experiment" are required to memorize a set of sequenced consonant letter strings. They are not informed that the sequences of letters in these strings are actually governed by the rules of an arbitrarily devised artificial grammar. In the testing phase of the experiment, the subjects are shown another set of letter strings, only 50% of which conform to the rules of the grammar; the remaining contain violations to the permissible sequence in a single position and hence are non-grammatical. The subjects are asked to make judgments on each of these new strings as to whether they conform to the hidden rule structure. The typical finding has been that subjects are able to discriminate between grammatical and non-grammatical strings at greater than chance levels, even though they tend to be unable to articulate any detailed information about the nature of the artificial grammar itself.

While the early AG experiments were conducted with neurologically normal subjects, later studies by Abrams and Reber (1988) with psychiatric inpatients, and

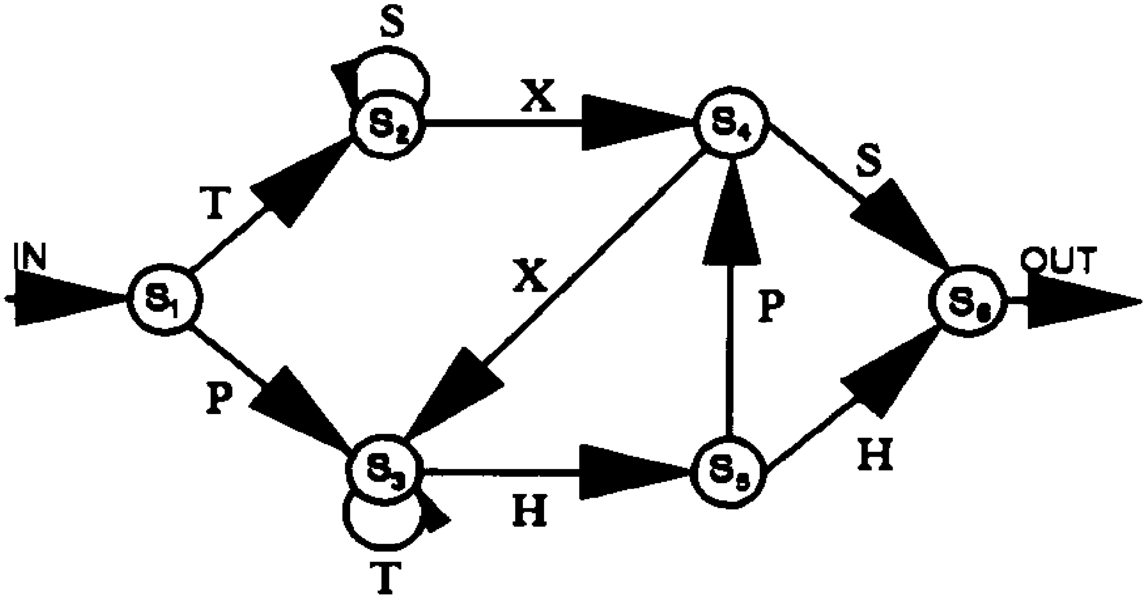
Knowlton, Ramus and Squire (1992), and Knowlton and Squire (1994) with amnesics have obtained similar findings. Furthermore, in the Knowlton, et al. studies, amnesic patients who performed normally on the grammaticality judgments were, in a follow up study with a different grammar, impaired in a recognition test for the letter strings seen in the initial learning phase. This finding supports a basic tenet of implicit learning theory, which posits that the knowledge supporting grammaticality judgments can be acquired and utilized independently of explicit memorial processes. Moreover, and in keeping with this view, these studies reported that performance on the AG task was not correlated with severity of amnesia, or IQ.

The evaluation of M.S. on the AG task and on a follow-up recognition task were structured as within-subject experiments. It was expected that M.S. would evidence intact implicit learning in the AG task by showing above chance performance in his ability to correctly classify letter strings, but would nevertheless perform at (or near) chance in recognizing the letter strings that he had previously viewed.

Materials. The stimuli for both the AG and recognition tasks consist of ordered letter strings generated by a finite state artificial grammar typical of those used in conducting implicit learning studies. As an example, the particular form of the grammar employed in the AG task is shown in Figure 5 and is the same as that employed in Reber and Lewis (1977).

Acceptable, that is, "grammatical" letter strings are generated by a progression through the nodes of the schematic as indicated by the arrows in the figure.

The Artificial Grammar



1. TXS
2. TSXS
3. TSSXXHH
4. TSXXTHPS
5. PHH
6. PTTHPS
7. PTHPXHPS
8. PTHPXHPS

Figure 5. The "artificial grammar" used to generate the sequenced letter stimuli employed in this study. Several examples of grammatical letter strings are provided.

Thus the most direct route from the initial state to the terminal state would result in a letter string three units in length — in this case either PHH or TXS. The remaining letter strings permitted by the grammar can be generated through the exploitation of the additional legal pathways of the grammar including the recursions indicated by the circled arrows at States 1 and 3. All told, this grammar produces 43 unique strings of lengths three through eight; of these 20 were used for presentation during the learning phase. Twenty five non-grammatical strings were also devised for use in the grammaticality judgment task. These strings are orthographically similar to the grammatical strings — that is, they utilize the same sample of letters, but do not conform to the rule structure in that each string contains a violation of the grammar in one location.

Procedure. The subject was introduced to the study as a "simple memory experiment". He was informed that 20 letter strings would be presented, and that the criterion for success on each learning trial would be to accurately reproduce the letter string twice in a row. This process is referred to as the "learning phase" of the experiment.

The letter strings were printed on self adhesive labels in a 17pt 5 CPI font and affixed to standard 3" x 5" index cards. The initial instructions were read to the subject from a protocol, and subject responses in both the learning and testing phases were made verbally by the subject and recorded on paper and pencil by the experimenter.

The index cards containing the letter strings were presented one at a time for a duration of four seconds. As soon as the stimuli was removed, the subject was required to reproduce the letter string exactly. The response was reported verbally to the experimenter. Feedback as to accuracy was provided immediately in all conditions. If the reproduction of the letter string was inaccurate, the same letter string was immediately re-presented and the subject made another attempt. The next letter string was introduced when the subject reached the criterion of two successive correct reproductions in a row. This procedure was followed until all 20 letter strings were utilized.

At the conclusion of the learning phase, the subject was given a five minute break, after which the next phase of the experiment began. In the AG task, a second set of instructional information informed the subject that the letter strings previously observed were constructed according to a rule based system, that is, that they were exemplars of the artificial grammar. The subject was informed that the next task of the experiment was to view another set of letter strings and to make a determination for each string as to whether or not it obeyed the same rule system. Fifty letter strings were used in this "testing phase": 25 grammatical strings and 25 strings that contained one or more violations to the grammar system were used. Over the course of the test, each string was presented twice, resulting in a total presentation of 100 strings.

As in the learning phase, the strings were presented one at a time and the subject was instructed to answer "yes" if the letter string was judged to conform to the grammar, and "no" if it was not. Grammaticality judgments were required for all of the one hundred stimulus strings.

In the recognition task, the learning phase was identical in every respect to that described for the AG task, except that a different (but equally complex) artificial grammar (which made use of different letter values) was employed. Instead of a testing phase in which the subject saw new strings and was asked to give grammaticality judgments, the subject was presented a second time with the strings seen in the learning phase, along with length-matched ungrammatical distractors, and was asked to identify the ones previously viewed. Each string and matched distractor were presented one at a time on individual index cards in random order. M.S. was given the recognition task 34 days after his evaluation on the AG task described above. Two groups of 15 undergraduate subjects (one group for each task) were also run for the purpose of providing comparison scores.

Results and discussion. Performance on the AG task can be evaluated against the binomial distribution; with 100 trials, and at the .05 level, a proportion of correct responses (*pc*) of at least .59 is significantly greater than the expected proportion of .50. M.S.'s *pc* of .61 places him above chance ($p = .018$) in his ability to discriminate grammatical from non-grammatical strings. In signal detection terms, $d' = .64 \pm .27$ and the response bias statistic, $c = -.52$. This value for c indicates a fairly low response bias in favor of identifying a given string as grammatical; overall he identified 69% of the presented strings as grammatical.

It is relevant to this analysis to make note of the dynamic quality of M.S.'s performance across the duration of this task. A split half analysis of his performance shows that while M.S. was well above chance in his judgments in the first half of the test (*pc* = .66, p = .008; d' = .84 ± .35) he performed at chance in the second half of the test (*pc* =.56, p = .240; d' = .53 ± .40). An analysis of the difference between the *pc* of the first and second halves shows that the 95% confidence interval includes the difference of zero (.10 ± .19); while this can be taken as an indication that the two proportions are not significantly different, it must be remembered that the values being compared are not independent (they were generated by the same person); this evaluation must be considered especially conservative[2].

A relaxation of response criterion in the second half of the test is also apparent; while in the first half he judged .62 of the letter strings to be grammatical (*c* = -.32), he judged .76 to be grammatical in the second half of the test (*c* = -.73). Although the 95% confidence interval around the difference between these proportions includes zero (.14 ± .15), this tendency toward decreased sensitivity and lowered response criterion across the duration of the task may reflect the progressive fatigue of this subject. It was noted at the time of test that M.S. showed clear signs of tiring toward the latter part of the session, and may have reacted to his fatigue by simply saying "yes" to the presented letter strings in a fairly indiscriminate fashion.

In this particular version of the AG task, five of the 25 grammatical strings that are presented for judgments have actually appeared in the learning phase. Because each

---

[2] The evaluation of the difference between proportions by calculating a confidence interval around the difference assumes that the proportions are independent. However, since the variance of the difference between proportions is the sum of the respective variances of these proportions (Macmillan & Creelman, 1991), a test using non-independent variances will tend to yield a smaller variance estimate. A test of the difference between non-independent proportions is therefore a conservative one, and is employed here as a tentative test of significance despite the violation of the assumption of independence.

string is presented twice, 10 of the 100 grammaticality judgments are upon strings that are "old", that is, they also appeared in the learning phase. An analysis of M.S.'s performance upon the these 10 strings revealed that he successfully identified every one of them as grammatical. The normal approximation to the binomial test reveals that this proportion of 1.00 is not quite significantly different from the *pc* of .75 which he achieved for the other grammatical strings (p = .072). Nonetheless, it is tempting to interpret this tendency as reflecting the advantage conferred by an explicit memory for the strings that were seen in the learning phase.

This interpretation, however, is not consistent with the results of the recognition test, in which M.S. failed to show evidence of explicit recognition memory for the 20 letter strings seen in the learning phase (*pc* =.58, p = .215; d'= .46 ± .43, c = -.61). Moreover, a split half analysis, such as was performed for the AG task data, shows that M.S. failed to perform above chance in either portion of the task (first half: *pc* = .60, p = .252, d' = .48 ± .62, c = -.67; second half: *pc* = .55, p = .412, d' = .39 ± .60, c = -.54).

A comparison of M.S.'s performance in the AG task (*pc* = .61) to that of the recognition task (*pc* =.58) by normal approximation to the binomial indicates that these values are not significantly different (p = .31); an analysis of the difference between the d' scores yields the same conclusion (variance of the d' difference = .70). Nevertheless, the important fact remains that M.S.'s performance in the recognition task failed to exceed chance. The question may be asked as to why M.S. was apparently able to form and utilize explicit memories for letter strings seen in the learning phase of the AG task, but failed to do so in the recognition test where that is what the task demands. A candidate explanation is that his perfect performance on the "old" strings in the AG task is not fundamentally supported by explicit memory, but rather, the instructions to render grammaticality judgments constitutes an implicit instructional set, and under these conditions, the previously seen items produce a priming effect, i.e., the subject is more willing to judge them as grammatical. However, under instructions to identify which strings were seen in the previous learning phase, as is the case in the recognition task, the priming effect is nullified by the invocation of the explicit memorial strategy. This result is suggestive of a heretofore unnoticed priming effect that can be demonstrated within the context of an AG implicit learning paradigm. The results of M.S.'s performance on both the AG task and the recognition task are summarized in Table 2.

Table 2.

Performance of M.S. on AG (Grammaticality) and Recognition Tasks

	Proportion Correct *pc*, *d'*		
	1st Half	2nd Half	Full Test
AG Task (100 trials)	.66 (p = .008) *d'* = .84 ± .35 *c* = -.32	.56 (p = .240) *d'* = .53 ± .40 *c* = -.73	.61 (p = .018) *d'* = .64 ± .27 *c* = -.52
Recognition Task (40 trials)	.60 (p = .252) *d'* = .48 ± .62 *c* = -.67	.55 (p = .412) *d'* = .39 ± .60 *c* = -.54	.58 (p = .215) *d'* = .46 ± .43 *c* = -.61

Although this evaluation was conducted as a within-subject experiment, it is instructive to compare the performance of M.S. to that of a sample of 15 undergraduates who were also tested on the same AG and recognition protocols. In the AG task, all but two subjects were above chance in their grammaticality judgments; their performance as a group ($pc = .647$, $SD = .044$) was well above chance ($p < .0001$) as determined by the normal approximation to the binomial test. The range of proportion correct scores in this group was .70 - .55; the median was .65. The mean $d' = .81 \pm .26$ and mean $c = .05$.

M.S.'s full test pc of .61, if compared to this group, would clearly be on the lower end of the distribution. While his score is marginally within one standard deviation of the mean, in an ordinal ranking of all 16 scores, M.S.'s score would tie for 14th place. However, as previously noted, the quality of M.S.'s performance deteriorated significantly on the second half of the task. If only the first half of the AG task is considered, it can be seen that M.S.'s pc of .66 ($d' = .84 \pm .35$) closely approximates that of the first half student group mean of .68 ($SD = .07$; $d' = .98 \pm .38$).

An analysis of recognition task data for a second group of students ($n = 13$) shows that as a group, they performed well above chance (mean $pc = .72$, $SD = .093$, $p = .0001$; $d' = 1.23 \pm .44$, $c = -.07$); the mean pc of .72 in this recognition task is significantly better than the mean pc of .647 achieved by the students in the AG task ($t_{(26)} = -2.66$, $p = .013$, two tailed). This pattern of results is in marked contrast to that of M.S., whose full recognition test pc of .58 did not exceed chance performance (p =

.215), while his *pc* in the AG task was significantly above chance ($p = .018$). Moreover, and as mentioned above, a split half analysis reveals that M.S. did not exceed chance performance in either half of the recognition task, while the students were significantly above chance on both halves of the test (first half: $pc = .76$, $SD = .11$ $p < .0001$; $d' = 1.48 \pm .66$, $c = -.17$; second half: $pc = .68$, $SD = .10$, $p < .0001$; $d' = 1.04 \pm .62$, $c = .03$).

The finding that M.S. is capable of above chance performance in the discrimination of grammatical from non-grammatical strings while showing chance performance in the recognition of such letter strings is consistent with results of previous evaluations of amnesic and psychiatrically disordered individuals. In contrast, M.S.'s performance in the learning phase of these tasks, in which the letter strings are originally presented and must be successfully reproduced by the subject (to a criterion of two reproductions per letter string) is at marked variance with the typical findings. M.S. required an average of 6.15 trials to reach criterion performance in the AG task, and an average of 6.95 trials in the learning phase of the recognition test. The corresponding values for the college students in the sample reported above were only 2.80 ($SD = .539$) and 2.83 ($SD = .401$). M.S.'s mean trial to criterion score in the AG task is fully 6.2 standard deviations above that of the student mean, and in the recognition task, the distance is in excess of 10 standard deviations. The amnesics reported in Knowlton, et al. (1992, 1994) successfully reproduced the learning strings on the first attempt (collapsed across both studies) 85.8% of the time. M.S. does so for only 40% of the strings. The fact that other amnesics have shown intact performance (as compared to their controls) on this measure is an indication that M.S.'s difficulty is probably not due to the general effects of his amnesic condition. Furthermore, it does not appear to be the case, given his assessment on relevant neuropsychological tests (see Broman et al. 1991; also Appendix B) that he suffers from a generalized short term memory impairment which could account for his deficient performance here. Rather, it may be that this task provides an indication of a perceptually-based deficit that involves the aberrant processing of sequentially ordered stimuli, producing a behavioral impairment which outwardly resembles "dyslexic" symptomology. Such a deficit in the processing of sequenced stimuli would naturally be highlighted in a task that requires the correct repetition of arbitrary letter sequences, as is the case in the learning phase task. It will be briefly mentioned here that a visual evoked potentials (VEP) evaluation of M.S. has provided evidence of a specific anomaly in magnocellular visual functioning, a condition which has been linked to developmental dyslexia (Livingstone, Rosen, Drislane, & Galaburda, 1991; Lehmkuhle, Garzia, Turner, & Baro, 1992). Also, it is important to note that language based deficits have been reported in other individuals who have suffered acute hypoxic episodes during childhood (Cooper & Flowers, 1987; Murdoch & Ozanne, 1990). Additional evidence that suggests an anomaly in sequential processing will be presented and discussed in later sections.

Chase Max

Chase Max game is a computer administered task that was designed to have the appearance and appeal of a simple video game. It takes its name from the cartoon cat whose movements across the monitor are the central focus of the task.

Chase Max is conceptually similar to the AG task in that it makes use of stimuli which are structured according to a covert rule system. It is different from the AG task in that the stimuli employed are not spatially sequenced strings of letters, but rather temporal sequences of changing spatial positions (Max's movements) across a video screen. In this sense, it is an implicit learning task that is a nonverbal analog to the AG task. Likewise, the rule system governing Max's movements is based directly on a version of the artificial grammar systems used to generate letter sequences.

Chase Max outwardly resembles, and is superficially based upon, the pattern learning task employed by Nissen and her colleagues (Nissen & Bullemer, 1987; Nissen, Willingham & Hartman, 1989). That task also made use of a patterned display across four spatial positions, but the stimulus display in those studies was a simple repeating sequence, whereas the target patterns in Chase Max have been generated by a stochastic rule system.

The subjects in Nissen, et al. (1987, 1989) were required to follow the movements of an asterisk across four positions on the screen by striking keys which corresponded to those four positions. The amnesic and control subjects in that study evidenced a sensitivity to the presence of the repeating sequence by a gradual decline in response times required to shadow the positional changes. They did not show a similar magnitude of decline in response times when the pattern was randomly structured. The amnesics showed this enhanced performance to the repeating sequence despite an absence of awareness of any difference between the patterned and random displays.

The Chase Max game also makes use of two stimulus conditions; one that is structured and one that is random, and uses reaction times as a dependent measure to highlight differential subject performance between these two conditions. However, as mentioned above, the structured display is not a simple repeating pattern, but is generated by an underlying rule-based system. Consequently, subjects in Chase Max cannot improve their performance simply through a rote rehearsal of a nonvariant pattern; rather, a meaningful improvement in the structured condition reflects a sensitivity to the probabalistic contingencies of the underlying rules. As successful performance on this task is thought to be based upon an implicit sensitivity to a covertly governed stimulus display, it was expected that M.S. would show a "learning" of the rule structure as evidenced by differentially decreasing reaction times across repeated sessions in the structured and random conditions.

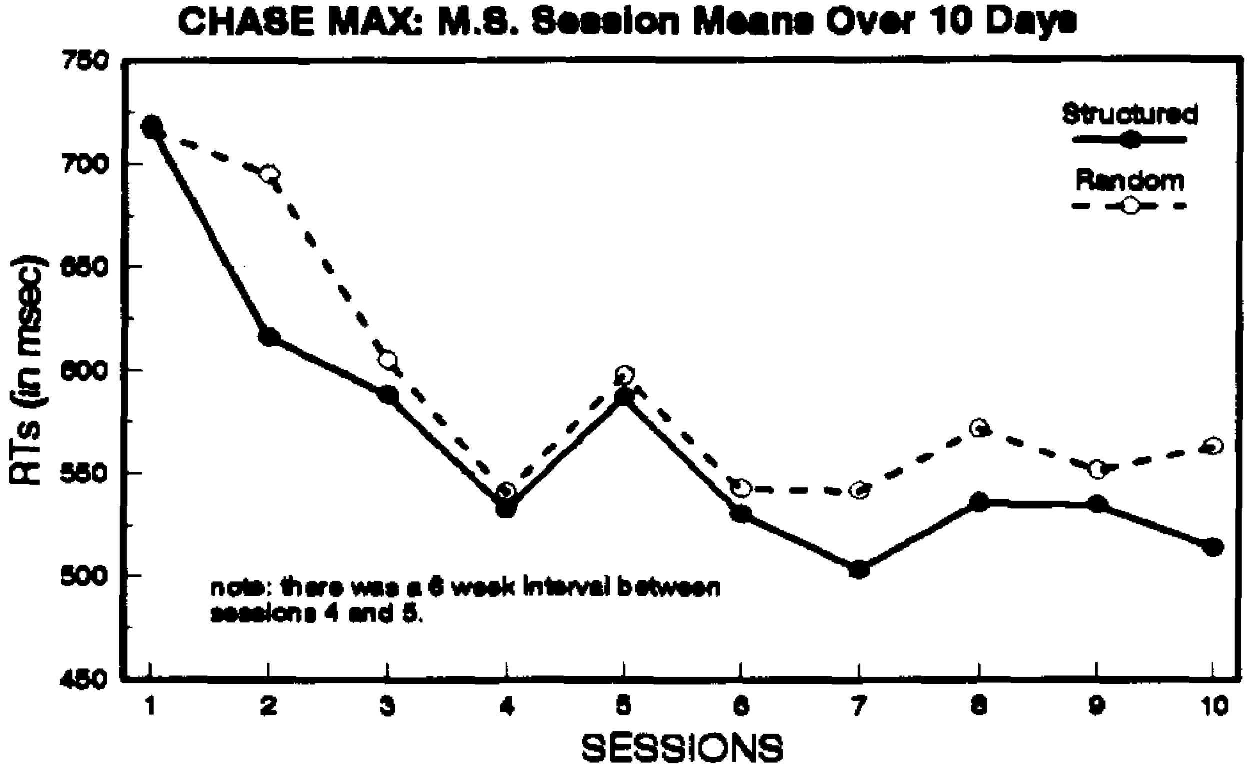
Materials. The Chase Max software, programmed by Andrew Hsaio, is implemented on a 386 25 megaHertz Intel based computer with a .31 dot pitch VGA display monitor. Both structured and random conditions involve the movements of Max the Cat from one of four on-screen positions to another. These positions are clearly indicated on the screen, as are the corresponding response locations on the keyboard. Each condition involves four blocks of 10 cycles with 12 trials per cycle. Thus there are 480 moves and responses for each condition.

Procedure. The task instructions were given to the subject via a short computer guided tutorial. The subject was shown the four on-screen positions and was informed that his task was to follow the progress of Max, as quickly and as accurately as possible, from one position to the other by pressing the appropriate key. If Max's movements are correctly followed, Max immediately moves to another position and waits for the appropriate keyboard response. If the subject responds with an incorrect key press, Max frowns and waits for the correct response. Each session included both structured and random conditions, the order of which was initially randomly determined, and was thereafter alternated in sequence. The accuracy and reaction time of response in both conditions was recorded and stored by the computer. M.S. was tracked over four weekly sessions and was also retested at various intervals to gauge his improvement in performance with extended practice. Thirteen undergraduate subjects were also run on Chase Max for two sessions which were separated by a one week interval.

Results and discussion. In all, M.S. was tested in 10 separate sessions over more than 16 months. His mean percent correct (in shadowing Max's movements) over all 10 sessions was 97.97%. The grand mean of reaction times for the Random condition across all 10 sessions was 592 msec, *SD* = 64.05; for the Structured condition, *M* = 566 msec, *SD* = 64.75. The means for both conditions across all 10 sessions are displayed in Figure 6.

Taken as a whole, the data indicate a trend in which the difference in mean reaction time between the two conditions widens progressively with repeated sessions;

this is particularly apparent in the later sessions. The difference in means across conditions for the first day of testing is virtually negligible (random = 717 msec; Structured = 719 msec) while the same statistic for the 10th day of testing is 49 msec with the advantage evident for the Structured condition.



note: there was a 6 week interval between sessions 4 and 5.

Figure 6. Performance by M.S. over 10 sessions in both Structured and Random conditions

The reduction in *RT* from the first day to the final day of testing for the Random condition was 154 msec, an improvement of 21.51%; the reduction in the Structured condition was 205 msec, an improvement of 28.54%, representing a 7.03% advantage for the structured condition. The elevated reaction times for both conditions in Session 5 likely reflects the partial loss in task aptitude that occurred over the six week interval between Sessions 4 and 5 (the sessions were conducted at irregular intervals after that). Session 10 was conducted 16 months after the initial session of testing.

The undergraduate subjects were also run for two sessions with a one week interval between sessions. Figure 7 displays the mean reaction times for the 12 subjects whose mean percent correct was within one *SD* of M.S.'s pc of .983 for the first two sessions. The corresponding data for M.S. are also shown. What is most apparent from this graph is that M.S. is markedly and consistently slower in his reaction times in both conditions in both sessions. Averaged across all four data points, M.S. is in excess of 3.6 standard deviations beyond the student mean. This result corroborates the finding of depressed simple reaction times on the part of M.S. reported in an earlier section.

A matched pairs analysis of the student data shows that the 5 msec difference between conditions in Session 1 was not significant ($T_{(11)} = -.24$ $p = .814$, two-tailed), but that the 33 msec difference between the conditions in Session 2 was significant ($t_{(11)} = -3.28$, $p = .007$, two-tailed).

The globally slower performance of M.S. compared to the students

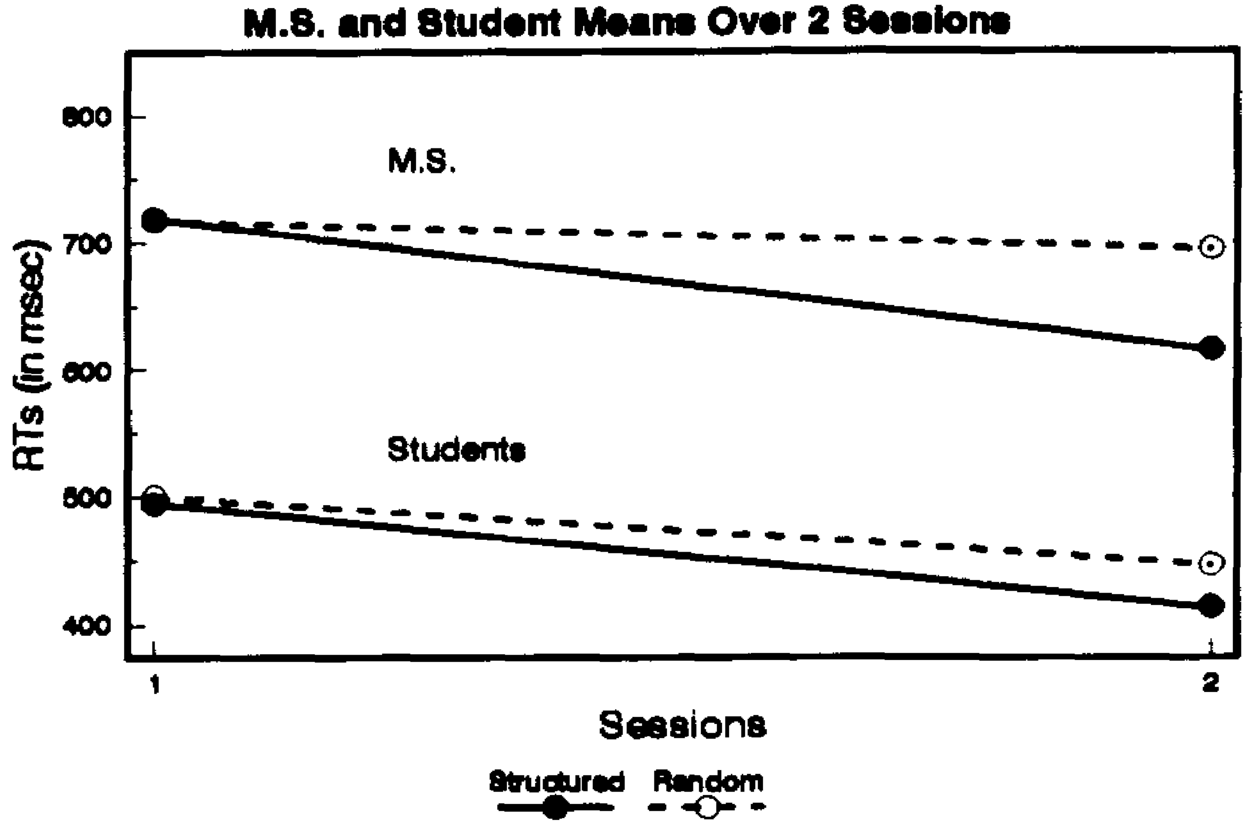


Figure 7. Mean reaction times (in milliseconds) for M.S. and student subjects on two sessions of testing.

notwithstanding, M.S. shows an enhanced performance in the Structured condition in the second session (difference between Structured and Random = 79 msec) that is 2.36 times as great as the difference between conditions for the students (difference = 33 msec).

The data reported here clearly suggest that M.S. developed a consistent and genuine sensitivity to structured stimulus contingencies as evidenced by his reduced reaction times relative to a random stimulus condition. This sensitivity developed incrementally across delayed sessions and was fully comparable to that demonstrated by student subjects over 1,980 trials of testing (two weekly sessions). This result was obtained despite the fact that, upon consistent post-session questioning, M.S. made no reference to the presence of a pattern, and did not report an awareness of any difference between the stimulus conditions.

Section summary. The Artificial Grammar task and the Chase Max game are two evaluations designed to assess the implicit learning of covert rule structures imbedded in stimulus displays. In the AG task, having been shown a series of letter strings that had been generated by an artificial grammar, M.S. was above chance in discriminating these and other "grammatical" letter strings from nongrammatical ones, although, in a separate evaluation, he performed at chance in recognizing the actual exemplars that had originally been shown. This result suggests that information regarding an underlying rule structure that is sufficient to support category-level discriminations can be learned and utilized without the explicit memory for individual exemplars, and is thereby consistent with previous findings in the literature. Furthermore, over the first half of the grammaticality task, M.S. performed as accurately as did a group of college undergraduates. However, while a second student group performed well above chance in recognition memory for letter string exemplars, M.S., as mentioned above, showed chance performance at this same task.

In the Chase Max game, M.S. gave evidence of sensitivity to an imbedded rule structure by a reduction in *Rts* that was larger in magnitude than that for a random stimulus display. This advantage for the rule structured condition was in evidence across blocks within sessions, as it was across sessions that were conducted at various delays over a period of nearly 17 months. In both within session and across session evaluations, M.S. showed an enhanced performance in the structured stimulus condition that was similar in magnitude to that demonstrated by a sample of college undergraduates.

Although in post-evaluation interviews, some of the students noticed the presence of a pattern in the stimulus display, M.S. never indicated any awareness of the presence of a pattern in one of the experimental conditions.

Implicit Memory - Priming Tasks.

Word-completion priming

When amnesics and normal controls are given a list of words to study, and then are tested for free recall of these items, the amnesics show an unsurprising impairment in performance. However, when given the initial three letter stems of the target words, amnesics have been shown to complete these items with words from the study list at a fully normal rate. As first demonstrated in a seminal study by Graf, Squire, and Mandler (1984), this effect is only obtained when the subjects are asked to complete the word-stems with the first words that come to mind (the "word-completion" task). When the subjects are specifically directed to complete the stems with words from the study list (the "cued recall" task), amnesics show impaired performance with respect to normals. That is, the performance of the normal subjects improves markedly under these instructions, while the amnesics do not improve beyond that of the word-completion priming condition.

This instructional effect is readily explained from the separate memory systems standpoint. The requirement that subjects use words from the study list is assumed to place a special demand upon explicit memorial processes, precisely the operations which are most directly affected in amnesia. In this condition the normal subjects are superior to the amnesics in their ability to retrieve and utilize the recently studied words. In contrast, the liberal requirement that the stems be completed with the first word coming to mind exempts the subjects from making direct reference to the contents of the study list, permitting the spontaneous priming process to be expressed in the subject's response. In this condition, the operation of explicit memory in the normals is effectively neutralized by the instructional requirements. The normals and amnesics, equated on the level of implicit priming capability, perform alike.

In this within-subject study, it was anticipated that M.S., would perform similarly to previously tested amnesics, in that he would demonstrate markedly enhanced performance in the word-completion condition relative to the free recall task. Furthermore, and again in keeping with the data from amnesic subjects, it was assumed that the instructions to complete the word-stems with items from the study list would not enhance his performance beyond that of the implicit instructional condition. This last result would follow from his inability to access an explicit memory for the study list items.

Materials. The stimuli, as based on those employed in Graf, et al. (1984), are common English words whose initial three letter stems can be completed with a minimum of 10 other common words. Twenty of these words function as target stimuli, twenty serve to assess the rate of baseline priming, and 10 serve as distractor items at the beginning and end of the study lists to prevent primacy and recency effects in subsequent testing. Two separate forms (A and B), were generated from these word stimuli. Each form contains a study list of 15 words, which is made up of 10 target words preceded and followed by distractors. Each form also contains a free recall form, and a list of word-stems, which is made up of a random arrangement of stems from the 10 targets and the 10 baseline words.

Unlike the Graf et al. study, in which each stimulus word was printed individually on index cards, the words on the study lists of both forms were printed in a vertical column on a single piece of paper. The word stems are likewise printed in two vertical columns on a single piece of paper, with underscores printed to the right of each stem, indicating where the word completions should be supplied by the subject.

Procedure. The first page (of either form A or B) is the study list of 15 words. The subject was instructed to rate the list according to how much each word is liked. This task was implemented in order to discourage the subject from directly attempting to memorize the words in anticipation of a memory test. A Likert scale ranging in values from 1 (Dislike Very Much) to 5 (Like Very Much) was provided at the top of the page to assist in these judgments. The subject was instructed to record the ratings in a space provided to the right of each word, to work as quickly as possible, and to refrain from checking over the work. Upon completion of this first page, a second list of the same words (in a different order) was given, and the subject was again asked to provide liking ratings for each word. M.S. was asked to say these study list items out loud, in order to verify his correct reading of the word stimuli.

Immediately upon completion of this second rating task, the subject was given a recall test for the words that had just been judged. This test was in turn followed immediately by the task in which the subject must complete word stems. In the "implicit" word-completion condition, the subject received the instructions to use the first word that came to mind; in the "explicit" cued recall condition, the instructions were to use words from the original list.

M.S. was tested in four separate sessions on the word-completion task. These four sessions were divided between forms A and B, which were alternated across successive sessions. The sessions were separated by a minimum of one month. A similar schedule was followed for the cued recall condition, which followed the word-completion testing by a six month period. This interval between conditions mirrors that employed by Graf et al. with their amnesic subjects.

Two groups of college students were also tested, one group on the word-completion ($n = 12$), and the other on the cued recall condition ($n = 12$). Within each group, subjects were tested on either Form A or Form B, which was randomly determined.

Results and discussion. The data for all subjects were collapsed across forms. Subject scores for both word-completion and cued recall were corrected for baseline performance by subtracting the proportion of baseline responses from the proportion of target item responses and dividing this value by 1 minus the proportion of baseline responses:

$$\frac{\text{prop. of target responses - prop. of baseline responses}}{\text{1 - prop. of baseline responses}}$$

The data for M.S.'s performance in both word-completion and cued recall conditions is displayed in Figure 8. Contrary to expectation, M.S.'s free recall score (25%) in the priming condition was nominally better than his word-completion score (17.5%). However, if these percentage values are converted to proportions, it can be seen that the 95% confidence interval around the difference between these proportions (.075 ± .1785) includes zero, and that the performance in these two conditions was not significantly different. Similarly, the nominal advantage for free recall in the cued recall condition (22.50% vs. 16.88%) was also not significant (.0562 ± .1738).

Nevertheless, it is striking that M.S. did not show the classic effect of an enhancement of performance in word-completion over free recall. However, a similar anomaly in the relationship between free recall and priming was also obtained with the student subjects who were tested on this protocol. The students in the priming condition actually showed a significant advantage for free recall over word-completion (59.16% vs. 42.96%, $t_{11} = 2.51$, $p = .029$).

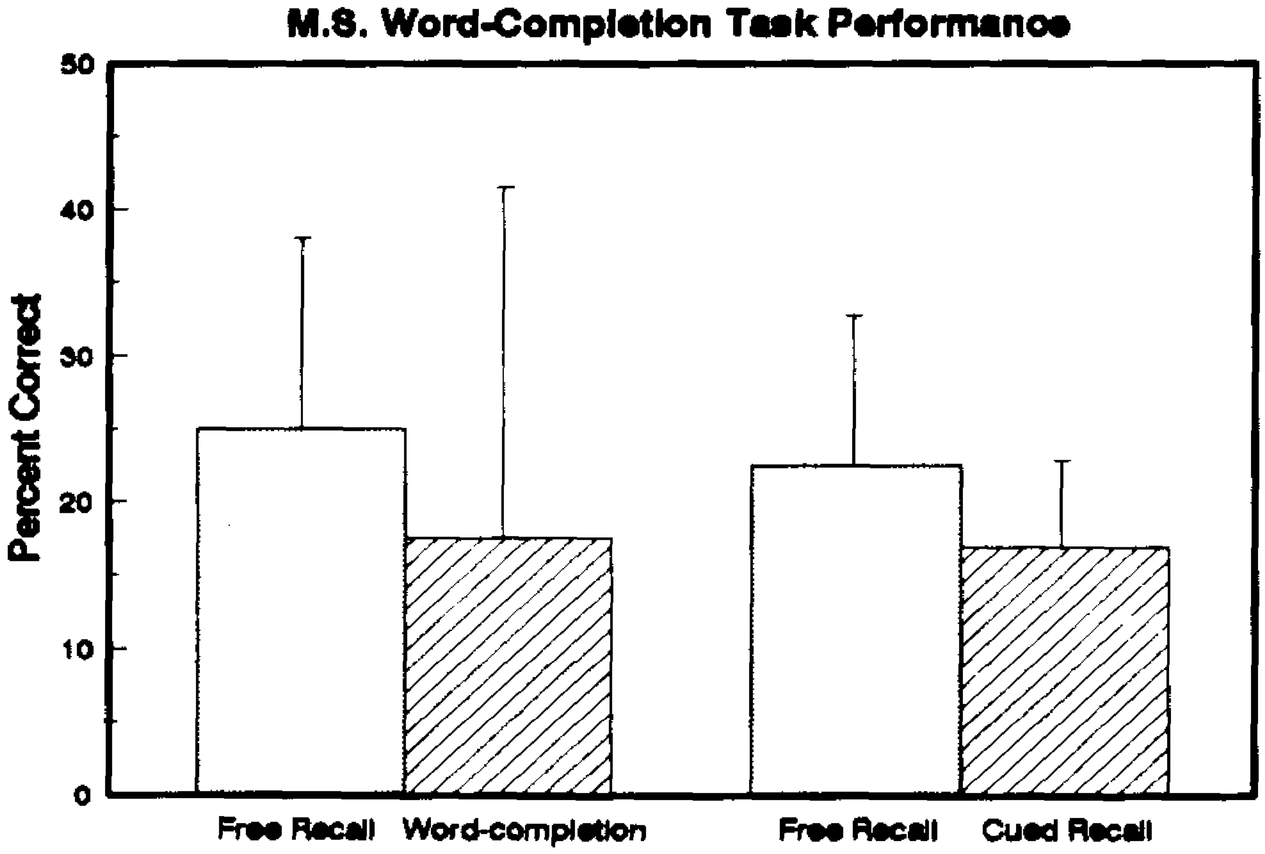


Figure 8. Mean percent correct for four sessions of testing on word-stem priming with both implicit (word-completion) and explicit (cued recall) instructions.

The students in the cued recall condition showed a very similar free recall performance (61.67%) suggesting that this range of scores reflects a reliable and genuine characteristic of student performance on this protocol.

Figure 9. displays the data for students who were run in the word-completion condition (n = 12), the cued recall condition (n = 12), and also presents the data for M.S. for ease of comparison. The averaged free recall scores (across word-completion and cued recall conditions) for both M.S. and the students is also presented.

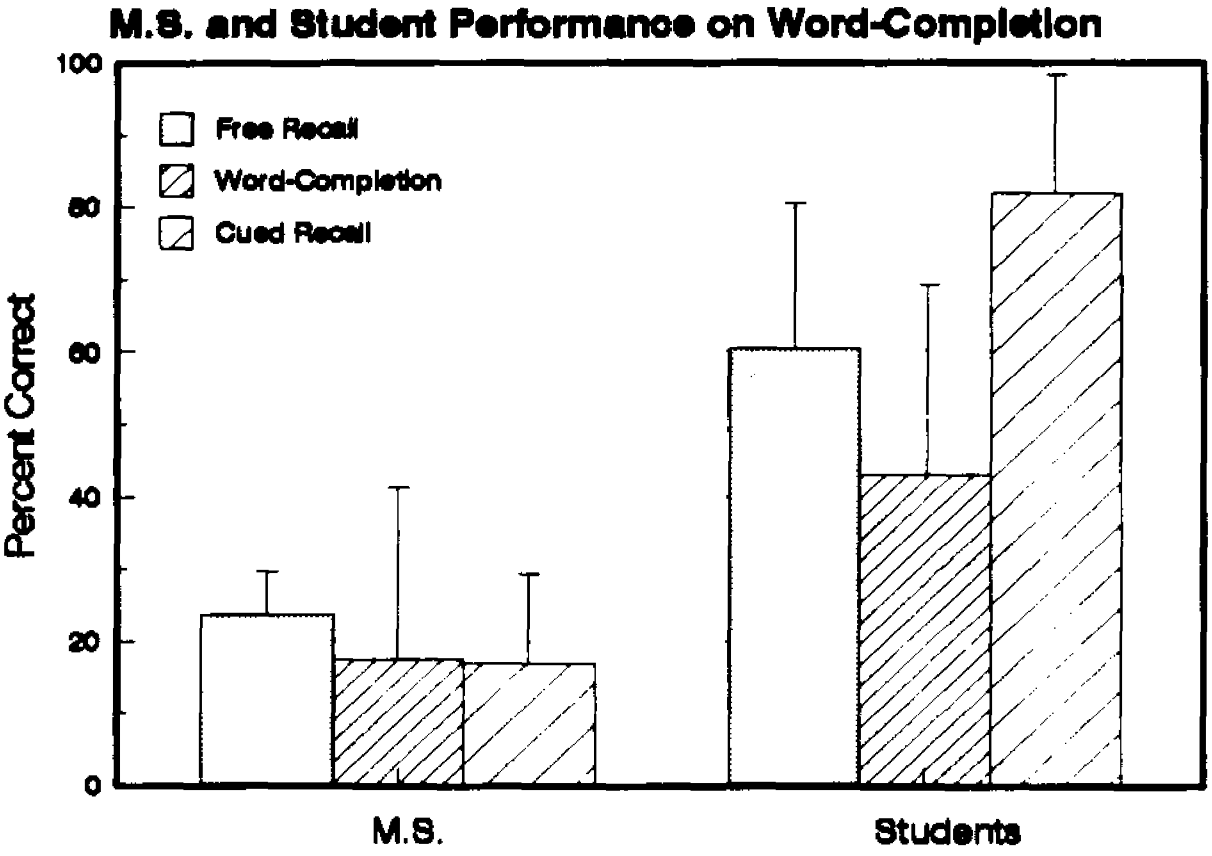


Figure 9. Averaged performance for M.S. and student subjects in free recall, word-completion, and cued

The advantage for free recall shown by the students here is at variance with the performance of normal subjects in other studies, such as those in Graf et al., who showed the weakest score for free recall (26.6%; Experiment 1, "Liking" orienting task), followed by the word-completion (43.1%: Experiment 1, "Liking" orienting task) and cued recall condition (69%; Experiment 3, "Liking" orienting task) respectively. A plausible explanation for the elevated recall scores in this study centers on methodological differences in stimulus presentation; while Graf et al. presented the word stimuli on index cards at a rate controlled by the experimenter, this study, in the interest of implementing a simple "paper and pencil" format, presented all 15 study words together on a single page. The subjects here were encouraged to complete the "liking" task as quickly as possible, and this may have permitted the target words to remain highly active in short term memory at the time of the free recall test (which followed immediately), resulting in the relatively inflated scores. Interestingly, this change in methodology did not seem to have a correspondingly large affect upon word-completion performance. The student subjects primed at a rate similar to the control subjects in Graf et al study (42.96% vs. 43.1%) although this comparison must remain very approximate, because Graf et al. did not report corrected priming values (uncorrected priming score for students in this study = 49.17%). The fact that a methodological factor could produce a dramatic effect in recall performance without necessarily producing a similar effect in word-completion parallels the results obtained by Graf, Mandler and Haden (1982), where it was found that elaborative encoding of the stimulus words affected recall but not priming scores. This effect is consistent with the interpretation that these two types of tests enlist cognitive processes which are independent of one another (see also Roediger, Weldon & Stadler, 1992; Thapar & Greene, 1994).

It is likely that M.S. also enjoyed a boost to recall performance in this version of the test; the equivalence of his recall and word-completion scores may reflect the methodological change which apparently inflated recall performance but not word-completion priming. Also, his high free recall score relative to cued recall (22.5% vs. 16.88%) may also reflect the fact that the target words were still active in short term memory at the time of the free recall test, but were lost to short term storage by the time of the subsequent cued recall test.

Although both M.S. and the students were quite variable in their word-completion scores (*SD* for M.S. = 23.67; *SD* for students = 26.36), the mean priming score for M.S. (17.5%) appears to be unduly low when compared to that of the students in this study (42.96%), or to that of the control subjects in Graf et al. (43.1%), or to the amnesics in that study (49.2%). It is tentatively suggested here that this result demonstrates a failure to produce the expected level of priming in this amnesic subject.

In considering this result, it must be remembered that M.S. comes to this task with extremely impoverished language and reading skills; his performance on most standardized reading and language tests is on a second or third grade level (see Subjects section and Appendix B). His ability to handle the basic requirements of this evaluation was clearly qualitatively different from that of the student subjects. For example, while the students were fluent in their reading of the simple words on the study list, M.S.'s reading of most of these words was effortful and halting. In some cases he had to be assisted in sounding out the words. It is tempting therefore to assume that M.S.'s apparently atypical performance on this task can be attributed entirely to his generally poor language skills. However, this explanation may not fully account for certain details of his performance. For example, while it is certainly the case that M.S.'s vocabulary is limited in comparison to the students, this should not necessarily present an impediment to success in this priming task. In fact, the probability of completing word-stems with recently presented items should be relatively high for someone with a limited repertoire of response alternatives. Furthermore, his belabored reading of the word list resulted in an extended period of study for those items, and the requirement that he read the words out loud should have provided an encoding advantage not enjoyed by the student subjects. Additionally, after his oral reading of the words, he frequently asked questions or made comments about them. While this elaborative rehearsal of study items may bear more directly upon recall as opposed to word-completion performance as noted above, the lengthened visual exposure time gained by M.S. to the items on the list may be considered relevant to the perceptual processes thought to support word-completion priming. Despite this advantage for both semantic and perceptual encoding, M.S. nevertheless seems to show depressed recall and inconsistent priming performance in comparison to the student group in this study, and apparently diminished priming relative to the amnesic group reported by Graf et al. (1984).

It is possible that the relatively weak priming effect shown by M.S. may owe to a specific perceptual deficit of the type previously mentioned in connection with his performance on the learning phase of the Artificial Grammar task. A perceptual difficulty that impairs the processing of sequenced stimuli would likely interfere with performance on tests that involve the ability to respond to ordered letter sequences, such as is the case in both the learning phase of the AG task, and word-stem completion in this task. It is possible that M.S. shows inconsistent priming because he has difficulty in forming a perceptual representation at the time of study which accurately captures the ordering of letters in the word stimuli; consequently, at the time of test, the word-stems do not evoke the previously studied whole-word forms to the extent that they do for other subjects.

It was reasoned that if M.S.'s difficulty with priming in this task was due to some mixture of generally unsophisticated language skills and/or a perceptual disorder, and not a failure of the presumed implicit functions that support priming capability, he would show better results on a priming evaluation that does not rely as heavily upon the orthographic form of the target stimuli. The following priming evaluation was conducted as a test of this prediction.

Fame priming

An interesting variant of priming effect first explored in normal subjects (Jacoby, Woloshyn, & Kelly, 1989; Neely & Payne, 1983) and later with amnesics (Squire & McKee, 1992) might be referred to as "fame priming". This term is descriptive of the basic finding that, having viewed a list which includes the names of a mixture of famous and non-famous people, subjects are subsequently more likely to judge those nonfamous names as being "famous" than similar names that were not previously read. In the Squire and McKee (1988) study, amnesics and controls exhibited this priming effect equivalently, although the amnesics were significantly impaired on a recognition test for the names that had appeared on the original study list.

This priming effect is different from that produced in word-stem priming in a fundamental way: it does not involve a simple facilitation in processing for the actual word form previously encountered, but produces a priming effect (in the form of a lowered response criterion) for an *attribute* of the previously viewed stimuli, i.e. "fame". As such, this priming effect may not be as strictly dependent upon the orthographic or sequential structure of the studied items as is word-completion priming. Also, since the priming effect occurs for non-famous names which are presumably new to the subjects, it can be regarded as a demonstration of priming for novel information.

Materials. A total of 120 first and last names, 60 of which are famous names and 60 of which are non-famous, are the stimuli in this test. The famous names employed by Squire and Mckee (1988) were those of people who became at least moderately famous over the decades of the 60's, 70's and 80's. They were specially selected to have, as a group, about a .50 probability of being recognized as famous. This list was amended for use with this subject by substituting some names of high and medium recognizability for names of low recognizability in order to provide a similar probability of recognition.

Every famous name is matched to a non-famous name in terms of length of first and last names, gender, and ethnicity. Some examples of famous/non-famous name pairs are: Roger Maris/Jerry Price, Al D'Amato/Ed Venusi, Jayne Mansfield/Randi Fairchild, and Kurt Waldheim /Eric Sulzberg. Each name is randomly assigned to one of three experimental forms, the study phase list, the fame judgment list, or the recognition test list, with the constraint that the famous names must be assigned to the same list as their matched pair.

The study phase list comprises 60 names, 30 famous and 30 non-famous names, arranged in random order. The fame judgment list, consisting of a total of 80 names comprises (a) 20 famous and 20 non-famous names that have been on the study list, and (b) 20 famous and 20 non-famous names that have not been on the study list. The recognition list consists of a total of 40 names, which are a) 10 famous and 10 non-famous names from the study list that are *not* on the fame judgment list, and b) 10 famous and 10 non-famous names never seen before.

All phases of this experiment were presented on a 80386 personal computer operating at 25 megahertz computer with a .31 dot pitch VGA display.

Procedure. The subject was told that he would be tested for his ability to read and properly pronounce a list of people's names and was presented with the list of 60 names on the study list, one at a time. No reference was made to the fact that some of the names were those of famous people. Immediately after the last name was read, the fame judgment phase began. The subject was told that some of the names he had read were the names of famous people, and that he would next see a new list which also contained some famous names. He was informed that the task was, for each name on the new list, to say whether that name is that of a famous person. It was also mentioned that it was not important to know exactly why a given person named is famous, but that it was enough to simply say "yes" or "no" in making a fame judgment for each name on the list.

As the subject rendered fame judgments on the 80 names on the list, the yes/no responses were recorded by hand. Priming was assessed by comparing the number of previously seen famous and nonfamous names that were judged famous to the corresponding value for new famous and non-famous names.

The recognition task began immediately after the final response for the fame judgments was recorded. The subject was told that he would see one more list of names, and was asked to judge each name on the list as to whether it appeared on the first list by providing a simple "yes" or "no" response. These responses were recorded manually by the experimenter.

Results and discussion. Figure 10 displays the percentage of names judged famous by M.S. for both "New" (never before seen) and "Old" (previously seen) famous and non-famous names.

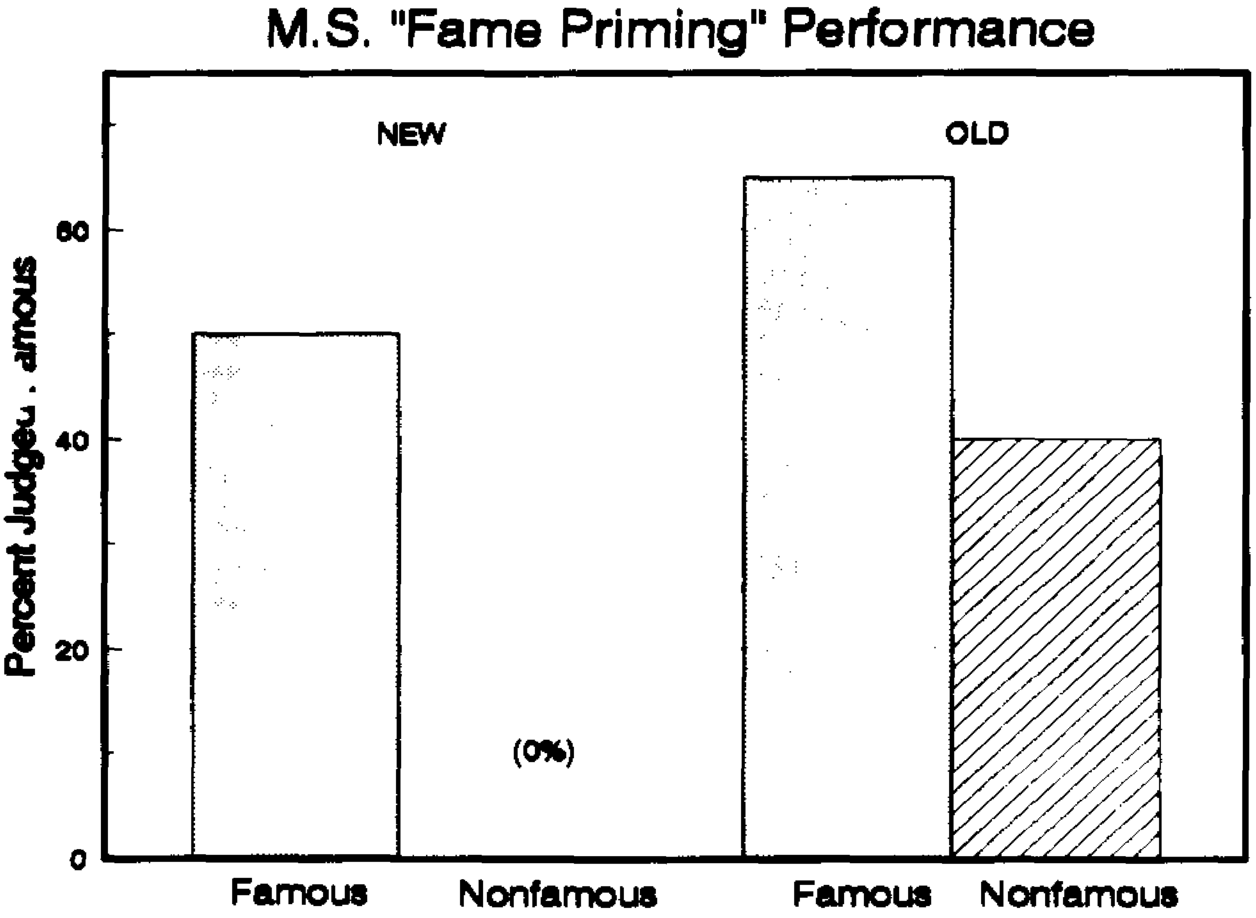


Figure 10. Performance of M.S. in the "fame priming" evaluation. Priming is demonstrated by the increase in fame judgments for previously seen names relative to similar names that have not been previously viewed.

Across both New and Old conditions, M.S. correctly identified 23 of 40 famous names, and correctly rejected 32 of 40 non-famous names, for a total of 69% correct (p= .001; d'= .729, c = .92). For the New names on the testing list, M.S. correctly identified 50% of the famous names as being famous, and judged 0% of the non-famous names as being famous (pc= .75). For the purposes of signal detection analysis, the 0% value for the non-famous names judgments (which corresponds to the false alarm rate) was converted to a proportion of .025 by the correction formula $1/(2N)$ (Macmillan & Creelman, 1991), in order to avoid a proportion of zero. Given a hit rate of .50, and a false alarm rate of .025, d'= 1.95 ± 0.648 and c = .974.

For the "old" names, M.S. showed a marked priming effect in that he judged 40% of the previously viewed non-famous names to be famous, a striking contrast to his baseline rate for "new" non-famous names of 0%. For the Old famous names, he judged 65% to be famous, a 15 point increase relative to the baseline rate of 50%. In this condition, pc = 62.5%, d' = .639 ± .40, c = -.066. The change in the value for the response bias statistic c from the New to the Old conditions (from .974 to -.066) indicates a marked loosening of response criterion, i.e., the willingness to identify a name as "famous". An alternate way of stating this is to note that his proportion of "No" (not famous) responses decreases from .75 to .48; since the 95% confidence band around the difference between these proportions (.27 ± .205) does not include zero, we can regard this as a significant difference. While it is true that M.S. also shows a decline in pc across the two conditions (.75 -.63 =.12), the 95% confidence interval around this difference (.12 ± .201) includes zero; this difference in accuracy therefore cannot be considered significant. The same conclusion is reached if the difference in d' scores is similarly evaluated (variance of the d' difference = .30). It appears that this apparent decline in accuracy is a function of the fact that the hefty "priming" effect in the Old non-famous category (false alarms) is accompanied by a relatively modest "priming" increase in the Old famous category (i.e., hits). This is probably best interpreted as a somewhat asymmetrical change in response bias between these conditions, rather than as a genuine change in the ability to discriminate between famous and non-famous names. The amnesic and control subjects in Squire and McKee (1992) also showed a relatively stronger priming effect for non-famous names. In that study the controls showed an 88.89% priming effect for non-famous, but only 21.57% for famous names, while the amnesics showed a 100% priming increase for non-famous, but only a 21.82% increase for famous names. M.S.'s performance here reproduces this tendency, but because of his perfect accuracy in the New non-famous category, the effect appears even more extreme.

In the recognition test for the names that had appeared in the original reading list (but did not appear in the judgment test), M.S. correctly identified only 22 out of 40 names, performing at chance (pc = .55, p = .32; d' = .312 ± .435, c = .69). The difference between M.S.'s overall proportion correct in the fame judgment task and the proportion correct in the recognition test (.69 - .55 = .14) does not, however, reach significance (i.e., the 95% confidence band surrounding this difference includes zero; .14 ± .1845).

Section summary In two separate assessments, M.S. showed evidence for strong, and apparently normal, priming ability in one task (fame priming), but an unstable and inconsistent performance in the other (word-completion). In the latter task, the performance of M.S. was at variance with that reported for other amnesics in that he showed a relatively low mean level of priming, and roughly equivalent levels of performance regardless of task instructions.

Both of the priming tasks employed here can be considered to be "verbal" in nature insofar as they entail the presentation of, and response to, verbal stimuli. However, the tasks appear to involve critically different processing requirements; word-completion involves the priming activity for a target word as evoked by a partial presentation of that word, while the fame judgment task involves the priming of a perceived property of the presented stimuli. Word-completion priming would therefore appear to place particular demands upon the perceptual mechanisms that govern the processing of orthographic word forms. In contrast, the fame priming task requires no regeneration of the target stimuli at the time of test, but only a simple "Yes" or "No" judgment about a conceptual attribute of the stimuli.

The possibility is considered here that M.S. failed to show appreciable levels of priming in the word-completion task due to his generally poor language and reading skills. It is interesting to note, however that his deficits in this area did not substantially affect performance in the "fame priming" study. An alternate (but not mutually exclusive) possibility is that a selective perceptual processing deficit, perhaps best conceptualized as an acquired perceptual processing disorder, may have especially interfered with the proper representation of word orthography and letter sequencing that is essential to word-completion priming. Such a deficit may have less consequence in a task such as "fame priming", where veridical orthographic representation of the target stimuli is not central to successful performance.

In recent years, some attention has been given to the possibility that priming and other implicit memory tasks may be used as forensic diagnostic instruments in the detection of feigned amnesia (Rubinsky & Brandt, 1986; Schacter, 1986; Wiggins & Brandt, 1988). A key consideration is whether individuals who feign amnesia (i.e., in the context of criminal or civil litigation) will tend to produce "impaired" performance on tasks in which genuine amnesics perform normally. These studies make it clear that the reliable discrimination of genuine from feigned memory impairments is a complicated matter, and that considerably more basic research must be conducted before such techniques can be established in applied settings. The results of the present study sound a further cautionary note; it must be recognized that certain language or perceptual disabilities may in fact impair performance on selected implicit tasks such as word-completion priming. It is clear that the performance of these special populations on implicit learning and memory tasks is in need of more precise characterization, and that the knowledge of their performance is important to both theoretical and applied considerations.

The Tower of Hanoi

This well-known puzzle has been used extensively in the study of problem solving capability in normal adults and children. As noted above, several researchers have employed it as a means of exploring the nature of skill learning in various patient populations, including amnesics (c.f. Beatty, Salmon, Bernstein, Martone, Lyon, & Butters, 1987; Butters, Wolfe, Martone, Granholm, & Cermak, 1985; Cohen, 1984; Cohen, Eichenbaum, DeAcedo, & Corkin, 1985). The weight of the more recently accumulated evidence suggests that amnesics do not learn the Tower of Hanoi at the same rate as controls despite an expectation that amnesics should show no deficit in tasks of cognitive skill acquisition. The speculation offered by Butters, et al. (1985), that the inferior performance of amnesics may owe to the frontal lobe pathology associated with Korsakoff's syndrome does not, however, account for the problems demonstrated by amnesics of other etiologies.

Given the history of performance by amnesics on this task, it was expected that M.S. would show clear evidence of improvement over repeated trials that is, nonetheless, inferior to that of previously reported normative data.

Materials. The Tower of Hanoi game board consists of a wooden stand supporting three equidistant vertical pegs. In this version, there are five wooden disks which are moved from peg to peg according to the game rules.

Procedure. At onset of the game the left-most peg contains the stack of five size-ordered disks, with the largest disk on the bottom and the smallest on top. The instructions were read to the subject, which explained that the object of the game is to move the stack of disks to a target peg in the fewest moves possible, moving only one disk at a time, and without placing a larger disk upon a smaller one. After Butters, et al. (1985) and Beatty, et al. (1988), the subject was allowed to choose which of the two remaining pegs would serve as the target peg.

The game was played (to solution) a total of 16 times. These 16 games were evenly divided over two consecutive days, there being eight games per day. Each day began with a block of four games, followed by a 15 minute break. Play resumed with a final block of four games for that day. The number of moves required for the solution of each game was recorded manually by the experimenter, and this tally was checked against a videotaped record. The minimum number of moves to solution in the five disk version is 31.

Results and discussion. The raw scores for the individual trials as well as mean scores over the four blocks of testing are presented in Table 3. The grand mean across all trials for M.S was 38.56, *SD* = 6.54 moves. An index of learning in this task is the percentage of possible improvement gained between the very first and very last of the testing blocks (i.e., Block 1/Day 1 and Block 2/Day 2). The percent improvement score for M.S., calculated by dividing his actual improvement (1.00) by his possible improvement (9.25) was 10.81%. The anoxic/hippocampal amnesic L.M., tested on the same protocol (Beatty et al. 1987), was reported as achieving a percentage improvement score of 39%, while concurrently run controls gained an average of 75 ± 27%. Thus M.S.'s improvement score of 10.81% is nearly 2.5 standard deviations below the mean improvement score of the normal subjects.

Table 3.

Trial by Trial and Block Mean Scores for M.S. on the Tower of Hanoi

DAY 1

	Trial # 1	2	3	4	Mean
Block 1	51	32	46	32	40.25
Block 2	35	31[a]	39	37	35.50

DAY 2

	1	2	3	4	Mean
Block 1	31[a]	52	39	35	39.25
Block 2	38	39	43	37	39.25

[a] Denotes perfect performance.

Figure 11 displays the performance curves of M.S., L.M., and the neurologically normal subjects reported in Butters et al., (1985) and Beatty et al., (1987). A striking and interesting fact that emerges from the graph of these data is that both amnesic patients show fully normal performance across the blocks on Day 1; in fact, M.S. shows numerically superior performance as compared to the normals across both Blocks 1 and 2. However, both M.S. and L.M. exhibit a definite loss in proficiency across the 24 hour delay. M.S loses 3.75 moves (79% of his gain on Day 1), while L.M. loses 8.00 moves, or 400% of his improvement on Day 1.

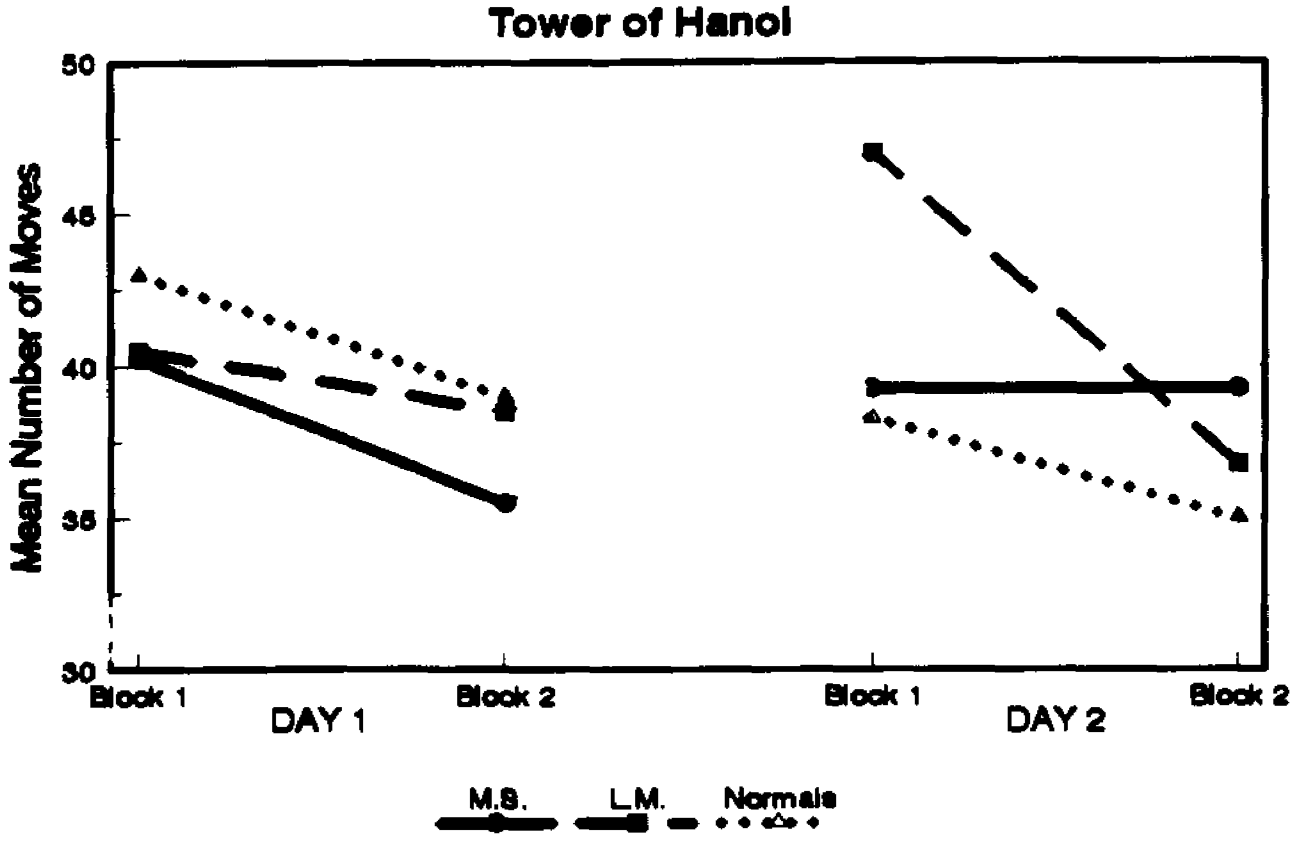


Figure 11. Block means for two hypoxic/hippocampal amnesics, M.S. and L.M. and for normal subjects (n = 12) for two days of testing on the Tower of Hanoi. The data for L.M. and for the normal subjects is adapted from Beatty, et al., (1987).

On the final block of testing, M.S shows no further loss in performance while L.M. shows a considerable gain, to within one point of the mean of the controls.

Although the Tower puzzle is often referred to as an example of a "procedural task", the requirements of this puzzle may place a premium upon explicit analysis of the puzzle state and its possible solutions. A parsimonious explanation for the large decrement in performance suffered by both amnesics across the 24 hour delay would cite the probable loss of explicit memory for the task relevant information gained on the first day of testing. The normal subjects, in contrast, show no decrement in performance across the 24 hour delay but do in fact show the slightest gain in their performance across any session of testing, which may be viewed as the effect of "normal" forgetting. These subjects never suffer a decline in performance over the duration of the testing, an outcome consistent with the idea that they are able (at least as a group) to utilize previously gained information in a cumulative fashion.

The fact that M.S. solved the puzzle in the minimum 31 moves on the very first trial following the 24 hour interval would seem to argue against the interpretation of a loss of explicitly held information across session days. Yet it is possible that his perfect performance here reflects a fortuitous, rather than intentional, sequence of moves. At the very least, this knowledge was extremely volatile; on the very next trial he requires a full 52 moves to solve the puzzle, his least efficient performance throughout the evaluation.

Figure 12 displays the curve of the averaged performance of the two anoxic amnesics, M.S. and L.M., along with that of the non-memory impaired subjects. A comparison of these curves highlights the impact of the 24 hour interval upon the performance of the anoxic amnesic subjects. The loss in task proficiency after this delay appears to be complete. By the final block on the second day, the anoxic group has recovered to the level of their Block 2, Day 1 performance, but not appreciably beyond. The slope of the Day 2 curve for the anoxic and normal groups appears highly similar, with the exception that the curve of the amnesics is offset toward the higher values. Within both daily sessions, the rate of learning for the two groups appears to be essentially equivalent.

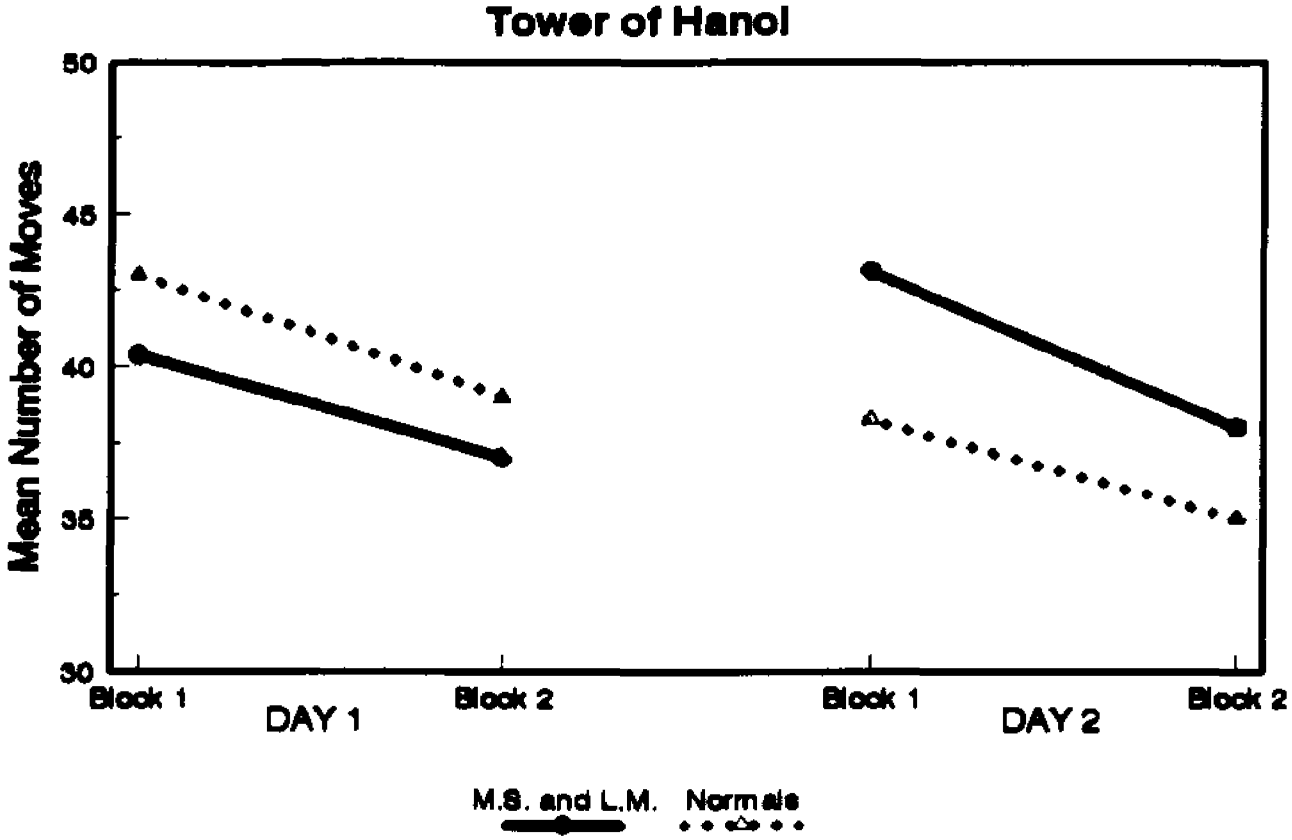


Figure 12. The combined data for M.S. and L.M. compared to the performance of the normal subjects from Beatty et al., (1987). The graph indicates that the 24 hour interval between daily sessions accounts for the loss of task proficiency by the amnesic patients.

Because data for individual normal subjects were not reported, it is not possible to assess whether some of these subjects might also have shown a decline in performance over the 24 hour interval similar to that shown by the two amnesics here. There is no way to tell whether to some extent this might be a "normal" performance characteristic. Nevertheless, the data clearly suggest that the fundamental difference in performance owes to an information loss suffered by the patients as a consequence of amnesia, as opposed to a cognitive difficulty that interferes with task acquisition. The major derailment in the performance of the amnesics occurred subsequent to the introduction of precisely the manipulation which would be expected to produce the greatest effect upon such subjects in an "explicit" task, i.e., a prolonged delay between testing sessions.

By the final trial of testing in the evaluation, M.S. required 37 moves to solve the puzzle, still six moves short of perfect performance. It must be concluded that M.S. was unable to acquire and/or adequately retain, the solution to the Tower puzzle during the course of the formal testing. However, there is a theoretically interesting epilogue to this account. Within hours after returning home on the final day of testing, M.S. was able to derive a solution algorithm for the puzzle on his own, without further instruction or encouragement, and has shown total retention of this solution (the "odds-evens rule") across the intervening year and a half. His parents (who have demonstrated a complete inability to solve the puzzle) recount that M.S. modeled the Tower puzzle at home by using three of his mother's makeup compacts to represent the peg locations, and metal washers of differing sizes to serve as the disks.

When he returned to the lab the following week, M.S. came equipped with his ad hoc version of the puzzle (minus the compacts), and solved the puzzle flawlessly.

In the "odds-evens rule" the correct move is determined by whether there is an odd or even number of disks on the source peg, and is valid regardless of the number of disks employed. On several occasions since his discovery of the algorithm, he has proven his ability to solve the puzzle with six and seven disks, and has even solved it perfectly using 10 disks, a condition which requires an uninterrupted sequence of 1,023 correct moves.

M.S.'s ultimate success with the Tower of Hanoi as described above implies that he was able to retain an accurate and complete explicit mental representation of the puzzle from the time he left the lab until he constructed his model at home. Furthermore, it is unquestionably the case that he has retained the explicit "odds-even rule" since that time: he can verbalize it upon request. M.S.'s ability to form explicit mental representations given repeated exposure to (or adequate rehearsal of) target information has been noticed on several other occasions; this may be regarded as a "residual declarative memory" capability, a de facto indication of the incomplete state of his amnestic condition. Some additional examples of this residual learning and memorial capacity will be discussed in following sections.

Possibly because the Tower of Hanoi can be interpreted as a sequence of puzzle-state transitions that can be instantiated as explicit statements or "procedures" (see Anderson, 1985), it has often been improperly conceptualized as a "procedural" task, in the alternate sense of the term which refers to the gradual acquisition of a skill which can be retained over delays without benefit of an explicit memory for the occasions of learning. The conceptualization of this task as "procedural" has led many researchers to the expectation that it could be learned in normal fashion by amnesic subjects. However, many evaluations of amnesics have failed to demonstrate normal learning, a fact which could be viewed as problematic for the position that such learning is preserved in amnesia. An alternate explanation, and the one that is offered here, is that the structural demands of the Tower of Hanoi task place substantial burdens upon explicit long-term memory, and it is therefore not a good example of a task which demonstrates "procedural" skill acquisition. This point is made clear upon close consideration of the requirements of the task. For one, there is the fact that the puzzle can be solved directly by the application of a simple algorithm, or a series of explicitly stated rules, without recourse to the learning of a "skill". For subjects who approach the puzzle in this fashion, it might be more accurately characterized as an explicitly based "rule discovery" task. Another consideration is that the number of moves to correct solution (31), clearly exceeds the accepted boundaries of immediate memory, so that even if the move-by-move solution is acquired by an amnesic subject on a particular trial, it could not be retained to the same extent as a non-memory impaired subject for use in the next trial. A similar point can be made concerning the length of time that it takes to effect a single trial to solution (particularly in the initial stages of familiarity), and also concerning the delay between blocks of trials (15 minutes), and between daily sessions (24 hours). Accordingly, the Tower of Hanoi puzzle can be seen as containing structural features that directly accentuate the special vulnerability of amnesic subjects. This same point has been raised about maze learning in amnesics (Corkin, 1965; Milner, 1965) as described in an earlier section, and also, in a more limited sense, in the previous discussion of the performance of M.S. on the game of Tetris.

An Evaluation of Frontal Lobe Functioning

Release from Proactive Interference

Proactive interference (PI) refers to a well established dynamic of memory performance: memory for items presented initially in a sequence can have an interfering effect upon the recallability of items subsequently learned (Underwood, 1957). This effect is most dramatically demonstrated when the to-be-remembered items are of the same taxonomic category (e.g., animals, furniture, etc). The fact that there is interference at work, and not just a decline in performance due to the increasing memory load, can be seen when the category of items is suddenly shifted (e.g., to fruits or board-games). In such instances, memory for the items of the new category improves strikingly, usually to a level approximating that of the very first items in the list. This phenomenon has been termed release from proactive interference (Wickens, 1972). Several studies have demonstrated that Korsakoff amnesics fail to show this expected release from PI (Cermak, Butters & Moreines, 1974; Warrington, 1982;, Winocur, Kinsbourne & Moscovitch, 1981). This deficit was interpreted as stemming from a superficial encoding process that did not adequately access word meaning; the change in categories did not result in a recovery of performance because the words were never fully processed on the level of meaningfulness. Moscovitch (1982) presented evidence that this effect is associated with frontal lobe pathology and is not fundamentally connected with amnesia; in that study, patients with frontal lobe damage who were *not* amnesic did not show release from PI, but left temporal lobe amnesics did. In a study that employed depressed patients, alcoholics, post-ECT patients, Korsakoff amnesics, a diencephalic amnesic (case N.A), and normal controls, Squire (1982) showed that only Korsakoff amnesics failed to release normally from PI. This, and similar deficits found only in Korsakoff amnesics, suggest that alcoholic Korsakoff syndrome may be viewed as an amnesic disorder complicated by frontal lobe pathology.

In a similar evaluation, Beatty, et al. (1987) reported that the anoxic/hippocampal amnesic L.M. (identified in that paper as M.R.L.) showed normal release from PI. This task was administered to M.S., with the expectation that he would likewise perform normally on this task.

Materials. The stimuli in this task, based generally upon Cermak, et al. (1974), are lists of word triads. Every list contains a series of four word triads of a particular taxonomic category (e.g., deer-lion-beaver, squirrel-racoon-fox, etc.). Half of the lists are assigned to the No-Shift condition, that is, the fifth triad in the list is of the same category as the preceding four. The other lists are assigned to the Shift condition, in which the fifth word triad is taken from a different category (i.e. mouth-arm-ear). 20 such word lists were parceled into five experimental forms, each form containing a total of four lists (two lists of the No-Shift and two lists of the Shift variety), in alternating order.

Procedure. In the studies listed above, the word triads were presented visually to the subjects for a period as brief as two seconds each (Squire, 1982). While this interval may be sufficient for patients who possess fully developed reading skills, pre-testing with M.S. made it clear that this exposure interval was not sufficient for him to adequately process three- word groupings. As a result, the word triads were presented orally to both patient M.S. and the normal controls. In order to insure that the words were heard correctly, the subjects were asked to repeat the triads once immediately after hearing them.

The subjects in this study were informed that they would be read lists of three words, and that an effort should be made to remember them. They were also told that immediately after hearing and repeating these words they would be given a three digit number and would be required to count backwards by threes for a period of 15 seconds, after which time, upon the signal from the experimenter, they would be asked to recall as many of the most recently presented words as possible. The recall attempt for each word triad was considered to be a single trial. The subject was scored on each trial by the experimenter, the range of scores being 0 (no words recalled) to 3 (all words recalled). This procedure was continued until all five word triads (trials) in the list were presented and a recall measure had been taken. A two minute break was interposed between word lists.

College undergraduates (n = 10) were tested from a pool of four forms, half of the subjects seeing two of these four, the other half seeing the remaining two. The subjects were tested on one form per day over two consecutive days. The forms used with these subjects were counterbalanced in the ordering of Shift/No-Shift word lists, and the order of administration of the two forms was counterbalanced across subjects. As was done with the case study subject N.A. in Squire (1982), M.S. was tested over a period of six months on three separate forms. Each test session was separated by an interval of at least one week.

The number of correct words recalled for each trial in both Shift and No-Shift conditions was collapsed over forms for both student subjects and M.S. Thus both students and M.S. yield two performance curves, one for average recall over the five trial positions in the No-Shift condition, and a corresponding curve over the five trial positions in the Shift condition.

Results and discussion. One of the student subjects was able to recall the word triads without an appreciable decline in performance over trials; as he did not show the requisite effect of proactive interference, his data were eliminated from consideration. Figure 13 displays the performance curves for both M.S. and the remaining nine students respectively.

The data points for M.S. represent the mean percent correct over a total of nine administrations of the task. It can be seen that M.S. and the students show essentially equivalent performance for the initial trial in both Shift and No-Shift conditions, with M.S. showing a slight numerical advantage. Both M.S. and the students develop proactive interference as evidenced by their decreasing accuracy across trials. In the fifth trial of the Shift condition, both show comparable release from proactive

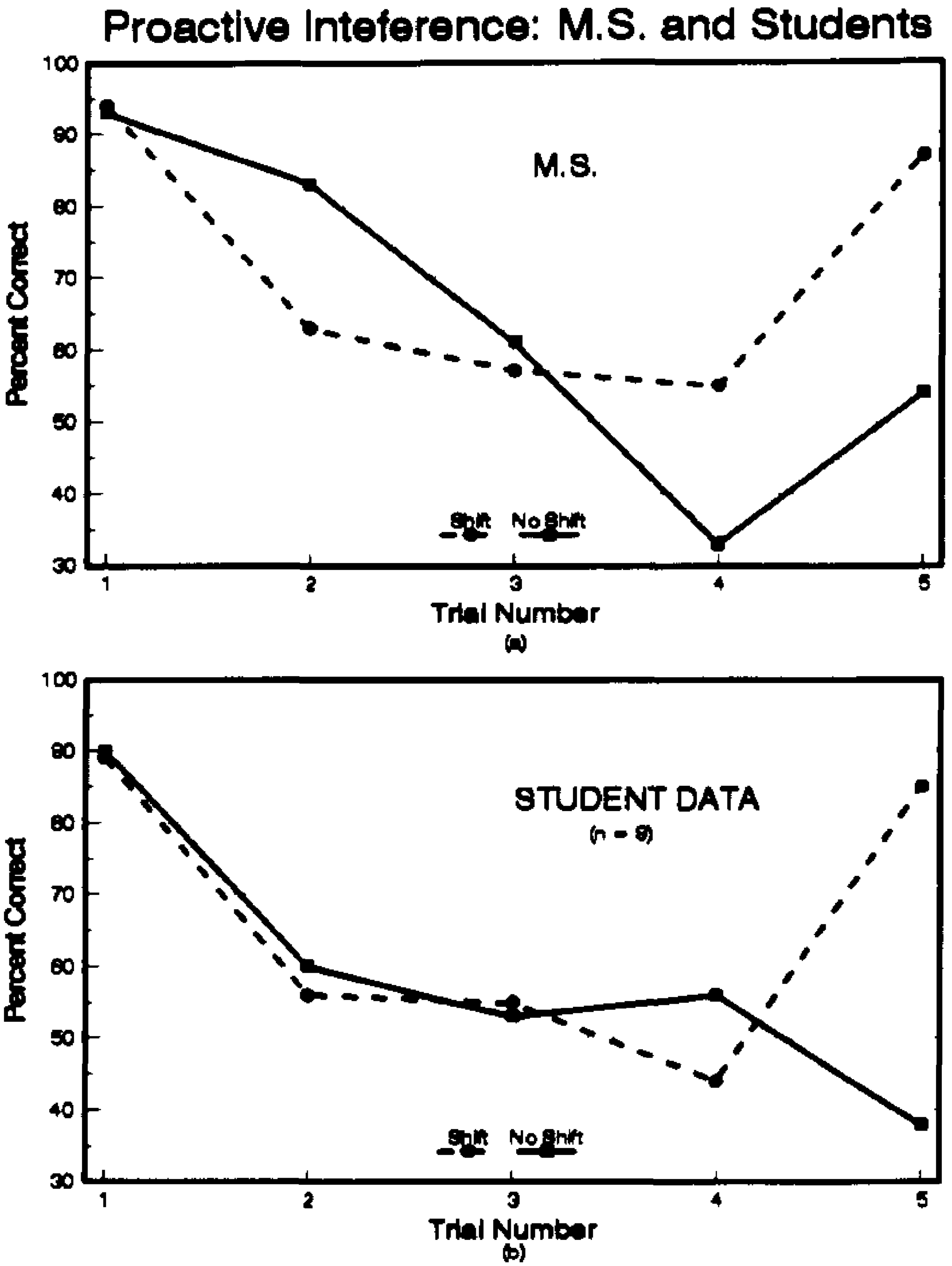


Figure 13. The data from the Release from Proactive Interference Task. Figure 13 (a) displays the mean percent correct achieved by M.S. on the five trials in both Shift and No Shift conditions, averaged across 9 separate sessions. Figure 13 (b) displays the corresponding data for a group of college undergraduates.

interference, as can be seen by their nearly complete recovery of performance. In the No-Shift condition, however, some interesting differences are in evidence. Although the students show the expected continuous decline through all five trials, M.S. actually shows a 21 percentage point improvement from the fourth to the fifth trial. A likely interpretation is that this result reflects a reapportionment of cognitive resources on the part of M.S. following his meager performance on the fourth trial, in which he averages only 33% correct. Having experienced difficulty in recalling the words on the fourth trial, he may have decided to devote less effort to performing accurately and quickly in the backwards counting task, and more effort to word rehearsal. This same reallocation of resources may have also occurred in the Shift condition, but its effect would have been overwhelmed by the benefit conferred by the category change.

An additional consideration is that of the effect of multiple evaluations upon M.S.'s performance. A look at the data from individual sessions reveals that he performed more accurately in the later sessions than in the earlier ones. There may be more than one factor responsible for this enhancement in performance. It is possible that M.S. developed some explicit memory for the words employed in the task since the same three forms were administered on three separate occasions, although this seems unlikely, since there was at least a three week interval between repetitions of the same form. A more important contribution to his improvement may be attributed to the effect of practice. Over time, the task of counting backward by threes may have become at least partially automatized, leaving more cognitive resources for the task of word rehearsal. Interestingly, though, the change to the requirement that he count backwards by five in the last three sessions of the evaluation did not appreciably derail his performance. It is possible, therefore, that he genuinely became better at negotiating the "procedures" of the task, particularly the requirement of word rehearsal while counting backwards, regardless of interval. Figure 14 compares the performance of M.S on the first four versus the final five sessions.

The improvement in performance between the blocks of sessions can be gauged by comparing the overall mean percent correct score across both conditions. In the first four sessions M.S. shows 58.6% correct; in the final grouping of sessions he achieves 77.1% correct, a 32% improvement. Perhaps most tellingly, his score on the fifth trial of the No-Shift condition improves from 38% correct in the first block of sessions to 67% correct on the second block, an improvement of 76%. The fact that this improvement on the fifth trial is not is not matched by a similar increase in accuracy on the fourth trial (which stays at 33%) suggests that his improvement here does not reflect a "genuine" enhancement in memory, but rather a shift in cognitive resources away from the distractor task, and toward word rehearsal, as mentioned above.

If only the data from the last five sessions were to be considered, M.S.'s performance across most of the trials would actually appear to be superior to that of the college students. It is likely that the first series of sessions provides a more valid assessment of his true, non-practiced, capability. Across these first four sessions, his performance is quite similar to of the students, most importantly with respect to Trial 5 in the Shift condition, in which the release from PI is demonstrated.

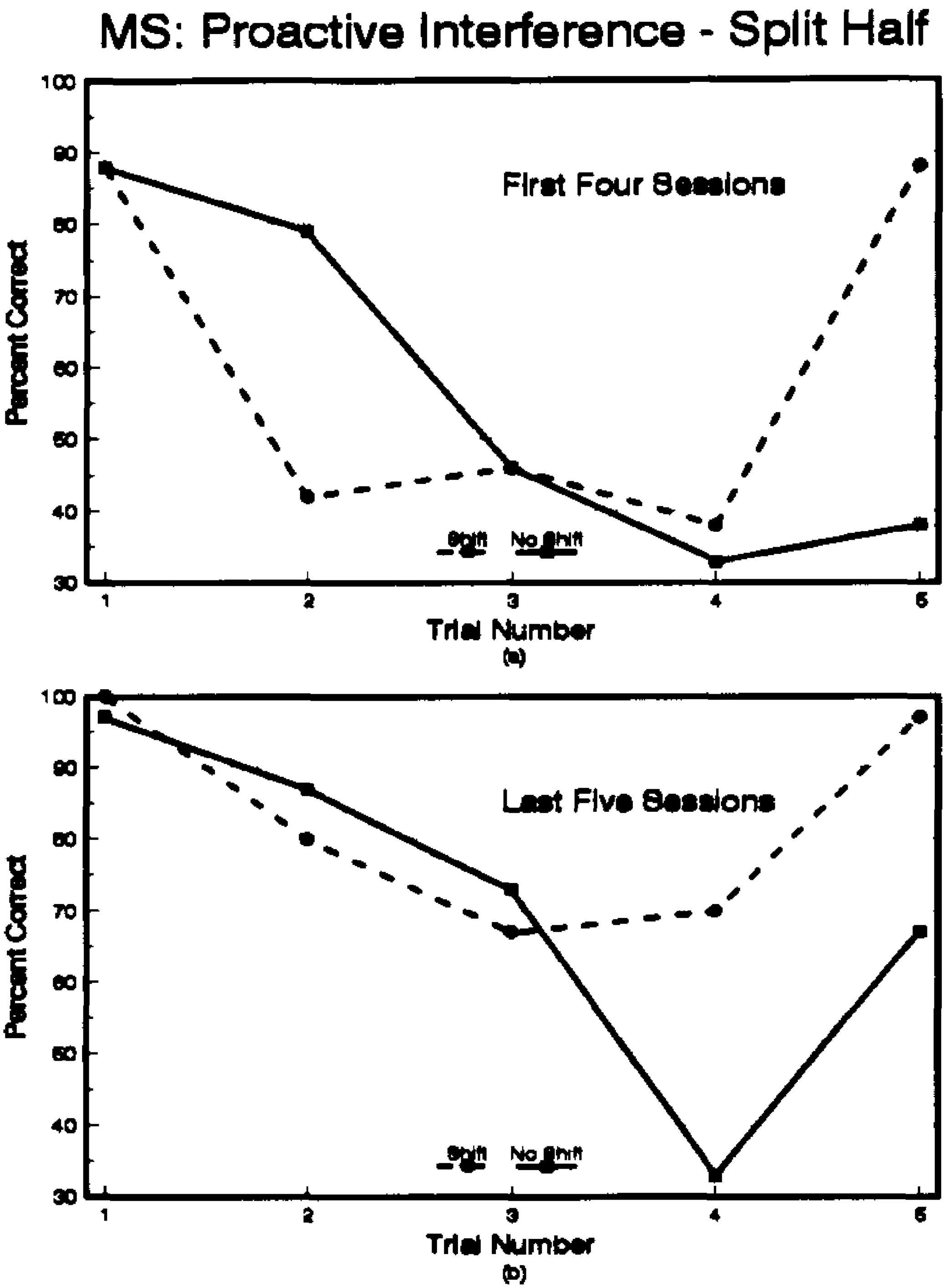


Figure 14. The differential performance of M.S. in the first four (upper graph) versus the final five sessions (lower graph) of the Release from PI Task.

As mentioned above, a failure to show normal release from PI has been considered an indicator of frontal lobe damage (Moscovitch,1982; Squire, 1982). M.S.'s strong performance on this point can be taken as negative evidence in this regard. Furthermore, the fact that his decline in performance on trials one through four resembles that of the student group suggests a normal decay in short-term memory given a distraction from rote rehearsal of target stimuli.

Semantic Learning and Memory

Fact vs. Source Memory

It is probably true that most people have had the experience of recalling some (even recently) learned fact without being able to remember exactly where or when that information was acquired. This experience attests to the psychological reality of the distinction between *fact* and *source* memory. Recent studies have explored this distinction in the amnesic syndrome (Schacter, Harbluk, & McLachlan, 1984; Shimamura & Squire, 1987; Shimamura & Squire, 1991) by attempting to teach amnesic subjects new facts, and then separately assessing retention for these facts and the memory for their sources.

Some of the facts employed in these studies were, as in Schacter, et al. (1984), fictitious (i.e., "Bob Hope's father was a fireman.") and some were genuinely factual (Angel Falls is located in Venezuela) as in Shimamura and Squire (1987, 1991). All of the facts employed involved general information, and were therefore potentially recallable without specific reference to the episode of learning.

A basic, perhaps unsurprising, finding from these studies is that the amnesics had great difficulty in learning the new factual information. It is especially clear from the Shimamura and Squire studies that while the amnesics could successfully acquire some new facts within the course of the study, their ability to learn this information was markedly impaired relative to controls. Furthermore, some, but not all, amnesics exhibited an additional impairment in the ability to identify the experimental session as the source of that factual knowledge, thereby displaying a *source amnesia* for those few facts which they were able to recall. Perhaps most interestingly, the occurrence of source amnesia was not related to severity of fact amnesia. Some patients whose level of recall and recognition for factual information was very low were still quite accurate in attributing their knowledge of these facts to the experimental session, while subjects who exhibited source amnesia recalled about as many facts as the patients who did not. Shimamura and Squire (1991) concluded that source amnesia is a disorder of memory that is dissociable from the core amnesic pathology, occurring in some amnesic patients independently of impaired factual memory.

Schacter, et al. (1987) reported that in their study, source amnesia was correlated with the incidence of frontal lobe pathology. A study by Janowsky, Shimamura and Squire (1989) further demonstrated that patients with frontal lobe impairments (who were not amnesic for factual information) could exhibit source amnesia. However, this apparent connection between frontal lobe pathology and source amnesia was not borne out by the results of the Shimamura and Squire (1991) study. While three Korsakoff patients (whose behavioral pathology appears to include an overlay of frontal impairment) did exhibit severe source amnesia in this study, four others did not, and two patients who demonstrated complete source amnesia in that study possessed no known frontal lobe pathology. Furthermore, a Spearman rank-order correlation of source recall performance with four tests thought to assess frontal lobe functioning (the Wisconsin Card Sorting Test, Verbal Fluency Test, a test for temporal order sequencing, and the Initiation/Perseveration subtest of the Dementia Rating Scale) produced no significant correlations.

One of the amnesic subjects tested in the Shimamura and Squire studies was patient L.M., whose precipitating trauma (respiratory arrest and grand mal epileptic seizure) strongly resembles that of subject M.S. The data presented for L.M show considerable fact memory impairments (recall score = 50% correct, control mean = 91.9%; recognition = 90% correct, control mean = 98.1 %), but absolutely no source memory impairment (source recall = 100%). It was expected therefore, that, on a source memory protocol based on Shimamura and Squire (1987, 1991), M.S. should likewise exhibit impaired fact but intact source memory.

Materials. A battery of 40 facts of general knowledge (e.g. *The ancient Greek gods lived on MT. OLYMPUS. The city that is nicknamed Beantown is BOSTON*) were devised to serve as target stimuli. An additional complement of 40 general information questions whose answers were not provided were used as distractors in the recall and recognition tasks only. These 80 facts and questions were divided into two forms consisting of 20 target facts and 20 distractor questions each. The two forms of the test, each of which constitute a complete administration, were given separately, with an approximate one year interval between tests (11/25/92 and 11/3/93). All facts and questions were printed on sheets of paper and were read orally to the subject.

Procedure. The subject was informed that he would be given some facts that he should try to remember. The facts that were actually used were drawn from a larger pool of candidate facts. These were first read to the subject in interrogative form (i.e., *Which city is nicknamed Beantown?*). If the subject knew the answer, the question was discarded and was not used as a target fact. If the subject did not know the answer to a given question, the answer was provided in the form of a direct declarative statement (i.e., *The city that is nicknamed Beantown is BOSTON*). This process continued until 20 facts which were previously unknown were supplied as targets to the subject. Immediately after, these same target facts were repeated in a different order for a second time.

After a two hour delay the subject was tested for recall of the facts presented earlier, although no reference was made to the earlier learning session. The 20 facts (now again in the form of questions) were randomly interspersed with 20 new (baseline) questions. In the first administration (11/25/92), these new questions were not presented in the learning phase. In the second administration (11/3/93), these "new" questions were pre-screened in the learning phase, but their answers were never given, i.e., like the target questions, the subject was screened for his knowledge of the answers to these questions, but unlike the targets, these 20 (incorrectly answered) questions were retained for use as distractors in the testing phase. Thus in this second administration of the test, the distractor questions were "new" in the sense that their answers had never been provided, although the questions themselves had been asked in the learning phase.

The questions in the recall test were asked one at a time. If a question was answered correctly, the subject was asked "When was the last time you heard this information?" This wording was employed to insure that the learning phase was unambiguously established as the source of the previously presented facts. In the event that the subject had actually learned a given fact at some earlier time, but only managed to generate the correct answer during the testing phase, the learning session would still be the correct source attribution. Thus if the subject claimed to have learned one of the previously supplied facts at some other time or place, it was counted as an instance of source amnesia. This type of source error is called an "extraexperimental source error", a term originally employed in the Schacter, et al. (1985) study mentioned above. The 20 new questions were included so that there were some factual answers whose source was not the experimental session. Thus it was not possible for the subject to appear to demonstrate intact source memory simply by guessing that the answer to all questions were provided earlier that day. Additionally, these questions made it possible for the subject to commit another kind of source error. This involves identifying the learning session as the source for the answers to these new questions; this kind of error is called an "experimental source error".

Answers and source attributions were collected by the experimenter for the 40 questions (in each administration) of the recall test. This was followed immediately on both testing occasions by an eight choice recognition test for these same questions.

Results and discussion. In the first administration, M.S. showed correct recall for five of the 20, or 25% of the "old" questions (i.e. questions whose answers had been previously supplied). Of these correctly recalled questions, he was unable to give correct source attributions for any of them, that is, he showed total source amnesia. His responses to the source attribution queries tended to be very general or tentative. For one question, he stated that he simply guessed the answer; on two other questions he claimed to be "not sure" as to when the information was acquired. His response for another question was that he had learned the answer "many years ago". Finally, he claimed to have learned one answer in some previous experimental session, but when asked if that session might have occurred earlier that morning, he said that it definitely had not. He denied, when it was directly suggested, that he had been taught some facts earlier that day.

On the "new" questions, M.S. correctly answered eight of 20, or 40%. As these questions (and their answers) had never been presented before, these eight facts must have been learned outside of the experimental context. Since he did not claim to acquire any of these facts in the earlier training session, he committed no "experimental" source errors. Although his recall performance for the "new" questions appears high relative to that for the "old", it must be remembered that the new questions in this administration of the test had not been pre-screened for prior knowledge, whereas candidate "old" questions that were correctly answered during screening were eliminated from further use.

On the recognition test that immediately followed, M.S. correctly identified eight (40%) of the answers for the "old" questions, a three item improvement over his performance on the recall test. Since the 95% confidence interval around the difference between these proportions includes zero (.20 ± .28), this difference is not significant. For the "new" questions, he performed at 50% accuracy, up 10% from his performance on the recall test. Again this is not a significant improvement, as the 95% confidence band surrounding this difference includes the difference of zero (.10 ± .31). This trend towards improvement, although not significant, may nonetheless reflect the expected advantage of recognition over recall.

On the second administration of this test (one year later), M.S. correctly recalled only three of the "old" questions. As was the case in the first testing, he showed complete source amnesia for these correctly recalled facts. For two of these three answers he claimed to be guessing; on the third he said that he had learned the answer from me the previous week, yet made no mention of the session two hours earlier in which these facts had actually been supplied to him.

M.S. correctly answered four of 20 of the "new" distractor questions in this test. This result is of particular interest because these distractor questions, unlike those in the earlier administration of this test, were pre-screened during the learning phase. Yet while these "new" questions were answered incorrectly during pre-screening, he was able to correctly answer 20% of these questions two hours later at the time of test. This apparent "hypermnesic" effect indicates that these facts must have been known to

M.S. prior to the evaluation, but that he could not or did not generate the correct responses at the time of the screening, suggesting a temporary failure of retrieval. His stated belief that he did not learn these facts in the earlier training session is therefore a partially accurate assessment, at least as far as these "new" questions are concerned.

In the recognition test for these same questions, M.S. recognized six of the "old" and five of the "new" correct answers, doubling his performance on the "old" questions, and increasing his performance on the "new" questions by one item. The difference in proportion correct for the former type of question was not significant (95% confidence band = .15 ± .25), nor was the corresponding difference for the latter type of question (95% confidence band = .05 ± .258).

The performance of M.S. on the target questions of both administrations of this evaluation demonstrate virtually complete source amnesia for facts successfully learned. The absolute quality of his performance is in keeping with previously reported findings: of twelve amnesics tested in Shimamura and Squire (1991), nine showed similarly unequivocal performance, five demonstrating perfect source memory, and four showing total source amnesia.

However, the finding of total source amnesia for M.S. is an apparent contradiction to the results obtained for the etiologically similar hippocampal amnesic L.M. (Shimamura & Squire, 1991), who showed 100% accuracy in his source attributions for correctly recalled facts. However, another hippocampal amnesic included in that study, W.H., whose precipitating injury is unknown, was like M.S. in that he also demonstrated complete source amnesia. This conflicting pattern of results among individuals with similar hippocampal pathology as well as the inconsistent results obtained from Korsakoff amnesics (see above) present difficulties to parsimonious interpretation. It is tempting to assume that both M.S. and W.H. have sustained some measure of frontal lobe damage which could account for their source amnesia, but radiological assessment of these individuals has given no indication of such injury. Furthermore, M.S. showed completely normal performance (when compared to college undergraduates) on the release from proactive interference evaluation (see above), which has been shown to be sensitive to frontal lobe pathology. And finally, the presumed connection between source amnesia and frontal lobe injury has itself been called into question by the failure to find a significant correlation between measures of source memory and frontal lobe pathology (Shimamura & Squire, 1991).

A consideration of the performance of M.S. on the distractor questions in the second administration of this task invites an alternative interpretation of the source memory impairment. As M.S. did not correctly answer any of these questions at pre-screening, and yet was correct on four of the 20 questions in later testing (*without* having been informed of their answers in the interim), it can only be assumed that he had prior knowledge of these answers but failed to retrieve them when first queried. This result raises the possibility of the presence of a dysfunction that is specific to retrieval processes, which can be viewed as ancillary to the deficit in memory consolidation which is generally regarded as the principle dysfunction of the amnesic syndrome (Squire, 1987, 1992). That amnesia is not itself a disorder of retrieval *per* *se* is demonstrated by the fact that amnesics show normal retrieval for facts and events that were successfully consolidated before their precipitating trauma, such as childhood memories, or native language vocabulary.

Given this evidence of a temporary failure of retrieval, it is possible that M.S. actually had prior knowledge of all the facts that he appeared to learn in this evaluation, including the target facts that were supplied in the learning phase. However, because the query regarding source attribution had the wording "when was the last time you heard this information?", his failure to identify the learning session as the most recent encounter can still be considered an error of source attribution.

It is possible to view source amnesia as entirely a function of faulty retrieval, as opposed to a deficit associated with memory consolidation. With respect to the present evaluation, it is reasonable to assume that dysfunctional retrieval would more severely affect memory for source information since the subject is directly taught the answers to the factual questions during the learning phase, but is never explicitly provided with the relevant source information. This asymmetry in stimulus presentation alone should result in some advantage for fact memory. Apart from this consideration, source information may be inherently more difficult to generate than factual information, perhaps critically so in patients with a deficit in this function. The difference between fact and source retrieval may be the difference between having to generate a specific fact and having to generate several related associations regarding the episode of initial encoding, i.e., the time, place, the medium of communication, etc. It is worth re-stating that only some of the amnesics tested in the studies mentioned above demonstrated a disproportionate deficit in source memory, and that this deficit was found to be unrelated to severity of amnesia. This suggests that a functional impairment involving a process other than that of memory consolidation is responsible for source memory failure. Perhaps it is the case that only amnesics with additional functional impairments in information retrieval will show this special deficit. Information retrieval, conceived in broadest terms, most probably involves the participation of multiple neo-cortical and sub-cortical areas including, but not limited to, frontal lobe sites. Disruptions in retrieval operations could conceivably occur due to damage in any one of several areas. It may be the case, for example, that frontal lobe patients exhibit source amnesia because of a failure to properly initiate the retrieval of distributed memory components. Patients with other loci of lesioning may experience a breakdown in some other stage or aspect of the retrieval process, perhaps in the re-association of distributed representations.

The available evidence seems to suggest that source amnesia is probably not directly or exclusively related to either frontal lobe or mid-temporal lobe pathology. The "functional" non-site specific perspective on source amnesia offered here provides an accommodation for the finding that frontal lobe patients tend to show source amnesia (Janowsky, Shimamura & Squire, 1989) and some patients with no known frontal involvement also do, as was the case with W.H. and M.S. That source memory deficits are not necessarily tied to a particular locus of brain lesion is supported by their observed occurrence in clinically intact older adults, apparently as a consequence of the normal aging process (Mcintyre & Craik, 1987; Schacter, Kaszniak, Kihlstrom

& Valdiserri, 1991).

Vocabulary learning

The deficits and preserved functions observed in the performance of amnesic patients have been discussed in this paper in terms of the distinction between implicit (or non-declarative) and explicit (or declarative) cognitive functions. However, other theoretical parsings have been offered to account for these dissociations. One such theory involves the distinction between *episodic* and *semantic* memory first proposed by Tulving (1972). The term episodic memory refers to memory for facts or events that are bound to a particular spatial and temporal context, such as autobiographical experiences. Semantic memory refers to memory for general information that is independent of contextual parameters. Kinsbourne and Wood (1975) applied this distinction to the amnesic condition, arguing that amnesia selectively impairs episodic, while sparing semantic memory. They suggested that the selective nature of this cognitive deficit accounts for the inability of amnesics to form new memories for personal experiences and contextually indexed information, while demonstrating a preservation of general linguistic and intellectual (i.e., semantic) functioning.

An evaluation of the episodic/semantic theory against the corpus of experimental findings suggests that it does not adequately capture the facts of the amnesic condition. One shortcoming is that it does not sufficiently address the preservation of perceptual and motor learning that has been demonstrated in amnesia. Perhaps more importantly, it is clear that contrary to the prediction of this theory, semantic learning and memory are compromised in amnesia. Attempts to instruct amnesic patients in de-contextualized semantic information (i.e., information that does not require reference to the episode of its acquisition in order to be recalled) show the amnesic subjects to be markedly impaired (Gabrieli, Cohen & Corkin, 1988; Schacter, Harbluk & McLachlan, 1984; Shimamura & Squire, 1987, 1991; see above).

Among the evaluations of semantic learning conducted by Gabrieli, Cohen and Corkin (1988) with H.M. was a test of his ability to acquire new English vocabulary. The words chosen were extremely low frequency, and were unlikely to have been part of H.M.'s premorbid vocabulary, or of the control subject's current lexicon. While the control subjects showed strong learning in this task, acquiring all eight of these uncommon words in only 3.1 trials, H.M showed little evidence of learning in 20 trials, and the task was aborted at that point.

It is clear from standardized reading and language scores that M.S. has suffered in his ability to learn new vocabulary in the course of his post-trauma life. Nevertheless, it is also clear from observations that he has been able to acquire some words, phrases, and factual information that have come into currency only recently. These include the names of television shows (St. Elsewhere, Seinfeld, Knight Rider), popular celebrities (David Letterman, Jerry Seinfeld, Magic Johnson), computer games (Tetris), and general facts about the world (Magic Johnson has AIDS, a disease that has no cure). Although H.M., as reported by Corkin (1984), has been able to learn some new information about the world since his trauma (Kennedy was the president who was shot, Archie Bunker calls his son-in-law Meathead), this acquired information store appears to be extremely impoverished. By comparison, M.S. appears to have a relatively greater residual explicit memorial capacity, as is evidenced by (among other things) his ability to learn about new people that he meets, including the name of the author of this paper, and of some of the many doctors and physicians that have evaluated him. He is aware that he has acquired several nieces and nephews in recent years, and has succeeded in learning their names, although it must be emphasized that he learns such verbal and factual information only after numerous repetitions.

In order to assess his ability to learn new vocabulary words, M.S. was tested on the same eight low frequency items that were used by Gabrieli, Cohen, and Corkin (1988) with H.M. In recognition of the possibility that these words might be either too difficult or too abstract to be effectively processed by an individual with such unsophisticated language skills, a second evaluation was conducted, which employed relatively common, more "ecologically valid" words. These were determined by pretest to be unknown to M.S.

Materials. The materials and procedure for the first evaluation were based upon the Gabrieli, Cohen and Corkin (1988) study mentioned above. The eight low frequency words were: *quotidian*, *manumit*, *hegira*, *anchorite*, *minatory*, *egress*, *welkin*, and *tyro*. These words were presented via CRT monitor in the Gabrieli et al. study. Here the words (and their definitions) were hand printed on oak tag strips in letters approximately 2.5 inches high and were displayed on a corkboard. This was done to insure maximum legibility.

The target words in the second evaluation were: *ailment*, *attorney*, *obnoxious*, *abolish, veer, glacier, authentic* and *obese.*

Procedure. M.S. was told that he was to be engaged in a word learning test. Initially, each word was presented individually on the corkboard along with its corresponding definition. He was asked to read each word and definition aloud, and was encouraged to memorize the word-definition pair for the purpose of later testing. After all eight words had been presented in this way, one of the words was placed at the top of the corkboard, with all eight definitions displayed directly below. The subject was asked to select the definition that matched the word.

In the first evaluation, the method of stimulus presentation detailed in Gabrieli et al. was followed exactly. In that procedure, if an incorrect definition selection was made, the subject was informed of his error and asked to choose again. If the correct definition was selected for a given word, that definition was removed, a new target word was presented, and the subject was again asked to select the corresponding definition from the reduced list of alternatives. This procedure results in a systematic diminution of the array of alternative definitions until, by the final word in the list, only the correct definition remains as a choice. Thus it is not possible to make an error in selecting a definition for the eighth word on the list. This procedure was kept in force for the first evaluation in order to allow a direct comparison of the performance of M.S. to that of H.M. For the second evaluation, the procedure was modified so that all eight definitions were presented as distractors for every word on the list. In this way the probability of a correct definition being chosen by chance was equalized across all words.

In both protocols, the process of word-definition selection continued until the correct choice was made for each of the eight words. If any incorrect definitions were chosen for any of the target words, the entire cycle of eight words was repeated. Each cycle through the list was considered to be one trial. The trials were continued until the subject was able to select the correct definition for all of the eight words in sequence, without error. The subject's performance was assessed by the number of trials required to achieve an errorless cycle through all eight words, by the number of errors per trial, and by the total number of errors made.

Results and discussion. On the first evaluation, the primary result was that M.S., like H.M., failed to perform to criterion through 20 trials of the low frequency word list, after which time the test was discontinued. His performance, as measured by mean number of errors per trial (12.2) and total number of errors (244), closely approximated the performance of H.M., whose corresponding scores (averaged across two separate administrations) were 13.5 and 269.5 respectively. That M.S. showed only meager learning across the 20 trials is demonstrated by a split-half error analysis; M.S. logged 132 errors over the first 10 trials, and 112 in the last 10 trials. An evaluation by the normal approximation to the sign test reveals that the proportion of errors committed in the first half (132/244 = .54) is not significantly different from .50 (p = .11), which would be the expected proportion if the number of errors were equally distributed across both halves of the test.

In the second evaluation, which used the eight relatively common words, M.S. did reach criterion performance, but did so only after 17 cycles through the list. His mean number of errors per trial in this evaluation (4.1) was a marked improvement over that of the first evaluation (12.2), as was his total number of errors (69 *vs.* 244). Furthermore, his errorless performance on trial 17 was followed by a second consecutive perfect performance on trial 18. A split half analysis of these 18 trials shows that M.S. logged 50 of the 69 errors over the first nine trials, committing only 19 errors over the final nine trials. The proportion of errors committed in the first half (50/69 = .72) is significantly different ($p < .0002$) from .50, which would be the expected proportion if the number of errors were equally distributed across both halves of the test.

When retested on the same words the following week, M.S. showed strong evidence of substantial savings as he reached criterion performance in only four trials, a 13 trial improvement over the previous week. Over these four trials he committed a total of 11 errors, a mean of 2.75 per trial. The data for M.S. for both word lists are displayed in Table 4.

Table 4.

Performance of M.S. on Vocabulary Learning Tests.

	# of Trials	Mean Errors Per Trial	Total Errors
Low Frequency Words	20[a]	12.20	244
Common Words (First Week)	17[b]	4.10	69
Common Words (Second Week)	4[c]	2.75	11

[a]Test discontinued after 20 trials. [b]Criterion performance reached on this trial. [c]Criterion

performance reached on this trial

Section summary. The two evaluations reported in this section involved assessments of the ability of M.S. to acquire new semantic information. In one case, an attempt was made to directly teach him new facts, the other involved the learning of new English vocabulary words. In the former evaluation, M.S. successfully learned a total of eight of 40 target facts as assessed by a recall test conducted two hours after his instruction. Superficially, this would seem to establish the fact that M.S. has retained some measure of declarative memory, at least as far as "semantic" information is concerned. However, it was also seen in that evaluation that M.S. showed "learning" for four facts that he was not taught and whose answers he did not know when screened for prior knowledge. It is possible, therefore, that all of the factual "learning" in this test can be attributed to the gradual retrieval of material acquired prior to this evaluation, and thus no genuine learning was actually documented here. The speculation was offered that this result signals the presence of a dysfunctional retrieval process which may also account for the source amnesia demonstrated in this evaluation, and by extension, may be relevant to the source memory deficits reported by other researchers. The conceptualization of source amnesia as a product of faulty memory retrieval (as opposed to one of faulty memory consolidation) is consistent with the finding that this deficit is unrelated to the severity of the amnesia of the patients in whom it occurs (Shimamura & Squire, 1987, 1991).

Moreover, dysfunctional retrieval could also be invoked to explain the modest level of vocabulary acquisition demonstrated in the second evaluation. Having showed virtually no learning for extremely low frequency words, M.S. showed perfect performance on three of the eight common vocabulary words (attorney, glacier, and authentic) after only a single instruction; this unusually rapid learning may reflect prior knowledge of these particular words. However, M.S. showed very gradual learning for the remaining five words. On the initial testing it took all of 17 trials for him to correctly choose the five corresponding definitions. In contrast to the three items which may have been retrieved from prior knowledge after one instruction, the rate of learning for these five words suggests a gradual acquisition of previously unknown items. The results for the second week are consistent with this interpretation; M.S. again showed errorless performance on the same three words that he had on the previous testing (plus an additional word, *veer*), and learned the remainder over four trials, reflecting a substantial savings from the earlier session. A plausible, and perhaps likely explanation for this pattern of performance is that these words were genuinely learned by M.S. during the course of the evaluation, and thus can be regarded as a demonstration of the acquisition of previously unknown information.

Discussion and Conclusion

The intention of this study was to conduct a detailed evaluation of the implicit and explicit cognitive functioning of an individual who has been identified as a hippocampal amnesic. The evaluations reported here, however, serve to illustrate some of the difficulties that can be encountered in the course of such an undertaking. A major source of difficulty, particularly insofar as the interpretation of results, stems from the often ignored fact that amnesics are in reality brain damaged people whose cognitive deficits include, but are not necessarily limited to, deficits of memory. In fact, it is probably naive to assume that a global brain trauma, particularly one sustained during childhood, should result in a completely circumscribed neuropathology, or a single and isolated behavioral impairment. Even in cases such as M.S., where an MRI has indicated that obvious gross anatomical pathology is limited to the mid-temporal lobe (and would therefore be expected to produce quite selective memorial deficits) the possibility can not be ruled out that less visualizable pathology, perhaps on the cellular level, may be present elsewhere. This point is illustrated by the fact that two earlier attempts to visualize brain pathology in M.S., a CT scan and an MRI, produced negative results. Mid-temporal neuropathology was demonstrated only when an MRI protocol devised specifically for visualization of the hippocampal area (see Press, Amaral, & Squire, 1989) was subsequently administered. Furthermore, damage to the amygdala was confirmed only upon a second testing which employed this specialized MRI protocol. Comorbid functional impairments resulting from unrecognized brain pathology always present the danger of providing significant sources of artifactual variance. Evidence suggesting the existence of such comorbid impairments was found in more than one of the evaluations conducted in this study. This evidence will be discussed individually in the following sections.

Possible comorbid pathologies

Motoric slowness. That slowed motoric response may have been a factor in M.S.'s ability to perform certain tasks was first considered in connection with his learning of the computer game Tetris. M.S. showed an arguably depressed rate of learning on this evaluation, despite his superior performance compared to college students in the conceptually similar Mental Rotation Task. These tasks are similar in the respect that they involve the "manipulation" of geometric objects, but only Tetris demands a motoric response via keyboard. Evidence that M.S.'s rate of learning in Tetris may have been substantially affected by a slight, but detectable, motoric slowness was provided by his clearly below par performance in a test of simple visual reaction time. Also, his consistently slower reaction time (as compared to student subjects) across both Random and Structured conditions in the Chase Max game is additional evidence in this regard. The situation is reminiscent of the evaluation of H.M. on the rotary pursuit and bi-manual tracking tasks (Corkin, 1968). That H.M.'s sub-normal performance on those simple motor-skill tasks was most probably a consequence of motoric rather than cognitive/memorial factors was also indicated by his impaired performance on a straightforward reaction time test.

It is worth noting that M.S. showed no major deficit in performance on another type of timed motor task, the Purdue pegboard test (see Appendix B). However, the pegboard test is not timed as precisely as the *RT* task, in which responses are measured in milliseconds; for this reason the *RT* task may be considered a more sensitive evaluation of response latency. Indeed, the disparity in mean *Rts* between M.S. and the student group was on the order of hundredths of a second, a difference which is beyond the resolution of the pegboard test.

Corkin (1984) suggested that cerebellar atrophy was responsible for H.M.'s reaction time deficit. None of the brain imaging protocols performed upon M.S. have revealed similar cerebellar pathology. Nevertheless, it is possible that some as yet undetected lesion or set of lesions, in this or some other motorically relevant portion of the brain, may account for his slowed motoric responses. Alternately, it is possible that this subtle motoric slowness is entirely explainable as a side effect of anti-convulsant or anti-asthmatic medication, or some interaction between these two classes of drugs.

Perceptual sequencing dysfunction. It is difficult to characterize precisely or positively identify the putative perceptual dysfunction demonstrated by M.S. The term *dyslexia* is reserved to denote a developmentally based dysfunction of reading skill that is disproportionately severe relative to generalized levels of cognitive functioning and which occurs in the absence of frank neurological defect. Because M.S. has confirmed brain neuropathology, he is necessarily disqualified from this designation. Moreover, his deficit does not neatly correspond to any subtype of acquired *alexic* condition, especially in that he does not seem to have the required deficit of (premorbidly acquired) word comprehension (Friedman & Albert, 1985). At the same time however, his constellation of language related deficits appears to be similar to those that have been previously documented in other cases involving the childhood occurrence of acute hypoxia (Cooper & Flowers, 1987; Murdoch & Ozanne, 1990). M.S.'s deficient performance on evaluations that are often used in the diagnosis of reading disorder, such as the Rapid Automized Naming Task, the Word Attack subtest of the Woodcock Johnson Battery, and the Coltheart Reading test, suggest the presence of an impairment that is difficult to explain as a consequence of long-term memory dysfunction. It is especially informative to consider the results of two tests, the Coltheart Reading Test, and a spelling test that was administered in November 1970 shortly before his precipitating trauma and again in November of 1992 (these tests are presented in their entirety in Appendix C).

These evaluations attest to the fact that M.S.'s difficulty with phonetic decoding is not due to the simple effect of retrograde amnesia. On the Coltheart test, M.S. shows nearly perfect accuracy (76/78) in his reading of the initial letter of every word, including those words on which he commits errors. It is only in the decoding of internal letter sounds and phonemic sequences that he shows consistent difficulty. The fact that he is successful in decoding a diverse sampling of phonetic values (as long as they are the initial values in a word) indicates that his basic ability to recognize simple grapheme-phoneme equivalencies has not been impaired by his brain injury, and that this knowledge has not been lost to retrograde memory failure. His difficulty only becomes obvious in the course of the decoding of subsequent consecutive values. A comparison of the results of the two administrations of the oral spelling test show a dramatic difference between pre and post trauma spelling capability. On the post-trauma test, he demonstrates a striking inability to handle the same simple phonetic sequences he dealt with successfully on the first administration. On this second test, at age 30, he scored only 30% correct for the same words upon which he showed 100% spelling accuracy in the second grade. However, his errors on the post-trauma test are similar to those displayed in the Coltheart test in that he shows a general ability to accurately assess the initial phoneme of a given word, but falters in his ability to find correct values for subsequent speech sounds, or to place them in the proper order.

The disparity between performance on the pre and post trauma spelling tests implies a phonetic decoding difficulty that is acquired, i.e is somehow related to his traumatic injury although apparently not a consequence of memory dysfunction. Recent investigations (Livingstone, et al. 1991; Lehmkuhle, Garzia, Turner, & Baro, 1992) with developmental dyslexics have suggested that at least some variant of reading disorder is associated with a specific pathology of the magnocellular (fast, transient) portion of the visual processing system. Prompted by this finding, a visual evoked potentials (VEP) analysis was performed upon M.S. This produced an indication of severe magnocellular pathology as evidenced by an abnormally late onset of early processing components. A tentative hypothesis to account for this finding is that large magnocellular neurons, having higher metabolic demands than the parvocellular counterparts, may be selectively vulnerable given an extreme hypoxic episode such as that experienced by M.S. Magnocellular dysfunction may critically affect visual operations related to reading in that the normal coordination of magno and parvocellular systems will not be maintained during saccadic eye movements. One proposal, forwarded by Lovegrove (1993), has suggested that in the absence of proper inhibitory action of the transient magnocellular system, the sustained parvocellular response to visual stimuli will persist across saccades, resulting in a perceptually confusing superimposition of images. It is thus possible that the impaired magnocellular functioning documented in M.S. contributes substantially to his reading difficulties, and furthermore, that corresponding magnocellular damage in the auditory system may account for the type of phonetic sequencing errors displayed by M.S. in the post-trauma oral spelling evaluation (Tallal, Miller, & Fitch, 1993).

That specific magnocellular dysfunction underlies the behavioral anomaly described here as a perceptual sequencing disorder must remain a conjecture. Any confident statement regarding a causal connection to any form of reading or sequencing deficit must await further research in this area, very possibly including the development of a prospective animal model such as that which has been created for amnesia. Furthermore, it is possible that magnocellular dysfunction is a necessary but not sufficient condition for the production of this behavioral deficit, and that additional neuropathology must be present in order for any significant effect to be manifest. More generally, it is almost certainly the case that similar "dyslexic" symptomology can be caused by completely unrelated factors, perhaps including maladaptive learned behaviors (Merzenich, Schreiner, Jenkins, & Wang, 1993). It is widely assumed that *dyslexia* as such is actually an heterogenous disorder based in a variety of etiological factors.

Finally, it must be stated that the proposed connection between hypoxia and selective magnocellular necrosis is not supported by any empirical finding. Evidence for similar selective magnocellular dysfunction has not, to my knowledge, been reported in connection with other hypoxic subjects. It is yet possible that such selective neuropathology may result from hypoxic trauma only if the episode occurs during the developmental years, such as was the case with M.S. Another point to be made is that VEP technology has not been conclusively shown to provide a valid indication of magnocellular pathology. Thus while it seems clear that M.S. does indeed have a reading or perceptual sequencing disorder, any connection to specific magnocellular pathology must remain purely speculative.

In the course of two formal evaluations reported in this paper M.S., produced results that may be viewed as convergent evidence of perceptual sequencing dysfunction. In the first instance, M.S. had inordinate difficulty in reproducing the correct sequences of letter strings in the learning phases of the AG grammaticality and recognition tasks. Because the subject is required to reproduce the letter sequences immediately after the presentation of the target string, a deficit of long-term memory should not affect performance, and yet, M.S. required 6.55 trials to reach criterion performance (averaged across both learning phases). This value is in excess of eight standard deviations beyond the mean of the student subjects. In contrast, the amnesic subjects tested in Knowlton, et al. (1992) actually showed numerically superior performance to their control subjects on this task.

A second instance occurred in the context of M.S.'s failure to show expected levels of priming in the word-completion task. M.S. showed no advantage of priming over free recall and also showed diminished priming relative to concurrently run student subjects, and to previously reported amnesic subjects and their controls.

That amnesics reliably show both an advantage of priming over explicit retrieval conditions and prime at a rate equivalent to that of normal subjects is one of the most robust and widely accepted findings in psychology. Word priming appears to be obtained equally across type (e.g., diencephalic or mid-temporal) and severity of amnestic disorder. Since amnesics show normal priming for target words while at the same time demonstrating impaired recall or recognition suggests that the priming effect is not dependent upon the ability to access representations from semantic memory, but may be a function of relatively "early-on" perceptual processing. Support for the view that priming is supported by a "perceptual representational system" (Schacter 1990; Tulving & Schacter, 1990) comes from a variety of sources. For one, instructional manipulations that alter the processing of the study list will affect subsequent word recall or recognition, but will not affect priming. That is, subjects who have been instructed to encode target words through semantic elaboration will show enhanced recall or recognition relative to subjects who have been instructed to search the target words for specific letters, but rates of priming will remain equivalent for both groups (Graf & Mandler, 1984; Graf, Mandler, & Haden, 1982; see also Jacoby & Dallas, 1981). Also, priming is highly sensitive to changes in modality of presentation across study and testing phases; rates of priming are greatly reduced, if not completely eliminated, by either changing the mode of stimulus presentation from an auditory study (hearing the words) to a visual test (seeing the target words), or vice-versa (Graf, Shimamura & Squire, 1985; Jackson & Morton, 1984; Jacoby & Dallas, 1981; Roediger & Blaxton, 1987).

Another form of evidence that this form of priming is a presemantic phenomena comes from PET scan studies that indicate that word-completion priming involves specific changes in metabolic activation of right extrastriate visual cortical areas (Squire, Ojemann, Miezin, Petersen, Videen, & Raichle, 1992) while semantic processing of words selectively activates more anterior regions of the left hemisphere (Petersen, Fox, Posner, Mintum, & Raichle, 1988). Finally, recent work with patients who have disorders that involve word meaning comprehension ("word-deafness") show that these subjects nevertheless exhibit intact priming capability (Schacter, 1990, 1993). The view that word priming is dependent upon pre-semantic perceptual representation carries the prediction that a selective dysfunction of this pre-semantic perceptual "system" should produce impaired priming. It is suggested here that the anomalous result of M.S.'s performance on word-completion priming confirms that prediction. However, the fact that M.S. showed strong performance on another type of priming task, "fame priming", is an indication that the nature of the impairment in performance can be quite specific. That is, a perceptual sequencing dysfunction should selectively impair performance on tasks in which subject responses depend critically upon the processing of sequenced stimuli.

Retrieval dysfunction. The possibility that a dysfunction of retrieval may have been demonstrated by M.S. was discussed in the context of his performance on the source memory evaluation. M.S. successfully answered four distractor questions at the time of test which he did not answer correctly during pre-screening. This occurred despite the fact that he was not informed of their answers in the interim. Given the fact that M.S. has proven to be unremittingly honest and guileless in his efforts as a subject, the only adequate explanation for this result is that he did in fact know the answers to these questions at the time of prescreening, but failed to *retrieve* these answers until the testing session two hours later. It has been noticed on a number of occasions that M.S. will require a fairly protracted period of time to generate a response to a given question; although this may result in the impression that he simply does not know the answer, he will sometimes succeed in providing the correct response if permitted sufficient time.

Tests of verbal fluency are often considered to be diagnostic of frontal lobe symptomology (as in Shimamura & Squire, 1991, discussed above). In functional terms, however, they are direct assessments of retrieval capability. Ostergaard (1987) employed a variant of verbal fluency test with the childhood-onset amnesic C.C. and compared his performance to age matched controls. The test required that subjects generate as many exemplars as possible, in turn, from five categories (*birds*, *furniture*, *occupations*, *fruit* and "*words that begin with T*") within a one minute time limit. Across all five categories, C.C. generated only 36 exemplars while the mean number produced by the control group was 71.7 (*SD* = 8.5). Given this same task, M.S.

performed at about the same level as C.C., generating a total of only 33 exemplars from all five categories. Both amnesic subjects performed in excess of four standard deviations below the mean of the control subjects of the Ostergaard study. Broman et al. (1991) reported that on the Benton Verbal Fluency test (in which he was required to give animal names that begin with the letters c, f, and l) M.S. performed at the 8th percentile, an age equivalency of 7. He also performed at the 8th percentile on the Rapid Automized Naming task, an age equivalency of six to 11. These statistics do not necessarily indicate, however, that the deficient performance on these verbal tasks is entirely a consequence of M.S.'s vocabulary store being limited to premorbid levels. For example, when asked to name as many occupations as possible, M.S. did not mention *policeman*, *fireman*, *store owner* or *salesman*, items which are certain to have been part of his premorbid lexicon, and are also currently known to him; rather, M.S.'s first response was "computer worker", a job which was relatively obscure at the time of his trauma in 1970, and is likely to have been learned only recently. Similarly, as examples of the category of *bird*, M.S. mentioned "flamingo" and "dove", but did not mention *pigeon* or *sparrow*, names of far higher frequency which are certainly known to him. This pattern of responding suggests that M.S.'s impaired performances on these evaluations were not primarily driven by an impoverished post-trauma vocabulary *per se*, but rather to some aspect of the retrieval process.

In an informal evaluation similar to the formal tasks described above, M.S. was asked to name as many *politicians*, *sports figures*, and *TV personalities* as he could, first through free recall, and then after having been provided with the first names of some of these people as cues. M.S. showed a particularly striking difference between free and cued recall conditions in the *sports figure* category . Although he was completely unable to name a single sports figure through free recall, he generated the following responses on the basis of first name cues: (Mickey) Mantle, (Babe) Ruth, (Dwight) Gooden, (Reggie) Jackson, (Joe) Namath, (Magic) Johnson, (Wilt) Chamberlain, (Phil) Rizzuto, (Darryl) Strawberry, and (Muhammad) Ali. A disproportionate enhancement in performance for cued recall such as demonstrated here would be expected in the presence of dysfunctional retrieval in that partial answers should substantially relieve the processing burden upon retrieval operations. It is also important to note that many of the sports figures whose names were generated through cued recall have come into public awareness only recently, virtually ensuring that these names were acquired postmorbidly despite the presence of severe amnesia.

Frontal lobe dysfunction. Certain behavioral and cognitive dysfunctions have come to be particularly associated with frontal lobe (or more precisely, prefrontal lobe) neuropathology. These include disorganized cognition or communication, attentional and encoding deficits, apathetic or inappropriate affect or emotionality, denial of deficit, lack of insight and foresight, disinhibition, perseveration of response, and a tendency toward confabulatory or irrelevant responses. Although the manifestation of deficits that result from prefrontal neuropathology vary according to locus of lesion, timing of onset, and other factors (see Damasio, 1985), an important subset of the symptoms commonly observed in frontally lesioned patients may be seen as constituting a "dysexecutive" syndrome (Baddeley & Wilson, 1988).

By many standards, M.S. shows little overt evidence of a frontally based "dysexecutive" syndrome. His communications are lucid, direct, relevant and non-tangential. He shows a strong ability to concentrate and focus attentional resources, and a normal ability to release from proactive interference, even when compared to the performance of college undergraduates (see above). He is aware of his amnestic deficit, his epileptic disorder, his asthmatic condition, and of his difficulty with reading and spelling. As reported by Broman et al. (1991), he performs within normal limits on the Wisconsin Card Sorting Task, perhaps the most commonly employed assessment of frontal lobe functioning, achieving four categories. Also as reported by Broman et al., he does not confabulate. In fact, he has proven to be almost painfully veridical in his responses. When confronted with a question whose answer he is either unsure of, or does not know, he will invariably admit as much directly without qualification. M.S's lack of confabulation or circumlocution in responding appears to be a stark contrast to the response tendencies of H.M. Consider the following excerpted transcript reported in an infrequently cited study conducted by Sidman, Stoddard, and Mohr (1968, pp 247-248). The researchers questioned H.M. as to whether he could explain the requirements of a just completed operant discrimination task. The task required H.M. to press a lighted key which contained a circular stimulus as opposed to a distractor which contained an ellipse. The vertical to horizontal axis ratio of the ellipse was varied from trial to trial making the task of discrimination more difficult as this value approached that of a circle. H.M. was rewarded with a penny every time he successfully discriminated the circle from the elliptical form. H.M. explained the task in the following way:

> H.M.: Well let's see. Something would flash up there and the idea was to pick out one of those squares and to point it toward dark. To tip it - to hit it with my finger tip and to match up. Each time the two matched a penny would drop in.
>
> E: Each time the two matched?
>
> H.M.: The two matched.
>
> E: Uh-huh. What was on them?
>
> H.M.: X
>
> E: X was on them?
>
> H.M.: Yeah.

... [a few minutes later]

> E: What were you pointing to - what were you pressing over there?
>
> H.M.: Well, one of these would light up and get one of them matched and every time one would match, of course, a penny would drop in.
>
> E: What did the one that matched look like?
>
> H.M. Cross.
>
> E: A cross. Uh-huh. A plus sign?
>
> H.M.: Uh-huh.

Despite the fact that H.M. showed good discrimination ability, he was completely unable to accurately describe the task after 32 experimental trials. His references to the presence of an "X" or a "cross", to the need to "point it toward dark" and to the principle of matching different squares are wholesale confabulations. It should be stressed that these questions were asked immediately after the completion of the task, and so H.M.'s wildly inaccurate account cannot be viewed as a consequence of long-term memory failure, nor can it be ascribed to an acute post-traumatic confusional condition, since this evaluation was conducted 15 years postoperatively.

Corkin (1993) reported that an MRI was recently performed on H.M. This test was delayed for many years until it could be confidently determined that the surgical clips remaining in H.M.'s skull were not magnetic. This MRI presented evidence of frontal lobe damage. Corkin suggested that this damage was an artifact of the supra-orbital surgical approach which displaced the prefrontal cortex in order to gain access to the medial temporal lobes. No speculation was offered as to the cognitive or behavioral consequences of this lesion. In previous reports (e.g., Corkin, 1984) H.M. has been characterized as being free of frontal lobe symptomology, based primarily upon his normal performance on the Wisconsin Card Sorting task and normal release from PI. However, it appears unquestionable that H.M is cognitively and behaviorally compromised beyond that of a selective impairment of explicit long-term memory, and the possibility should be entertained that the prefrontal neuropathology demonstrated by the recent MRI may in fact be a contributing source to these deficits.

In the many hours of evaluations performed by this author, M.S. has never been observed to offer any verbal response as dissociated and irrelevant as that of H.M.'s recounted above. As previously stated, his responses are straightforward, lucid and germane, virtually without exception. M.S. simply does not confabulate, and to the extent that confabulation is a valid indicator of frontal lobe pathology, this fact must be considered as negative evidence in this regard.

At the same time, however, there are subtle behavioral signs that could be interpreted as pointing to some frontal dysfunction. Although M.S. achieved a (normal) total of four categories on the Wisconsin Card Sorting Test, he also committed 12 perseverative errors, and failed to maintain category set four times (Broman et al, 1991). While he has no trouble comprehending even complex verbal instructions, and in effecting simple, direct verbal responses, he has difficulty in organizing more elaborate verbal responses. For example, Broman et al. (1991) report that he was unable to write a short descriptive paragraph. As mentioned above, he does poorly on a variety of verbal fluency tasks, and showed complete source amnesia on two separate occasions, although it is probable that these capabilities are not exclusively linked to frontal lobe functioning. And finally, he shows a pronounced immaturity of affect, which may conceivably be connected to frontal lobe dysfunction in that it may be construed as a disorder of "executive" emotional development.

In considering the question of whether M.S. may show impairments that have been conventionally linked to prefrontal lobe lesions, it is important to remember that M.S.'s trauma occurred at the age of 8, when frontal lobe development is not yet complete (Yakolev & Lecours, 1967). Perhaps the occurrence of a major episode of respiratory arrest at this juncture may have prevented the normal course of frontal lobe neurodevelopment, as well as producing some selective damage to already established frontal neural systems. If this is the case, it may be that an "executive" behavioral and affective pathology would result from the arrest of prefrontal development at the time of the trauma.

Consequences of epilepsy. The fact that M.S. suffers from complex partial epilepsy is probably not without cognitive consequence. This disorder has been associated with many cognitive deficits, including those related to attention and concentration, language, motoric abilities and memory (Bennet, 1992). Interestingly, selective hippocampal damage to an area which generally corresponds to the CA1 field was first identified in connection with epilepsy, and not amnesia specifically (Meldrum & Corsellis, 1984; Sommer, 1880).

Dysnomic symptomology is an especially frequent concomitant of epilepsy and has been cited as a major source of confound in the assessment of specific memory dysfunction in these individuals (Mayeaux, Brandt, Rosen, & Benson 1980). As it is possible to view dysnomia as a special case of retrieval disorder, it is an interesting speculation that the retrieval dysfunction hypothesized to be present in M.S. is an example of an epilepsy-linked dysnomia.

The Status of Implicit Functioning

A sequence of evaluations was implemented with the intention of sampling diverse aspects of implicit functioning. Two of the evaluations placed special emphasis upon perceptual/motoric skills (Tetris and Chase Max), others were more strictly perceptual in nature (word-completion and fame priming tasks), and another involved the cognitive skill of implicit categorization (the artificial grammar task). It is of interest to note that the most unambiguous demonstrations of intact implicit functioning were obtained through evaluations that had little or no motoric component. Although it is commonly assumed that motor-skill learning is a fundamentally preserved capacity in amnesia, evidence was presented here that in the case of M.S., a subtle, but clearly measurable motoric slowness may have interfered with optimal learning on such tasks (i.e., Tetris and Chase Max). A similar motoric impairment was determined to be a factor in certain motor-skill evaluations of H.M. (Corkin, 1968), and it is probable that comorbid motoric pathologies are not uncommon threats to the assessment of motor-skill learning in brain injured populations.

Of the non-motor based tasks employed here, two were examples of direct priming. M.S. showed unsatisfactory performance on one priming evaluation (word-completion), but adequate levels of priming on a second (fame priming). This discrepancy was attributed to the apparent interference in performance provided by a specific perceptual dysfunction on the former, but not on the latter, task. This asymmetry in interference can be accounted for by the difference in processing demands inherent in the separate tasks.

M.S. performed similarly to college students on what may be considered the paradigmatic implicit learning test, the artificial grammar task. Despite the fact that M.S. has a reading age equivalent of 7 - 8 years, has a WAIS-R I.Q. that is barely within the lower range of normal (82), has never finished elementary school, has a severe amnestic condition, and had exceptional difficulty in reproducing the letter sequences in the learning phase, he was as accurate in his grammaticallity judgments across the first half of the test as was a comparison group of college undergraduates. This result is consistent with previously published assertions that implicit category acquisition is a cognitive capability that is independent of explicit memorial processes, and, more generally, explicit intelligence as measured by I.Q. (Knowlton & Squire, 1994; Reber, Walkenfeld & Hernstadt, 1991).

It is concluded that, on balance, this study has been successful in demonstrating intact implicit functioning in this subject. The tasks on which M.S. failed to show normal performance were not taken as contradictions to this interpretation, but rather, for reasons addressed in some detail above, as indications of the confounding effects of comorbid pathologies.

On the special characteristics of the amnesia of M.S.

The available evidence from both prospective animal models and behavioral studies of human amnesics indicates that the extent of damage across midtemporal lobe structures is a determining factor in the severity of the resultant amnestic condition. Squire (1992) concluded that subject R.B. (Zola-Morgan, Squire & Amaral, 1986) was demonstrably less amnesic than H.M., owing to the fact that his bilateral lesion was confined to one portion of the hippocampus, while H.M.'s lesion encompassed greater area and involved more structures within the midtemporal lobe. By this same logic, it would follow that the memory impairment of M.S. should be more severe than that of R.B., but less severe than that of H.M.

Although the direct evidence is limited, an indication that R.B.'s memory impairment may have been less severe than that of M.S. can be seen by comparing their respective I.Q. and memory scale scores. Zola-Morgan et al. (1986) reported a WAIS-R score of 111 and Wechsler Memory Scale (WMS) quotient of 91 for this subject. As these two scores are equivalent in normal subjects, a 20 point differential is conventionally interpreted as indicative of a memory impairment. However, it should also be noted that the WMS quotient of 91 is within one standard deviation of the population mean. In comparison, Broman et al. (1991) reported a WAIS-R score of 82 and WMS-R delayed recall score of < 50 for M.S. Not only is the differential between the I.Q. and Memory Scale scores greater for M.S., but the delayed recall score for M.S. is beyond the norms of the scale, at least three standard deviations below the population mean (this comparison must remain a gross approximation, however, since the Revised version of the WMS employed with M.S. was not available at the time of R.B.'s testing).

That M.S. is less severely impaired than H.M. with respect to memory has been frustratingly difficult to document within the context of a formal evaluation. As reported above, M.S. performed as poorly as H.M. in the learning of low frequency

English vocabulary words (Gabrieli, et al , 1988). For both subjects, the evaluation had to be discontinued after 20 unsuccessful trials. This result is especially frustrating because it has become manifestly obvious that M.S. is capable of learning new words, names and factual information encountered in the ambient environment. Moreover he can acquire such novel information without benefit of a formal program of instruction. Perhaps his ability to acquire new information in the course of his daily life, and his inability to convincingly demonstrate the same under formal testing conditions speaks to the cognitive advantage of distributed over massed practice, and perhaps also to the importance of affective and motivational factors.

Our extended experience with M.S. has led to the observation that his learning is dependent upon repeated exposure to target information. Given sufficient repeated encounters with specific items of novel information (i.e., names of things, such as advertised products, or names of people, or general facts), M.S. is capable of forming memorial representations that can be retrieved, manipulated, mentally examined, compared, reorganized and re-stored. He is therefore capable of performing flexible analytical operations upon acquired representations, suggesting that the newly acquired information is something other than the product of a simple conditioned association or learned procedure.

Consider his discovery of the algorithm for the Tower of Hanoi. Although he was unable to completely "learn" the puzzle during the course of the two day testing period, he became sufficiently familiar with the structure and rules of the task to be able to create a working model at home after the conclusion of the evaluation. Once this model was constructed, he was able to employ it for the purpose of working out the "odd-even" algorithm to the puzzle. The question may be asked as to how he might have mentally represented the essential features of the game across the considerable interval of time prior to the construction of the model. While it is possible that he managed to retain a representation of the task in working memory through rote repetition, this would require the rehearsal of not only the physical layout of the game (three pegs and five different size disks), but also the rules (move only one disk at a time, a larger disk cannot be placed upon a smaller disk) and the goal of the game (all disks must end up on the target peg in the proper size arrangement). It seems likely that support of this elaborate set of propositions would exceed the resources of working memory alone, particularly considering the elapse of time between the conclusion of testing and his arrival at home. A more probable explanation is that the retention of this information was supported by a long-term memory representation. The fact that he is currently able to recall and correctly utilize this "odd-even rule" nearly two years after his initial discovery is an unambiguous indication that this information is represented explicitly in long-term memory. Moreover, it is important to note that while he discovered this algorithm in the context of the five disk puzzle, his representation of this rule is sufficiently flexible to permit its application regardless of the number of disks employed. He does not generate and apply the "odd-even rule" reflexively in the context of the five disk arrangement. The algorithm is available to him as a flexible proposition that can be intentionally retrieved and applied across varied situations.

M.S. has in many other instances demonstrated the acquisition of what may be best characterized as explicit semantic memories. Continuing with the example of the Tower puzzle, he not only has retained the name "Tower of Hanoi" and the "odds-even" algorithm, but can also recognize the puzzle in altered form, i.e. in a computerized format or in a schematic diagram. Again, this attests to the flexibility and explicit accessibility of the stored representation. Memories of similar quality have been formed for other evaluations in which he has participated, such as Tetris and Chase Max, and also for general experiences encountered at the laboratory at Brooklyn College. According to his parents, he often discusses such experiences while at home, and even does so in an unprompted and spontaneous fashion during their winter-long vacation in Florida. M.S. has also shown explicit memories for facts and information regarding the family home in Florida, which was acquired many years after the onset of his amnesia. When tested six weeks after returning from a visit, he was able to draw an accurate floor plan of the family condominium, provide certain details as to the furnishings, describe the view from his window (a parking lot) and identify an adjacent landmark (a golf course).

In contrast, the literature indicates that the amnesic H.M. is not possessed of a similar explicit memorial capability. This subject is routinely characterized as being unable to acquire new factual information regardless of repetition (e.g. Corkin, 1984, 1993). Given their similar scores on standardized tests of memory and the results of evaluations such as the vocabulary learning task reported above, H.M. and M.S. may appear to be equally severely amnesic. However, the residual explicit memorial capability evidenced by M.S. and not shown by H.M. permits the statement that the amnesia of M.S. is less dense or severe than that of H.M.

With respect to performance on standardized tests, it is important to remember that such tests are administered in one session and do not take repeated measures distributed over time. Thus while it is certain that standardized neuropsychological tests can identify individuals with memory impairments, they can not discriminate among those individuals who will learn new factual information given sufficient repetition and those who possess no such residual capability, as is the situation with M.S. and H.M. Any formal testing procedure designed to assess residual explicit learning capability would require an accommodation for distributed repeated measures.

As has been described above at some length, there are strong indications that M.S. suffers from comorbid cognitive and behavioral deficits which serve to complicate the specific assessment of his hippocampally based memory impairment. The speculation is offered here that at least some portion of this supplementary pathology is a consequence of the fact that his precipitating trauma occurred during the course of his brain development. For example, the specific perceptual and retrieval difficulties which appear to be factors in M.S.'s performance are not typically reported in association with adult-onset anoxic amnesia. Notwithstanding the effects of these deficits, or the primary memorial disability that is a consequence of his hippocampal pathology, M.S. has demonstrated a residual ability to construct memorial representations that are by all appearances "explicit" or "declarative" in nature. If we accept this as an accurate portrayal of the nature of these acquired representations, it follows that such memories can in fact be formed, albeit at an abnormally slow rate, independent of a substantial functional contribution from the hippocampus.

A Theoretical Interpretation of the Amnesia of M.S.

Throughout this paper, the terms *implicit* and *explicit* have been employed to make reference to qualitatively different forms of memorial representation. Use of these terms, however, does not in itself imply support for the separate (or multiple) memory systems model. Schacter (1987) has been careful to state that his use of these terms is purely descriptive, and not denotive of the existence of separate memory systems. "Process" theorists, such as Roediger (Roediger, 1990a, b; Roediger & Blaxton, 1987) have used this same distinction to refer to different cognitive processes of a unified memory system which are selectively enlisted according to the nature of the task and the properties of the stimuli involved. Reber's implicit *vs.* explicit distinction identifies qualitatively different knowledge acquisition mechanisms (i.e., volitional and reflective *vs.* spontaneous and non-reflective) which he has come in recent years to view from an evolutionist\functionalist perspective (Reber, 1989, 1992, 1993). Reber sees explicit cognition as a relatively recent product of phylogenetic evolution which has been layered upon implicit functioning in an hierarchical fashion. This view may be thought of as a separate systems model that assumes that implicit and explicit mechanisms operate interactively and in parallel.

The terms declarative and procedural memory (Cohen, 1984; Cohen & Squire, 1980) allude to the basic distinction, originally framed by Ryle (1949), between "knowing how" and "knowing that". This model maintains that the brain systems supporting memory for facts and events ("knowing that") are neurologically distinct from those involved with other forms of memory, such as the memory for learned skills (knowing how"). More recently, this classification has been modified to that of *declarative* vs. *non-declarative*, in the acknowledgment that the domain of functioning referred to as "procedural" actually consists of a heterogenous collection of abilities with differing characteristics (Squire & Zola-Morgan, 1988). For example, direct priming effects are typically achieved after a single exposure to a stimulus item, whereas skills such as those involved in mirror reading develop slowly across many trials of practice.

These classificatory schemas are similar in many respects, and yet there are important differences in how well they account for the facts of preserved and compromised learning in amnesia. The "process" theories, which were developed largely in the context of priming studies with normal subjects, have particular difficulty in explaining why amnesics show such a marked dissociation in performance if, as they argue, the only relevant consideration is the interaction between task demands at study and at test. Strictly interpreted, this model predicts no special deficit in amnesic performance relative to normals.

Although it is closer to a "systems" model than a "process" model, the episodic *vs.* semantic distinction (Kinsbourne & Wood, 1975; Tulving, 1972) likewise fails to adequately capture the facts about amnesic performance. The contention that amnesia spares "semantic" memory, or memory for de-contextualized information, has not been borne out by empirical investigations (see the section above on semantic learning). The fact that amnesics do retain their premorbid language ability is likely due to the fact that such information is highly overlearned and well-consolidated prior to the precipitating injury. Additionally, there is little reason to suspect that the episodic-semantic distinction is mirrored by any corresponding distinction in neurological systems, or that they are independent in any other sense. Memory for "episodes" may be little more than the coordinated retrieval of "semantic" representations that are associatively linked. Experimental work with simulated eyewitness accounts has shown that "episodic" memories can be substantively modified by the introduction of new semantic information (e.g., Loftus 1979; Loftus & Hoffman, 1989; Zaragoza & Lane, 1994). In fact, it appears to be the case that under certain conditions, entire episodes of memory can be wholly fabricated by way of externally supplied verbal suggestions, as indicated by recent well-publicized cases of falsely "recovered" memory (Wright, 1994; Yapko, 1994).

In the declarative-nondeclarative model, declarative memory includes memories for both facts (semantic memories) and events (episodic memories). Although the term explicit memory does not overtly identify these as componential aspects, explicit functioning is generally understood to include the ability to recall, recognize, or cognitively represent information irrespective of this semantic - episodic distinction. As the evidence from the amnesia literature approaches the consensus that it is this class of memorial functions that is specifically affected in amnesia, it appears that the declarative-nondeclarative, and also the explicit-implicit models seem, on balance, to map most comfortably on to the basic dissociation that is observed in amnesic performance.

The statement that declarative or explicit functioning is compromised in amnesia does not imply that these memorial functions are completely absent. As detailed above, M.S. shows a residual capacity for acquiring novel information that has been encountered on several occasions. In contrast, he learns little, if anything, when his experience is limited to a single exposure. This limitation to his learning has the interesting consequence of appearing to interfere with the formation of memories for personal "episodes". That is, since episodes are by definition unique, one-time occurrences, they can not be re-experienced in the same way that de-contextualized factual information can, for example, by re-reading a passage, or by distributed rehearsal. The fact that propositional information can be re-experienced while episodes, in and of themselves, cannot, may account for the frequently cited observation that memory for episodes is especially compromised in amnesia. The disadvantage for episodic information relative to semantic information may be explained in terms of this asymmetry in frequency of exposure.

It is also possible to understand the volatility of "episodic" information in terms of the particular functioning of the hippocampus. One view of the role of the hippocampus is that it is responsible for the forming of conjunctions between normally unrelated events, or for the encoding of unique configurations of stimuli (Squire, 1992; Squire, Shimamura & Amaral, 1989; Sutherland & Rudy, 1989). If this assessment of hippocampal functioning is valid, it would follow that damage to the hippocampus would affect memory for singular episodes, as the memory for these particular events would be dependent upon the representation of unique conjunctions or configurations among stimuli. Thus the noted disturbance in episodic memory in amnesics may in fact be due to a failure of hippocampally mediated "one-trial" learning.

Although episodes cannot be directly re-experienced, derived semantic descriptions of such episodes can be repeatedly encountered or mentally rehearsed; in this way amnesics such as M.S. can, through much repetition, acquire specific facts about their lives apart from a direct recollection of the originating events. So, for example, although M.S. is typically unable to remember what he had for breakfast on a given day, he does know what he has had frequently in the past, and can make a reasonable guess based upon that information. A striking example on this point involves the manner in which M.S. learned about the birth of his youngest nephew. Soon after the birth, M.S. and his parents traveled to see the baby for the first time. After a full day's visit in which M.S. was able to view his nephew at some length, the family was heading home on the parkway when M.S. remarked " I wonder when [his sister] will have the baby". Although M.S. was unable to internalize the occurrence of this event on the basis of a single exposure, he has subsequently learned this and related facts (such as the gender and name of the child, that it is the youngest of three siblings, etc.) but only after numerous re-exposures to this information.

An interesting implication of the proposition that amnesics do not acquire explicit memories through single experiences, but rather through semantically derived, or multiply experienced information, is that the personal information that they do acquire may not have the same emotional immediacy as "normal" autobiographical events. Such a disconnection from autobiographical experience in amnesics was in fact proposed by Claparède (1911), who described amnesia as a disturbance in the sense of "moiité", or "me-ness".

The literature on the amnesic disorder is replete with findings of preserved implicit functioning despite the presence of unambiguously impaired explicit learning and memory. Less well documented is the phenomenon of residual explicit learning. Important work on the acquisition of explicit knowledge by amnesics has been conducted by Glisky and her colleagues (e.g., Glisky, 1992; Glisky & Schacter, 1989; Glisky, Schacter & Tulving, 1986). These studies have demonstrated the fact that, although the rate of learning is clearly abnormally slow, amnesics can systematically be taught novel semantic information under controlled laboratory conditions. Glisky and her colleagues demonstrated this in the context of teaching amnesic subjects computer data-entry skills. The amnesic subjects were taught computer related terminology and corresponding keyboard responses through an innovative training technique called the *method of vanishing cues*. This technique capitalizes upon the advantage conferred by repeated exposure to specific items, and also upon the ability of amnesics to benefit from the presentation of partial information, as has been shown in perceptual priming tasks. The target answers to computer administered questions are first presented with as many letter cues as is needed for the subject to supply the correct completion. On subsequent trials, the targets are presented in incrementally reduced form, until finally the subject must respond without benefit of a cue. The rate of progress is determined by the individual subject's ability to respond correctly to the diminished word forms; if the subject responds incorrectly at a given stage, more letters are supplied, as needed. This technique has proven successful in teaching specific, functional, semantic information to amnesics where conventional mnemonic strategies have yielded largely disappointing results (O'Connor & Cermak, 1987; Salmon & Butters, 1987).

These authors have characterized the knowledge that derived from the vanishing cues instructional technique as *hyperspecific*, that is, inflexibly attached to the conditions in which it was learned (Glisky, et al., 1986, 1989). However, in later studies (e.g., Glisky, 1992) subjects were permitted a more extensive learning phase, and showed the ability to transfer previously acquired factual knowledge to novel task conditions, thereby demonstrating some measure of the flexibility that should attend explicit level memory. It is possible, then, that much of the hyperspecificity observed by these authors was a function of the training procedure itself. Invariant and highly structured learning conditions may result in relatively inflexible memorial representation, particularly when the information is then tied to skill-based measures (i.e, data-entry procedures), as was the case with the subjects in these studies. That is, information that is acquired largely in the context of highly specific and controlled conditions, or in the course of the learning of a particular skill, may result in a more rigid and task-bound representation than would be the case for information acquired under more variable circumstances. It may be that the ability of amnesics to form truly flexible and adaptable memorial representations that can justifiably be referred to as "explicit" is dependent upon multiple exposures to target information in a variety of contexts.

How can we understand the fact that many, if not most, amnesics show the residual ability to acquire new semantic memories, whether through direct training or on their own, as has been the case with M.S.? Tulving, Hayman, and MacDonald (1991) reported the acquisition of novel semantic information in a severely amnesic patient, and, adhering to the episodic-semantic distinction, suggested that such learning is supported by an intact, or nearly intact, semantic memory. According to this view, amnesics learn at an abnormally slow rate because, unlike normals, they do not enjoy the benefit of access to an episodic memory for the learning occasions. Another possibility, one that follows from the declarative-nondeclarative distinction, is that while amnesia compromises both episodic and semantic memory, in most cases it does not entirely eliminate these functions; the learning shown by amnesics is a consequence of this damaged, but still partially active subsystem of memory.

Another possibility is that the ability of amnesics to learn novel semantic information is supported and underpinned by intact implicit learning mechanisms. Glisky and colleagues (e.g., Glisky, Schacter & Tulving, 1986) have suggested that priming may account for much of the learning that is produced through the method of vanishing cues. However, the characteristics of priming are fundamentally dissimilar to this form of learning. Priming occurs after only one or two exposures, does not develop gradually, is relatively modality specific, and the effect is brief in duration. In contrast, the semantic learning referred to here is acquired gradually over many trials, shows the property of transfer, and is of long-term duration. These characteristics suggest the operation of a process more akin to a cognitive skill or habit system, such as the implicit learning mechanisms discussed by Reber (1989, 1993) and also in

Sherry and Schacter (1987).

The proposal that intact implicit learning mechanisms may underlie residual explicit learning is, at least superficially, at variance with current "horizontally" dichotomous models which emphasize the independence of separate memory systems. The present model may be seen as "vertically" oriented, in that it suggests that explicit functions have been built upon a foundation of primary implicit mechanisms in something like a hierarchy of structure. Reber (1992, 1993) has already formally articulated this last point in the context of his evolutionary perspective on the emergence of learning and memory. A major premise of Reber's evolutionary framework is that implicit cognitive functions constitute a class of fundamental representational systems which are evolutionarily antecedent to explicit, top-down operations occurring within "awareness". In arguing for the "primacy of the implicit", Reber invokes the *developmental lock* model of Schank and Wimsatt (1987), which proposes that successful functions and forms, once established in phylogeny, become the foundation for further evolutionary elaboration. In keeping with this scheme, the suggestion is being made here that implicit learning mechanisms constitute a foundational cognitive system which is sufficiently generalized to support, at least in part, such "added on" functions as semantic information acquisition. The semantic learning that takes place in amnesia occurs in the gradual, protracted fashion which is the hallmark of implicit acquisition, because explicit learning processes, which normally operate in parallel and which could provide instantiated representations of the target stimuli, have been compromised.

One of the major objections to the notion of separate or multiple memory systems is the specter of a proliferation of proposed systems to account for every newly observed nuance or subtle effect (e.g., Roediger, 1990a, b). In response to this criticism, attempts have been made to establish criteria by which candidate systems can be evaluated (Sherry & Schacter, 1987; Tulving, 1985, 1987). However, framing the investigation of memory in terms of the identification of separate and independent systems may be an unpromising enterprise. As Squire (1992) has pointed out, as many as 30 separate areas of the primate visual cortex have been identified which are in some measure functionally and anatomically distinct. It is possible that the right combination of stimulus forms and task requirements could produce a priming effect through the activity of each one of them. Even if these were to meet the specified criteria of separate memory systems, few would argue that it would be meaningful to identify them as such. An analogy can be made to the similar question, first raised in classical times, as applied to the senses. Aristotle's list of five senses can be expanded to include such things as proprioception, balance and the sensitivity to temperature and pain. But since pain sensation involves fast and slow responding sub-divisions that are functionally discrete and have identifiably distinct neural pathways, should these also be considered separate sensory mechanisms? It is clear that the list can be increased to an arbitrarily large number. The same is likely to be true in the case of memory systems.

An additional point is that the identification of so many "independent" memory systems does not adequately acknowledge the fact that this function has arrived at its present form through an unbroken chain of phylogenetic evolutionary development. The separate systems view as it is presently expressed too easily leads to the notion that memory is best described as a varied collection of independent and autonomous functions. Perhaps it is better to conceptualize human memory from the outset as the coordinated activity of several interactive subsystems whose processing output is integrated in adaptively meaningful terms at some executive level. That this must be so may seem patently obvious, and yet this framing of the issue appears to be largely absent from the discussion. Although it is unquestionably true that functionally and neurologically distinct mechanisms can be identified, the importance of this arrangement to the organism (and by extension, to the species) is that these systems provide a rich array of non-redundant information that is integrated and interpreted in the service of the organism as a whole.

Another consideration raised by Reber (1992, 1993) is the issue of the comparative robustness of implicit functions. If implicit functions are foundational in terms of the evolution of responsive, representational mechanisms they should be less easily compromised by generalized trauma than recently emerged explicit operations. The principle essentially parallels that proposed for the neurological hardware that supports these functions: phylogenitically older portions of the nervous system are thought to be more resistant than the newer (Brierley & Graham, 1984). The disorder of amnesia can be considered to be a paradigmatic example of this prediction. As noted in an earlier section, a variety of brain traumas can precipitate amnesia, including closed head injury, viral infection, hypoxia, ischemia, tumors, vascular malformations, etc. These etiologies, although diverse, tend to produce a rather selective compromise of explicit functions, leaving implicit capabilities relatively unaffected. The case of M.S., as his performance on a variety of evaluations presented in this paper has revealed, demonstrates this basic pattern of compromised and preserved cognitive functions, and as such, is interpreted here as consistent with this evolutionary heuristic.

Appendix A

Medications Currently Taken by M.S. [3]

Anti-Asthmatics

1. Albuterol (Proventil). A bronchodilator. *associated side effects*: skeletal muscle trauma; cardiovascular overstimulation; tachycardia
2. Cromolyn Sodium (Intal). Inhibits bronchial constriction. *associated side effects*: (infrequent and minor) bronchospasm, coughing, wheezing, laryngeal irritation, joint swelling, angio-edema, headache, rash, nausea.
3. Flunisolide (Aerobid). Anti-inflammatory adrenocortical steroid. *associated side effects*: pituitary adrenal suppression (transient); fluid and electrolyte disturbance; hypertension; hyperglycemia and glycosuria; posterior subcapsular cataracts, abnormal enlargement of fat tissue, "central obesity", striae, acne, hirsutism; increased susceptibility to infection, peptic ulcer, osteoporosis, myopathy, manic-depressive or schizophrenic symptomology.
4. Methylprednisolone (Medrol). Anti-inflammatory adrenocortical steroid. *associated side effects*: see above.

---

[3] Based upon the descriptions appearing in A.G. Gilman, T.W. Rall, A.S. Nies, & P. Taylor (eds.). *The Pharmacological Basis of Therapeutics.* 8th ed. New York: Pergamon.

Anti-convulsants

1. Carbamazepine (Tegretol). Anticonvulsant. *associated side effects*: drowsiness, vertigo, ataxia, diplopia, nausea, hypersensitivity (dermatitis, eosinophilia, lymphadenopathy, splenomegaly).
2. phenytoin (Dilantin). Anticonvulsant. *associated side effects*: cerebellar-vestibular effects (nystagmus, diplopia, vertigo, nausea); ataxia; behavioral changes (i.e. hyperactivity, silliness, confusion, dullness, drowsiness); gastrointestinal symptoms, gingivitis, osteomalacia, megaloblastic anemia.

Other

1. Claritin - antihistamine: listing of side effects unavailable.
2. TAO - antibiotic: listing of side effects unavailable.

Appendix B

Summary of Neuropsychological Testing of M.S.

I. General Intelligence

Wechsler Adult Intelligence Test- Revised

Verbal IQ	78
Performance IQ	94
Full Scale IQ	82

WAIS-R Subtests

Information	5	Picture Completion	11
Digit Span	8	Picture arrangement	8
Vocabulary	4	Block Design	13
Arithmetic	6	Object Assembly	10
Comprehension	6		
Similarities	8		

Woodcock Johnson - Revised: Summary Scores (1992)

	Age Equivalent	Percentile Score
Broad Cognitive Ability	13.2	16th %tile
Long-Term Retrieval	5.2	3rd %tile
Short-Term Memory	14.3	35th %tile
Auditory Processing	9.0	18th %tile
Visual Processing	12.2	16th %tile
Comprehension-Knowledge	11.1	2nd % tile
Fluid Reasoning	11.8	24th % tile
Knowledge-Aptitude		25th % tile
Oral Language Aptitude		1st %tile
Basic Reading Skills	7.9	0.3 %tile

Woodcock Johnson - Revised Individual Test Scores (1992)

	Age Equivalent	Percentile Score
Memory for Names	5.0	4
Memory for Sentences	29	86
Incomplete Words	12.9	32
Visual Closure	12.6	17
Picture Vocabulary	12.7	3
Analysis-Synthesis	15.0	39
Visual-Auditory Learning	5.6	2
Memory for Words	7.7	13
Sound Blending	7.11	17
Picture Recognition	12.9	29
Oral Vocabulary	10.1	1
Concept Formation	10.2	17
Delayed Recall -		
Visual-Auditory	4.0	1
Memory for Names	4.0	K.0
Numbers Reversed	8.8	3
Sound Patterns	6.7	3
Spatial Relations	16.4	29
Verbal Analogies	11.8	14
Letter-Word Identification	8.1	0.1
Word Attack	7.1	2
Reading Vocabulary	8.11	.02

Wide Range Achievement Test- Revised (from Broman et al., 1991)

Reading	< 3rd grade	.09 %tile
Spelling	< 3rd Grade	.4 % tile
Arithmetic	5th Grade	2 % tile

II. Memory

Wechsler Memory Scale -Revised: (from Broman et al., 1991)

	Scaled Score
Verbal Memory	51 (< 3 *SD*)
Visual Memory	57 (< 2 *SD*)
General Memory	< 50 (< 3 *SD*)
Attention/Concentration	95 (average)
Delayed Recall	< 50

Brown-Peterson Memory Test: (from Broman et al., 1991)
11/12 correct 0" - 60" retention intervals (average)

California Verbal Learning Test: (from Broman et al., 1991)
Standard score = 50.5 3+ S.D. below Mean

Rey-Osterreith Figure: (from Broman et al., 1991)
Copy: 32/36 50th %tile
Immediate: 7/36 < 25th %tile
Delayed: 0/36 (no recall after 20 minutes)

III. Basic Language Ability (from Broman et al., 1991)

Expressive

Rapid Automatized Naming:	Slow 4/4 6 to 11 AE
Boston Naming Test:	41/60 correct; 6 w/phonemic cue - 8.0 AE
Benton Verbal Fluency (c,f,l; animals:	8th %tile; 6.0 AE
Spreen-Benton Sentence Repetition:	14th %tile 7.0 AE

Receptive

Peabody Picture Vocabulary Test:	< 1st %tile 9.0 AE
Boston Diagnostic Aphasia:	
(Complex Ideational Material)	11/12 (Average)
Token Test for Children:	12 to Adult AE
Menyuk Syntax Comprehension Test:	12 to Adult AE

III. Specific Tests Related to the Diagnosis of Reading or Perceptual Dysfunction

Woodcock Johnson - Revised Subtests (1992)

Memory for Names	5.0 AE	4th %tile
Memory for Sentences	29 AE	86th %tile
Sound Blending	7.11 AE	17th %tile
Sound Patterns	6.7 AE	3rd %tile
Letter-Word Identification	8.1 AE	0.1 %tile
Word Attack	7.10 AE	2nd %tile
Reading Vocabulary	8.11 AE	0.2% tile

Coltheart Reading Test:
22/39 correct (regular words)
15/39 correct (irregular words)
difference score of 7 is non-significant.

IV. Attention and Mental Control

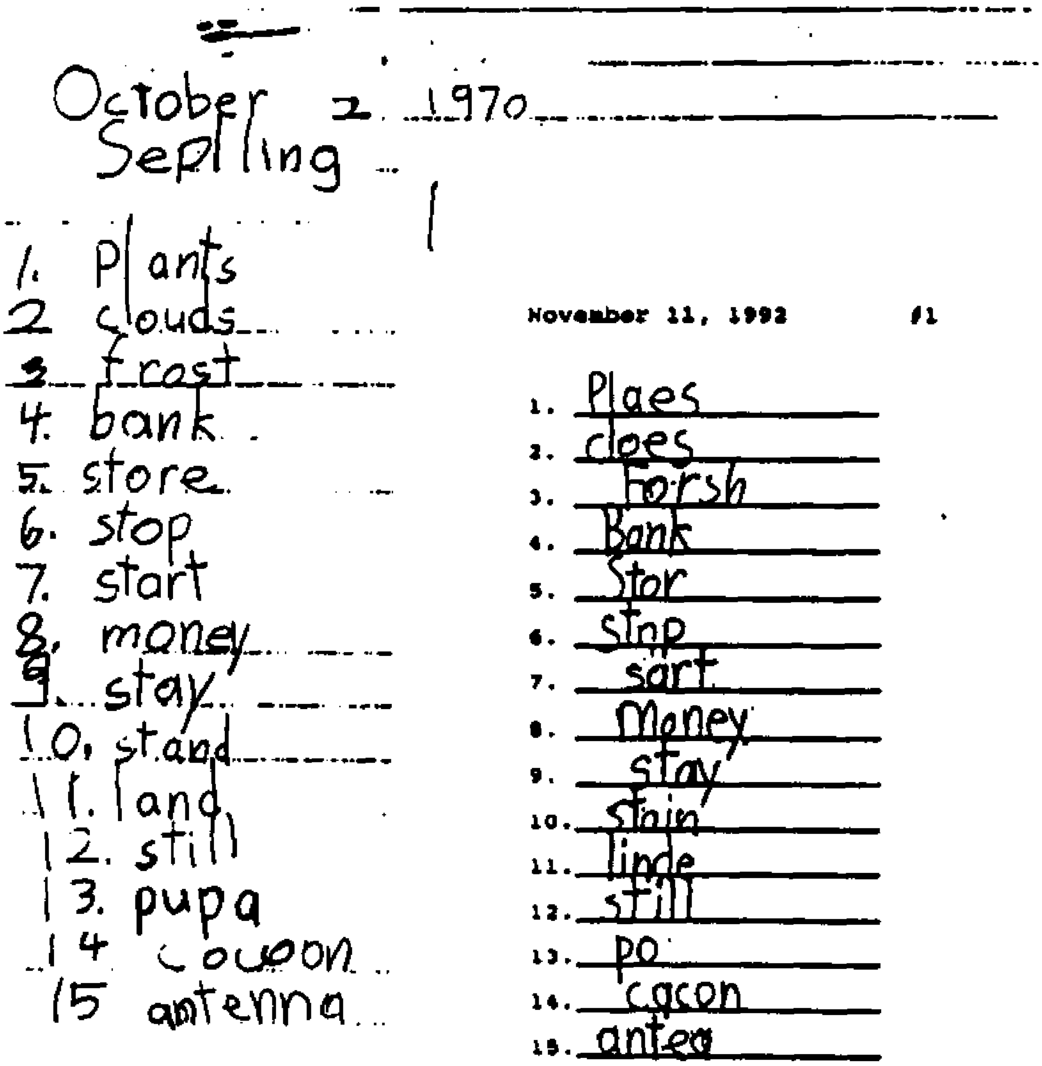
Rosen Cancellation Test: (from Broman et al., 1991)
Slow / Very Accurate
Trail Making Test: (from Broman et al., 1991)
A= 25 - 50 %tile B = < 10 % tile
Wisconsin Card Sorting Test : (from Broman et al., 1991)
91 correct (Average) 42 errors (Average)
12 perseverative errors (Average)
4 categories achieved (Average)
3 failures to maintain set (Impaired, 1+ s.d. below mean)

V. Motor Coordination

Purdue Pegboard: (from Broman et al., 1991)
(15 year old norms)
R = 14; = 25% tile
L = 14: = 40th %tile
Both = 12; = 35th %tile
Assembly = 32; Level = 40th %tile

Denckla Motor Coordination Battery: (from Broman et al., 1991)
Slow Movements: 3 Right; 3 Left
Overflow: 0 right; 0 left
Dysrhythmia: 0 Right; 1 Left

Appendix C



October 2 1970
Seplling

1. plants
2 clouds
3 frost
4. bank
5. store
6. stop
7. start
8. money
9. stay
10. stand
11. land
12. still
13. pupa
14 cocoon
15 antenna

November 11, 1992 #1

1. Plaes
2. cloes
3. Forsh
4. Bank
5. Stor
6. stop
7. sart
8. Money
9. stay
10. stain
11. linde
12. still
13. po
14. cacon
15. antea

Appendix D

Name: MS

COLTHEART READING LIST

Score first attempts only. Circle letter if correct.

1.	barge	belge	R
2.	prove		[✓ I]
3.	move		[✓ I]
4.	lose	lost	I
5.	glove		[✓ I]
6.	horse	houses	R
7.	pint	cat	I
8.	debt	dip	I
9.	sure		[✓ I]
10.	yacht	yacca	I
11.	sword		[✓ I]
12.	answer	anowr	I
13.	scarce	DK	I
14.	free		[✓ R]
15.	trout		[✓ R]
16.	come		[✓ I]
17.	base	bees	R
18.	pine	plan	R
19.	spear	Spar	R
20.	county		[✓ R]
21.	grill		[✓ R]
22.	broad	bored	I
23.	break	báck	I
24.	laugh	latch	I
25.	aunt		[✓ I]
26.	plug		[✓ R]
27.	throng		[✓ R]
28.	save		[✓ R]
29.	shrug	Shunned	R
30.	turn	train	R
31.	spade		[✓ R]
32.	flood	flood	I
33.	blood		[✓ I]
34.	tooth		[✓ R]
35.	shove	Shave	I
36.	kept	keep	R
37.	rub		[✓ R]
38.	treat		[✓ R]
39.	capsule		[✓ R]
40.	duel	dull	R
41.	bury	[illegible]	[✓ I]
42.	gang	can	R
43.	stupid	DK	R
44.	protein		[✓ R]
45.	shampoo		[✓ R]
46.	strewn	stew	R
47.	thorough	thought	I
48.	gauge	DK	I
49.	bowl		[✓ I]
50.	steak	steek	I

51. circuit circus I
52. castle ________ [✓ I]
53. borough Dk I
54. build ________ [✓ I]
55. slate ________ [✓ R]
56. biscuit discount I
57. sew saw I
58. gross grass I
59. subtle subtle I
60. cult cute R
61. trough Dk I
62. gone ________ [✓ I]
63. sort short R
64. soul ________ [✓ I]
65. spend speed R
66. cough cough I
67. mortgage Dk I
68. love ________ [✓ I]
69. sign sing I
70. take ________ [✓ R]
71. sherry sharing R
72. dance ________ [✓ R]
73. distress distance R
74. fresh ________ [✓ R]
75. check ________ [✓ R]
76. splendid ________ [✓ R]
77. mile ________ [✓ R]
78. quick ________ [✓ R]

Regular correct: 22 / 39
Irregular correct: 15 / 39
7 ns

References

Abrams, M. & Reber, A.S. (1989). Implicit learning in special populations. *Journal of Psycholinguistic Research, 17*, 425-439.

Alexander, M.P. & Freedman, M. (1984). Amnesia after anterior communicating artery aneurysm rupture. *Neurology, 34*, 752-757.

Anderson, J.R. (1985). *Cognitive psychology and its implications.* Second edition . New York : W.H. Freeman.

Arrigoni, G., & De Renzi, E. (1964). Constructional apraxia and hemispheric locus of lesion. *Cortex, 1*, 170-197.

Baddeley, A. (1982). Amnesia: A minimal model and interpretation. In L.S. Cermak (Ed.). *Human memory and amnesia.* (pp. 305-336). Hillsdale, NJ: Erlbaum.

Baddeley, A. & Wilson, B. (1988). Frontal amnesia and the dysexecutive syndrome. *Brain and Cognition, 7*, 212-232.

Beatty, W.W., Salmon, D.P., Bernstein, N., Martone, M., Lyon, L. & Butters, N. (1987). Procedural learning in a patient with amnesia due to hypoxia. *Brain and Cognition, 6*, 386-402.

Becker, J.T, Walker, J.A. & Olton, D.S. (1980). Neuroanatomical bases of spatial memory. *Brain Research, 200*, 307-320.

Bennet, T.J. (1992). Cognitive effects of epilepsy and anti-convulsant medications. In T.J. Bennet (Ed.), The neuropsychology of epilepsy. New York: Plenum Press.

Berry, D. & Broadbent, D. (1984). Interactive tasks and the implicit-explicit distinction. *British Journal of Psychology, 79*, 251-272.

Brierley, J.B. & Graham, D.I. (1984). Hypoxia and vascular disorders of the central nervous system. In J.H. Adams, J.A.N. Corsellis, L.W. Duchen (Eds.). *Greenfield's Neuropathology.* 4th ed. New York: John Wiley & Sons.

Broman, M., Kriengkrairut, S., McCarthy, C. & Rose, A. (1991). *A case of severe anterograde amnesia in an adult with onset at seven years of age as a result of presumed anoxic encephalopathy.* Poster presented at the 11th Annual conference of the New York Neuropsychology Group of the New York Academy of Sciences, March 10, 1990.

Broman, M., Kriengkrairut, S., McCarthy, C. & Rose, A. (1994). *A case of severe* *anterograde amnesia in an adult with onset at seven years of age as a result of presumed anoxic encephalopathy.* manuscript in preparation.

Brooks, D. N., & Baddeley, A. (1976). What can amnesic patients learn? *Neuropsychologia, 14.* 111-122.

Butters, N. (1984). Alcoholic Korsakoff's syndrome: An update. *Seminars in Neurology, 4,* 226-224.

Butters, N., Wolfe, J., Martone, M., Granholm, E., & Cermak, L.S. (1985). Memory disorders associated with Huntington's disease: Verbal recall, verbal recognition,and procedural memory. *Neuropsychologia, 23,* 729-743.

Cermak, L.S. (1976). The encoding capacity of a patient with amnesic due to encephalitis. *Neuropsychologia, 14,* 311-326.

Cermak, L.S. (1982). The long and short of it in amnesia. In L.S. Cermak (Ed.). *Human memory and amnesia.* (pp. 43-60) Hillsdale, NJ: Erlbaum.

Cermak, L.S., Butters, N., & Goodglass, H. (1973). Role of verbal mediation in the performance of motor skills by Korsakoff patients. *Perceptual Motor skills, 37,* 259-262.

Cermak, L.S., Butters, N. & Moreines, J. (1974). Some analysis of the verbal encoding deficit of alcoholic Korsakoff patients. *Brain and Language, 1,* 141-150.

Cermak, L.S., Talbot, N., Chandler,K., & Wolbarst, L.R. (1985). The perceptual priming phenomenon in amnesia. *Neuropsychologia, 23,* 615-622.

Claparède, E. (1911). Recognition et moiité. *Archives de Psychologie, 11,* 79-90.

Cohen, N.J. (1984). Preserved learning capacity in amnesia: Evidence for multiple memory systems. In L.R. Squire and N. Butters (Eds.). *Neuropsychology of memory* (pp. 83-103). N.Y.: Guilford Press.

Cohen, N.J., Eichenbaum, H. DeAcedo,, B.S., & Corkin, s. (1985). Different memory systems underlying acquisition of procedural and declarative knowledge. In D.S. Olton, E. Gamzu & S. Corkin (Eds.), *Memory dysfunctions: An integration of animal and human research from preclinical and clinical perspectives* (pp. 54-71.). New York: Annals of the New York Academy of Sciences.

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.

Cooper, J.A. & Flowers, C.R. (1987). Children with a history of acquired aphasia: Residual language and academic impairments. *Journal of Speech and Hearing Disorders, 52,* 251-262.

Corkin, S. (1965). Tactually guided maze learning in man: Effects of unilateral cortical excisions and bilateral hippocampal lesions. *Neuropsychologia, 3,* 339-351.

Corkin, S. (1968). Acquisition of motor skill after bilateral medial temporal lobe excision. *Neuropsychologia, 6,* 255-265.

Corkin, S. (1984). Lasting consequences of bilateral medial temporal lobectomy: Clinical course and experimental findings in H.M. *Seminars in Neurology, 4,* 249-245.

Corkin, S. (1993, April). *Memory and the hippocampus: H.M. revisited.* Paper presented at the American Academy of Neurology, New York, NY.

Corkin, S., Cohen, N.J., Sullivan, E.V., Clegg, R.A., Rosen, T.J. & Ackerman, R.H. (1985). Analyses of global memory impairments of different etiologies. In D.S. Olton, E. Gamzu & S. Corkin (Eds.), *Memory dysfunctions: An integration of animal and human research from preclinical and clinical perspectives* (pp. 11-40). New York: Annals of the New York Academy of Sciences.

Damasio, A.R. (1985). Frontal lobes. In K.M. Heilman and E. Valenstein (Eds.). *Clinical Neuropsychology.* (pp. 339-402). New York: Oxford University Press.

Damasio, A.R., N.R., Eslinger, P.J., Damasio, H., Van Hoesen, G.W., & Cornell, S. (1985). Multimodal amnesic syndrome following bilateral temporal and basal forebrain damage. *Archives of Neurology, 42,* 252-260.

Darlington, R.B., & Carlson, P.M. (1987). *Behavioral statistics: Logic and methods.* New York: The Free Press.

Daum, I., Channan, S., & Canavar, A. (1989). Classical conditioning in patients with severe memory problems. *Journal of Neurology and Neurosurgery Psychiatry, 52,* 47-51.

Davis, M. (1986). Pharmacological and anatomical analysis of fear conditioning using the fear-potentiated startle paradigm. *Behavioral Neuroscience, 100,* 814-824.

Diamond, R. & Rozin, P. (1984). Activation of existing memories in the amnesic syndrome. *Journal of Abnormal Psychology, 93,* 98-105.

Eichenbaum, H., Cohen, N.J., Otto, T., Wibble, C. (1991). Memory representation in the hippocampus: Functional domain and functional organization. In L.R. Squire, N.M. Weinberger, G. Lynch, J.L. McGaugh (Eds.). *Memory: Organization and locus of change*. (pp.163-204). New York: Oxford University Press.

Friedman, R.B, & Albert, M.L. (1985). Alexia. In K.M. Heilman and E. Valenstein (Eds.). *Clinical Neuropsychology*. (pp. 49-74). New York: Oxford University Press.

Gabrieli, J.D.E., Keane, M.M., & Corkin, S. (1987). Acquisition of problem-solving skills in global amnesia. *Society for Neurosciences Abstracts, 13*, 1455.

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

Gardner, H., Boller, F., Moreines, J., & Butters, N. (1974). Retrieving information from Korsakoff patients: Effects of categorical cues and reference to the task. *Cortex, 12*, 163-175.

Glisky, E. (1992). Computer-assisted instruction for patients with traumatic brain injury: Teaching of domain-specific knowledge. *Journal of Head Trauma Rehabilitation, 7*, 1-12.

Glisky, E., Schacter, D.L. (1989). Models and methods of memory rehabilitation. In F. Boller and J. Grafman (Eds.), *Handbook of Neuropsychology, Volume 3*. Elsevier.

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

Gollin, E.S. (1960). Developmental studies of visual recognition of incomplete objects. *Perceptual Motor Skills, 11*, 289-298.

Graf, P. & Mandler, G. (1984). Activation makes words more accessible, but not necessarily more retrievable. *Journal of Verbal Learning and Verbal Behavior, 25*, 553-568.

Graf, P., Mandler, G. & Haden, P.E. (1982). Simulating amnesic symptoms in normals. *Science, 218*, 1243-1244.

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,* 385-395.

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.

Haist, F., Musen, G. & Squire, L.R. (1991). Intact priming of words and nonwords in amnesia. *Psychobiology, 19,* 275-285.

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

Hirst, W. (1982). The amnesic syndrome: Descriptions and explanations. *Psychological Bulletin, 91,* 435-460.

Jackson, A. & Morton, J. (1984). Facilitation of auditory word recognition. *Memory and Cognition, 12,* 568-574.

Jacoby, L.L. & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 3,* 306-340.

Jacoby, L.L., Woloshyn, V., & Kelly, C. (1989). Becoming famous without being recognized: Unconscious influences of memory produced by dividing attention. *Journal of Experimental Psychology: General, 118,* 115-125.

Janowsky, J.S., Shimamura, A.P. & Squire, L.R. (1989). Source memory impairment in patients with frontal lobe lesions. *Neuropsychologia, 27,* 1043-1056.

Johnson, M.K., Kim, J.K. & Risse, G. (1985). Do alcoholic Korsakoff syndrome patients acquire affective reactions? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 22-36.

Kinsbourne, M. & Wood, F. (1975). Short-term memory processes and the amnesic syndrome. In D. Deutsch, J.A. Deutsch (Eds.). *Short-term memory.* (pp. 257-292). New York: Academic Press.

Knowlton, B.J., Gluck, M.A., & Squire, L.R. (1993). Probalistic category learning in amnesia. *Society for Neurosciences Abstracts.*

Knowlton, B.J., Ramus, S.J., & Squire, L.R. (1992). Intact artificial grammar learning in amnesia: Dissociation of classification learning and explicit memory for specific instances. *Psychological Science, 3,* 172-179.

Knowlton, B.J., & Squire, L. R. (1993). The learning of categories: Parallel brain systems for item memory and category knowledge. *Science, 262,* 1747-1749.

Knowlton, B.J., & Squire, L. R. (1994). The information acquired during artificial grammar learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 79-91.

Kolb, B. & Whishaw, I.Q. (Eds.) (1985). *Fundamentals of human neuropsychology.* Second Edition. New York: W.H. Freeman.

Korsakoff, S. S. (1889). Etude médico-psychologique sur une des maladies de la mémoire. *Révue Philosophique, 28,* 501-530.

Kunst-Wilson, W.R. & Zajonc, R.B. (1980). Affective discrimination of stimuli that can not be recognized. *Science, 207,* 557-558.

Ledoux, J.E. (1987). Emotion. In J.M. Brookhart & V.B. Mountcastle (Eds.). *Handbook of physiology: The nervous system v. higher functions of the nervous system.* (F. Plum Vol. Ed., pp. 419-460). Bethesda, MD: American Physiological Society.

Lehmkuhle, S., Garzia, R.P., Turner, L. & Baro, J.A. (1992). The effects of uniformed field flicker on visual evoked potentials in children with reading disability. *Investigative Opthamology and Visual Science, 33, Suppl.,* 718.

Linn, M.A. & Petersen, A.C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, 56,* 1479-1498.

Livingstone, M.S., Rosen, G.D. Drislane, F.W. & Galaburda (1991). Physiolkogical and anatomical evidence for a magnocellular deficit in developmental dyslexia. *Proceedings of the National Academy of Sciences (USA), 88,* 7943-7947.

Loftus, E.F. (1979). The malleability of human memory. *American Scientist, 67.* 312-320.

Loftus, E.F., & Hoffman, H.G. (1989). Misinformation and memory: The creation of new memories. *Journal of Experimental Psychology: General, 118*, 100-104.

Lovegrove, W. (1993). Weakness in the transient visual system: A causal factor in dyslexia? In P. Tallal, A.M. Galaburda, R.R. Llinás, C.V. Euler (Eds.), Temporal Information processing in the Nervous System: Special Reference to Dyslexia and Dysphasia. (pp. 57-69). New York: Annals of the New York Academy of Sciences.

Macmillan, N.A. & Creelman, C. D. (1991). Detection theory: A user's guide. Cambridge: Cambridge University Press.

Mandler, G. (1980). Recognizing: The judgment of previous occurrence. *Psychological Review, 87*, 252-271.

Martone, M., Butters, N., Payne, M., Becker, J. & Sax, D.S. (1984). Dissociations between skill learning and verbal recognition in amnesia and dementia. *Archives of Neurology, 41*, 965-970.

Mayes, A.R., Meudall, P.R. & Neary, D. (1978). Must amnesia be caused by either encoding or retrieval disorders? In M.M. Gruneberg, P.E. Morris, & R.N. Sykes, (Eds.). *Practical aspects of memory*. (pp.712-719). London: Academic Press

Mayeux, R., Brandt, J., Rosen, J. & Benson, F. (1980). Interictal memory and language impairment in temporal lobe epilepsy. *Neurology, 30*, 120-125.

McIntyre, J.S. & Craik, F.I.M. (1987). Age differences in memory for item and source information. *Canadian Journal of Psychology, 41*, 175-192.

Meldrum, B.S. & Corsellis, J.A.N. (1984). Epilepsy. In J.H. Adams, J.A.N. Corsellis, L.W. Duchen (Eds.). *Greenfield's Neuropathology*. Fourth edition. New York: John Wiley.

Merzenich, M.M., Schreiner, C., Jenkins, W. & Wang, X. (1993). Neural mechanisms underlying temporal integration, segmentation, and input sequence representation: Some implications for the origin of learning disabilities. In P. Tallal, A.M. Galaburda, R.R. Llinás, C.V. Euler (Eds.), Temporal Information processing in the Nervous System: Special Reference to Dyslexia and Dysphasia. (pp. 1-22). New York: Annals of the New York Academy of Sciences.

Milner, B. (1962). Les troubles de la mémoire accompagnant des lésions hippocampiques bilatérales. In *Physiologie de l'hippocampe*. Paris:Center National de la Recherche Scientifique.

Milner, B. (1965). Visually guided maze learning in man: Effects of bilateral hippocampal, bilateral frontal, and unilateral cerebral lesions. *Neuropsychologia, 3,* 317-338.

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.

Mishkin, M. & Delacour, J. (1975). An analysis of short-term visual memory in the monkey. *Journal of Experimental Psychology: Animal Behavior Processes, 1,* 326-334.

Mishkin, M. (1978). Memory in monkeys severely impaired by combined but not by separate removal of amygdala and hippocampus. *Nature, 273,* 297-298.

Mortensen, E.L. (1980). The effects of partial information in amnesic and normal subjects. *Scandinavian Journal of Psychology, 21,* 75-82.

Moscovitch, M. (1982). Multiple dissociations of function in amnesia. In L.S. Cermak (Ed.). *Human memory and amnesia.* (pp. 337-370). Hillsdale, NJ: Erlbaum.

Murdoch, B.E., & Ozanne, A.E. (1990). Linguistic status following acute cerebral anoxia in children. In B.E. Murdoch (Ed.), *Acquired Neurological Speech/Language Disorders in Children.* (pp. 177-198). New York: Taylor and Francis.

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

Musen, G., Shimamura, A.P., & Squire, L.R. (1990). Intact text-specific reading skill in amnesia. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 1068-1076.

Musen, G. & Squire, L.R. (1991). Normal acquisition of novel verbal information in amnesia. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 1095-1104.

Neely, J.H., & Payne, D.G. (1983). A direct comparison of recognition failure rates for recallable names in episodic and semantic memory tests. *Memory & Cognition, 11,* 161-171.

Nissen, M.J. & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology, 19,* 1-32.

Nissen, M.J., Willingham, D. & Hartman, M. (1989). Explicit and implicit remembering: When is learning preserved in amnesia. *Neuropsychologia, 27*, 341-352.

O'Connor, M., & Cermak, L.S. (1987). Rehabilitation of organic memory disorders. In M.J. Meier, A.L. Benton, L. Diller (Eds.). *Neuropsychological Rehabilitation*. (pp. 260-279). New York: Guilford Press.

Olton, D.S. (1983). Memory functions and the hippocampus. In W. Siefert (Ed.). *Neurobiology of the hippocampus*. New York: Academic Press.

Olton, D.S. & Papas, B.C. (1979). Spatial memory and hippocampal function. *Neuropsychologia, 17*, 669-682.

Ostergaard, A.L. (1987). Episodic, semantic, and procedural memory in a case of amnesia at an early age. *Neuropsychologia, 25*, 341-357.

Ostergaard. A.L.(1994). Dissociations between word priming effects in normal subjects and patients with memory disorders: Multiple memory systems or retrieval? *The Quarterly Journal of Experimental Psychology. 47A* in press.

Petersen, S.E., Fox, P.T., Posner, M.I., Mintum, M., & Raichle, M.E. (1988). Positron emission tomographic studies of the cortical anatomy of single-word processing. *Nature, 331*, 585-589.

Packard, M.G., Hirsh, R, & White, N.M. (1989). Differential effects of fornix and caudate nucleus lesions on two radial maze tasks: Evidence for multiple memory systems. *Journal of Neuroscience, 9*, 1465-1472.

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

Penfield, W. & Milner, B. (1958). Memory deficit produced by bilateral lesions in the hippocampal zone. *American Medical Association Archives of Neurology and Psychiatry, 79*, 475-497.

Posner, M.I. & Keele, S.W. (1968). On the genesis of abstract ideas. *Journal of Experimental Psychology, 77*, 353-363.

Posner, M.I. & Keele, S.W. (1970). Retention of abstract ideas. *Journal of Experimental Psychology, 83*, 304-308.

Press, G.A., Amaral, D.G. & Squire, L.R. (1989). Hippocampal abnormalities in amnesic patients revealed by high-resolution magnetic resonance imaging.

Nature, 341, 54-57.

Rall, T.W. & Schleifer, (1990). Drugs effective in the therapy of the epilepsies. In A.G. Gilman, T.W. Rall, A.S. Nies, & P. Taylor (Eds.). *The Pharmacological Basis of Therapeutics.* 436-462. Eighth edition. New York: Pergamon Press.

Reber, A.S. (1989). Implicit learning and tacit knowledge. *Journal of Experimental Psychology: General, 118,* 219-235.

Reber, A.S. (1992). The cognitive unconscious: An Evolutionary perspective. *Consciousness and Cognition, 1,* 93-133.

Reber, A.S. (1993). *Implicit learning and tacit knowledge: An essay on the cognitive unconscious.* NY : Oxford University Press.

Reber, A.S. & Lewis, S. (1977). Toward a theory of implicit learning: The analysis of the form and structure of a body of tacit knowledge. *Cognition, 5,* 333-361.

Reber, A.S., Walkenfeld, F.F., & Hernstadt, R. (1991). Implicit and explicit learning: Individual differences and I.Q. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 888-896.

Reber, P.J., & Kotovsky, K. (1992). Learning and problem solving under a memory load: Implicit and explicit processes in problem solving. Unpublished manuscript.

Roediger, H. (1990a). Implicit memory: A commentary. *Bulletin of the Psychonomic Society, 28,* 273-380.

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

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

Roediger, H., Weldon, M.S., & Stadler, M.L. (1992). Direct comparison of two implicit memory tests: Word fragment and word stem completion. *Journal of Experimental Psychology: Learning, Memory and Cognition, 18,* 1251-1259.

Rose, A., & Broman, M. (1994). *Amnesia with onset in childhood.* [Summary]. Paper presented at neurology grand rounds, State University of New York Health Science Center at Brooklyn, Brooklyn, NY.

Rubinsky, E.W., & Brandt, J. (1986). Amnesia and criminal law: A clinical overview. *Behavioral Sciences and the Law, 4*, 27-46.

Ryle, G. (1949). *The concept of mind.* London: Hutchinson.

Salmon, D.P., & Butters, N. (1987). Recent developments in learning and memory: Implications for the rehabilitation of the amnesic patient. In M.J. Meier, A.L. Benton, L. Diller (Eds.). *Neuropsychological Rehabilitation.* (pp. 280-293). New York: Guilford Press.

Scarborough, D.L., Cortese, C. & Scarborough, H. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 1-17.

Sidman, M., Stoddard, L.T., & Mohr, J.P. (1968). Some additional quantitative observations of immediate memory in a patient with bilateral hippocampal lesions. *Neuropsychologia, 6*, 245-254.

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. (1986). On the relation between genuine and simulated amnesia. *Behavioral Sciences and the Law, 4*, 47-64.

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

Schacter, D.L. (1989) Memory. in M.I. Posner (Ed.). *Foundations of cognitive science.* Cambridge: MIT Press.

Schacter, D.L. (1990). Perceptual representation systems and implicit memory: Toward a resolution of the multiple memory systems debate. In A. Diamond (Ed.). *The development and neural bases of higher cognitive functions.* (pp. 543-571). New York: New York Academy of Sciences.

Schacter, D.L., Cooper, L.A., Tharan, M., & Rubens, A.B. (1990). Preserved priming of novel objects in patients with memory disorders. *Journal of Cognitive Neuroscience, 3*, 117-130.

Schacter, D.L., & Graf, P. (1986). Preserved memory in amnesic patients: Perspectives from research on direct priming. *Journal of Clinical and Experimental Neuropsychology, 8*, 727-743.

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

Schacter, D.L., Kaszniak, A.W., Kihlstrom, J.F., & Valdiserri, M. (1991). The relation between source memory and aging. *Psychology and Aging, 6,* 559-568.

Schacter, D.L., McGlynn, S.M., Milberg, W.P. & Church. B.A. (1993). Spared priming despite impaired comprehension: Implicit memory in a case of word-meaning deafness. *Neuropsychology, 7,* 107-118.

Schank, J.C. & Wimsatt, W.C. (1987). Generative entrenchment and evolution. In A. Fine & P. Machamer (Eds.), PSA 1986: Proceedings of the meetings of the Philosophy of Science Association. (pp.33-60). East Lansing, MI : Philosophy of Science Association.

Scoville, W.B. (1954). The limbic lobe and memory in man. *Journal of Neurosurgery, 11,* 64.

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

Shepard, R.N. & Meltzer, J. (1971). Mental rotation of three dimensional objects. *Science, 171,* 701-703.

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

Shimamura, A.P., Janowsky, J.S., & Squire, L.R. (1990). Memory for the temporal order of events in patients with frontal lobe lesions and amnesic patients. *Neuropsychologia, 28, 8.* 803-813.

Shimamura, A.P. & Squire, L.R. (1984). Paired associate learning and priming effects in amnesia: A neuropsychological study. *Journal of Experimental Psychology: General, 11,* 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. (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.

Sommer, W. (1880). Erkrankung des Ammonshorns als aetiologisches Moment der Epilepsie. Archiv für Psychiatrie und Nervenkrankheiten 10, 631-675.

Squire, L.R. (1982). Comparisons between forms of amnesia: Some deficits are unique to Korsakoff's syndrome. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8,* 560-571.

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

Squire, L.R. (1992). Memory and the hippocampus: A synthesis from findings with rats, monkeys, and humans. *Psychological Review, 99,* 195-231.

Squire, L.R., & Frambach, M. (1990). Cognitive skill learning in amnesia. *Psychobiology, 18,* 109-117.

Squire, L.R., & McKee, R. (1992). Influence of prior events on cognitive judgments in amnesia. *Journal of Experimental Psychology: Learning, Memory and Cognition, 18,* 106-115.

Squire, L.R., Ojemann, J.G., Miezin, F.M., Petersen, S.E., Videen, T.O. & Raichle, M.E. (1992). Activation of the hippocampus in normal humans: a functional anatomical study of memory. *Proceedings of the National Academy of Science, 89,* 1837-41.

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

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

Squire, L.R., Wetzel, C.S., & Slater, P.C. (1978). Anterograde amnesia following ECT: An analysis of the beneficial effect of partial information. *Neuropsychologia, 16,* 339-347.

Squire, L.R. & Zola-Morgan, S. (1988). Memory: Brain systems and behavior. *Trends in Neurosciences, 11,* 170-175.

Squire, L.R. & Zola-Morgan, S. (1991). The medial temporal lobe memory system. *Science, 253,* 1380-1386.

Squire, L.R. & Zola-Morgan, S. & Chen, K. (1988). Human amnesia and animal models of amnesia: Performance of amnesic patients on tests designed for the monkey. *Behavioral Neuroscience, 102,* 210-221.

Starr, A. & Phillips, L. (1970). Verbal and motor memory in the amnesic syndrome. *Neuropsychologia, 8,* 75-88.

Sutherland, R.W. & McDonald, R.J. (1990). Hippocampus, amygdala, and memory deficits in rats. *Behavioral Brain Research, 37,* 57-79.

Thapar, A. & Greene, R.L. (1994). Effects on level of processing on implicit and explicit tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 671-679.

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.). *Organization of memory.* New York: Academic Press.

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. (1991). Concepts of human memory. In L.R. Squire, N.M. Weinberger, G. Lynch, J.L. McGaugh (Eds.). *Memory: Organization and locus of change.* (pp.3-44). New York: Oxford University Press.

Tulving, E. Hayman, G. & MacDonald, C. (1991). Long-lasting perceptual priming and semantic learning in amnesia: A case experiment. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 7,* 595-617.

Tulving, E. & Schacter, D.L. (1990). Priming and human memory systems. *Science, 247,* 301-396.

Tallal, P., Miller, S., & Fitch, R.H. (1993). Neurological Basis of speech: A case for the preeminence of temporal processing. In P. Tallal, A.M. Galaburda, R.R. Llinás, C.V. Euler (Eds.), Temporal Information processing in the Nervous System: Special Reference to Dyslexia and Dysphasia. (pp. 27-47). New York: Annals of the New York Academy of Sciences.

Talland, G.A. (1965). Deranged memory: A psychonomic study of the amnesic syndrome. New York: Academic Press.

Underwood, B.J. (1957). Interference and forgetting. *Psychological Review, 64,* 49-60.

Vandenburg, S. & Kuse, A.R. (1978). Mental rotations: a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills, 47,* 599-604.

Vandenburg, S. & Kuse, A.R. (1979). Spatial ability: A critical review of the sex-linked major gene hypothesis. In M. Wittig & A.C. Petersen (Eds.). *Sex-related differences in cognitive functioning.* (pp. 67-95). New York: Academic Press.

Victor, M., Adams, R.D. & Collins, G.H. (1989). *The Wernicke-Korsakoff syndrome and related neurological disorders due to alcoholism and malnutrition.* (2nd ed.). Philadelphia: F.A. Davis.

Victor, M. & Agamanolis, J. (1990). Amnesia due to lesions confined to the hippocampus: A clinical-pathological study. *Journal of Cognitive Neuroscience, 2,* 246-247

Volpe, B.T., & Hirst, W. (1983). The characterization of an amnesic syndrome following hypoxic ischemic injury. *Archives of Neurology, 40,* 436-440.

Warrington, E.K. (1982). The double dissociation of short and long-term memory deficits. In L. Cermak (Ed.), *Human Memory and Amnesia.* Hillsdale, N.J.: Erlbaum:

Warrington, E.K. & Weiskrantz, L. (1968). A new method of testing long-term retention with special reference to amnesic patients. *Nature, 217,* 972-974.

Warrington, E.K. & Weiskrantz, L. (1974). The effects of prior learning on subsequent retention in amnesic patients. *Neuropsychologia, 12,* 419-428.

Weiskrantz, L. & Warrington, E.K. (1979). Conditioning in amnesic patients. *Neuropsychologia, 17,* 187-184.

Wickens, D.D. (1972). Characteristics of word encoding. In A.W. Melton & E. Martin (Eds.). *Coding processes in human memory.* Washington, D.C: Winston & Sons.

Winocur, G., Kinsbourne, M., & Moscovitch, M. (1981). The effect of cuing on release from proactive interference in Korsakoff amnesic patients. *Journal of Experimental Psychology: Human Memory and Learning, 7, 56-65.*

Wiggins, E.C. & Brandt, J. (1988). The detection of simulated amnesia. *Law and Human Behavior, 12,* 57-78.

Winter, B. & Reber, A.S. (1994). Implicit learning and natural language acquisition. In N. Ellis (Ed.). *Implicit and explicit learning of languages.* London:

Academic Press.

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.

Wright, L. (1994). *Remembering Satan.* New York: Alfred A. Knopf.

Yakolev, P.T. & Lecours, A.R. (1967). The mylogenetic cycles of regional maturation of the brain. In A. Minkowski (Ed.), *Regional development of the brain in early life.* (pp. 3-70). Oxford: Blackwell.

Yapko, M.D. (1994). *True and false memories of childhood sexual trauma.* New York: Simon & Schuster.

Zaragoza, M.S. & Lane, S.M. (1994). Source misattributions and memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 934-945.

Zola-Morgan, S. & Squire, L.R. (1984). Preserved learning in monkeys with medial temporal lesions: Sparing of motor and cognitive skills. *Journal of Neuroscience, 4,* 1072-1085.

Zola-Morgan, S. & Squire, L.R. (1985). Medial temporal lesions in monkeys impair memory on a variety of tasks sensitive to human amnesia. *Behavioral Neuroscience, 99,* 22-34.

Zola-Morgan, S. & Squire, L.R.(1990). Neuropsychological investigations of memory and amnesia: Findings from humans and non-human primates. In A. Diamond (Ed.). *The development and neural bases of higher cognitive functions.* (pp. 434-436.). New York: New York Academy of Sciences.

Zola-Morgan, S., Squire, L.R., Alvarez-Royo, P. & Clower, R. (1991). Independence of memory functions and emotional behavior: Separate contributions of the hippocampal formation and the amygdala. *Hippocampus, 1,* 207-220.

Zola-Morgan, S., Squire, L.R., & Amaral, D.G. (1986). Human amnesia and the medial temporal region: Enduring memory impairment following a bilateral lesion limited to the CA1 field of the hippocampus. *Journal of Neuroscience, 6,* 2950-2967.

Zola-Morgan, S., Squire, L.R., & Amaral, D.G. (1989). Lesions of the amygdala that spare adjacent cortical regions do not impair memory or exacerbate the impairment following lesions of the hippocampal formation. *Journal of Neuroscience, 9,* 4355-4370.

Zola-Morgan, S., Squire, L.R., Rempel, N.L., Clower, R.P., & Amaral, D.G. (1992). Enduring memory impairment in monkeys after ischemic damage to the hippocampus. *Journal of Neuroscience, 12,* 2582-2596.

Zola-Morgan, S. & Squire, L.R. (1993). Neuroanatomy of memory. *Annual Review of Neuroscience, 16.* 547-563.