The Cognitive Mechanisms and Neural Substrates Underlying Repetition Priming

by

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Abstract

A growing body of neurophysiological evidence indicates that nondeclarative memory can be supported by the same neural circuits that are recruited to perform the task on which learning is being measured. The investigations of repetition priming presented in this thesis were motivated by a modified proceduralist theory: Repetition priming is a byproduct of the plasticity in information processing systems whose primary function is not nondeclarative memory. This theoretical orientation impels careful analysis of the processes engaged by the tasks in which learning is displayed as the best way to elucidate the cognitive and neural systems that support different examples of nondeclarative memory. The modified proceduralist approach affords greater analytic precision and greater predictive power than a memory systems approach, in which behavioral dissociations are interpreted as evidence for the existence of different memory systems. The research presented in Chapters 2 and 3 tested the hypothesis that two types of repetition priming, word-stem completion priming and perceptual identification priming, arise primarily from plasticity in discrete information processing systems. The experiments in Chapter 2 tested H.M. and normal control subjects with pre-1953 and post-1965 words, the latter because they were unfamiliar to H.M. Chapter 3 employed this same manipulation in a series of experiments with college students, using familiar and unfamiliar words. The experiments in Chapter 4 explored the phenomenon of pattern priming in Alzheimer's disease, producing data that characterize more fully the dynamic properties of this kind of learning, and exploring the boundary conditions of nonverbal perceptual nondeclarative learning in AD.

Writing is like the hair: the more you comb it, the more it shines.
Gustave Flaubert

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Publications

Refereed journals

Postle, B.R., Corkin, S., and Growdon, J.H. (1996). Intact implicit memory for novel patterns in Alzheimer's disease. Learning and Memory, **3**, 305-312.

Postle, B.R., Jonides, J., Smith, E., Corkin, S. Growdon, J.H. (1997). Spatial, but not object, delayed response is impaired in early Parkinson's disease. Neuropsychology, **11**, 171-179.

Postle, B.R., Locascio, J.J., Corkin, S. and Growdon, J.H. (in press). The time course of spatial and object learning in Parkinson's disease. Neuropsychologia.

Postle, B.R. and Corkin, S. (in revision). Manipulation of familiarity dissociates word-stem completion priming from perceptual identification priming, Memory & Cognition.

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Abstracts

Postle, B.R., Stern, C.E., Rosen, B.R., Corkin, S. (submitted). fMRI of Spatial and Nonspatial Visual Working Memory Reveals Differences in Posterior, but not Prefrontal, Cortex. Society for Neuroscience Abstracts. Submitted for Fall 1997 annual meeting.

Postle, B.R., Stern, C.E., Rosen, B., and Corkin, S. (1997). Whole-brain fMRI reveals differences in spatial and object working memory. Cognitive Neuroscience Society: Fourth annual meeting.

Kim, L.H., Postle, B.R., and Corkin, S. (1997). Verbal interference disrupts "object," but not spatial, working memory. Cognitive Neuroscience Society: Fourth annual meeting.

Postle, B.R., Growdon, J.H., and Corkin, S. (1996). Pattern priming, intact in Alzheimer's disease, reveals perceptual nondeclarative learning that is insensitive to encoding time. Society for Neuroscience Abstracts, **22**, 1123.

Hood, K.L., Postle, B.R., and Corkin, S. (1996). Habit learning in H.M.: Results from a concurrent discrimination task. Society for Neuroscience Abstracts, **22**, 1867.

Postle, B.R. and Corkin, S. (1996). Spatial, but not object, learning and memory are impaired in early Parkinson's disease. Abstracts of papers presented at the 1996 meeting on Learning & Memory, Cold Spring Harbor Laboratory, October 2-6, 1996, 6.

Postle, B.R. and Corkin, S. (1996). Word-stem completion priming and perceptual identification priming rely on two distinct mechanisms. Cognitive Neuroscience Society: Third annual meeting, 68.

Postle, B.R., Jonides, J., Smith, E., Corkin, S. and Growdon, J.H. (1995). Selective vulnerability of spatial delayed response in early Parkinson's disease. Society for Neuroscience Abstracts, **21**, 755.

Corkin, S., Postle, B.R., and Growdon, J.H. (1995). Alzheimer's disease patients show implicit learning of novel patterns. Society for Neuroscience Abstracts, **21**, 1444.

Postle, B.R., Corkin, S., and Growdon, J.H. (1995). Alzheimer's disease patients show implicit learning of novel patterns. Proceedings of the 8th Meeting of the International Study Group on the Pharmacology of Memory Disorders Associated with Aging, Zurich, Switzerland, 18 February 1995.

Postle, B.R. and Corkin, S. (1994) H.M. shows impaired word-stem completion priming with novel words. Society for Neuroscience Abstracts, **20**, 1289.

Postle, B.R., Corkin, S., and Growdon, J.H. (1993) Dissociation between two kinds of visual working memory in Parkinson's Disease. Society for Neuroscience Abstracts, **19**, 1002.

Non-refereed articles

Nitsch, R.M., Marinescu, V., Postle, B.R., Corkin, S., and Wurtman, R.J. (1995). Eighth Meeting of the International Study Group on the Pharmacology of Memory Disorders Associated with Aging, Zurich, Switzerland. February 17-19, 1995: The Neurobiology of Alzheimer's Disease. Amyloid, **2**, 204-212.

Nitsch, R.M., Postle, B., Marinescu, V., and Wurtman, R.J. (1995). Biological mechanisms in the pathogenesis and cure of AD. Drug News and Perspectives, **8**, 181-188.

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CHAPTER 1

Introduction

Taxonomies of human memory distinguish declarative (explicit) memory, conscious recollection of facts and past events, from nondeclarative (implicit) memory, the influence of previous experience on task performance without conscious referral to stored information (Graf and Schacter, 1985; Schacter, et al.; 1993, Zola-Morgan and Squire, 1990). Theoretical characterizations of this dichotomy include declarative vs. procedural memory (Cohen and Squire, 1980), memory vs. habit learning (Mishkin, 1984), declarative vs. nondeclarative memory (Zola-Morgan and Squire, 1990), and explicit vs. implicit memory (Graf and Schacter, 1985). Models positing yet other dichotomies of memory have been summarized by Richardson-Klavehn and Bjork (1988), Roediger and McDermott (1993), and Schacter (1987; Schacter et al., 1993). Declarative memory relies on the medial temporal-diencephalic system (Brown and Schäfer, 1888; Bechterew, 1900; Mishkin, 1992; Corkin, 1984; Corkin et al., in press; Murray, et al., 1993; Scoville and Milner, 1957; Squire, 1992). Many disparate mnemonic phenomena fall under the rubric of nondeclarative memory, including the acquisition of motor (Milner, 1962; Corkin, 1965; Milner et al., 1968; Corkin, 1968), and perceptual (Cohen and Squire, 1981) skills , perceptual learning (Warrington and Weiskrantz, 1968; Milner et al., 1968; Warrington and Weiskrantz, 1970; Schacter et al., 1991), learning with verbal stimuli in cued completion paradigms (Warrington and Weiskrantz, 1970; Graf et al., 1984), and learning in category exemplar production tasks (e.g., Gardner et al., 1973; Keane et al., 1997).

Although the neural substrates for these phenomena are not well defined, a growing body of neurophysiological evidence indicates that nondeclarative memory can be supported by the same neural circuits that are recruited to perform the task on which learning is being measured. For example, plastic changes in motor cortex parallel nondeclarative learning on motor skill learning tasks (Brashers-Krug et al., 1995; Grafton, 1995; Karni et al., 1995a), and plastic changes in visual cortex are associated with nondeclarative learning on a visual skill learning task (Karni et al., 1995b). The dissociation between declarative and nondeclarative memory derives in large part from studies of global amnesia, in which declarative memory is severely impaired, but nondeclarative memory can be intact, compared to the performance of healthy control subjects (Corkin, 1965; Corkin, 1968; Corkin, 1984; Milner, et al., 1968; Shimamura, 1993). The evidence to date suggests that every kind of nondeclarative memory depends upon brain areas outside the medial temporal-diencephalic system (but see Schacter et al. [1995]).

One type of nondeclarative memory, repetition priming, occurs when prior exposure to a stimulus biases or facilitates the processing of the stimulus on subsequent exposures. Repetition priming differs from other types of nondeclarative memory in that a single exposure to a stimulus is sufficient to produce learning. This thesis examines three kinds of repetition priming: word-stem completion (WSC) priming, perceptual identification (PI) priming, and pattern priming. The research presented here was motivated by the hypothesis that nondeclarative memory is a byproduct of the plasticity intrinsic to the central nervous system and, thus, that it can be observed in virtually any process that the central nervous system carries out (e.g., motor control, lexical search, visual perception). Illustrations of this idea are found in motor learning, in which regions of motor cortex can change their patterns of activation in association with improved performance of simple motor tasks (Brashers-Krug et al., 1995; Grafton et al., 1995; Karni et al., 1995a), and in visual perceptual skill learning, in which discrete regions of visual cortex can undergo plastic changes in concert with gradual improvement on a perceptual learning task (Karni et al., 1995b; Bertini et al., 1995). Although motor skill learning and visual skill learning each fit under the rubric of "skill learning" in taxonomies of memory (Squire, 1986), these two examples of nondeclarative memory are evidently supported by different brain regions.[1] Analogous to this neural dissociation, I will argue in the chapters that follow that different types of repetition priming, although revealed in tasks that share common methodological characteristics, can differ from one another in that they arise from the function of disparate information processing systems and are supported by disparate neural substrates. I believe that careful analysis of the processes engaged by the tasks in which repetition priming is displayed represents the best way to elucidate the cognitive and neural systems that support different examples of nondeclarative memory. The work presented in this thesis demonstrates that the task analysis approach affords greater analytic precision and greater predictive power than a memory systems approach, in which behavioral dissociations are interpreted as evidence for the existence of different memory systems. This task analysis approach has similarities with the proceduralist approach to memory theorizing, as described by Crowder (1993), and I will characterize it as a modified proceduralist approach. My modified approach diverges from strict proceduralist theorizing (Crowder, 1993) in that it asserts a neural and cognitive distinction between declarative and nondeclarative memory.

The theoretical premise of this thesis challenges the assumption by many researchers that most types of verbal repetition priming rely on a common system, or a common set of processing principles that are perceptually based (e.g., Roediger, 1990; Rajaram and Roediger, 1993; Squire et al., 1992; Schacter, 1994). Illustrative of these models (which I will refer to as "common-perceptual-mechanism" models) are the hypotheses of Squire and colleagues (Haist et al., 1991; Squire et al, 1992; Hamann and Squire, 1996), who suggest that visual repetition priming relies on transient change in perceptual circuits in posterior visual cortex, and of Schacter (e.g., Schacter, 1994), who proposes that a system of perceptual representation systems (PRS) supports learning in repetition priming tasks. (The data presented in this thesis are consistent with models positing a role for PRS in PI priming and pattern priming; see Chapter 5).

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[1] Sherry and Schacter (1987) have suggested that anatomical dissociation alone is neither necessary nor sufficient evidence to posit the existence of distinct memory systems. I will consider this issue in Chapter 5.

An important goal of contemporary cognitive neuroscience is identifying the regions of the adult brain that support different kinds of learning and memory, and understanding the mechanisms that underlie these plastic changes (Ungerleider, 1995). In an effort to understand the nature of the representations that support repetition priming phenomena, researchers have sought to map out the conditions under which subjects can or cannot demonstrate nondeclarative memory for novel information. Intact priming on a repetition priming test employing novel stimuli provides evidence that the priming phenomenon in question is supported by newly formed representations, and does not rely on premorbid mnemonic representations (Haist et al., 1991; Schacter, 1992). The research presented in Chapters 2 and 3 employs this logic to elucidate the representations that underlie nondeclarative learning with the WSC and PI tasks. Pattern priming, the focus of Chapter 4, is a paradigm that has been used to demonstrate intact learning with novel nonlinguistic stimuli in amnesic subjects (Gabrieli et al., 1990a; Musen and Squire, 1992; Verfaellie et al., 1992; Gooding et al., 1993; Gooding et al., 1994). The experiments with subjects with Alzheimer's disease (AD) that are presented here extend the earlier work by providing clues about the neural substrates that support this type of learning, by characterizing more fully the dynamic properties of this learning, and by exploring the boundary conditions of nonverbal perceptual nondeclarative learning in AD.

CHAPTER 2

Impaired Word-Stem Completion Priming but Intact Perceptual Identification Priming with Novel Words: Evidence from the Amnesic Patient H.M.

WSC priming is demonstrated when exposure to a word in a study list increases the likelihood that subjects will complete a three-letter stem to that word. Previous work has shown that severely amnesic subjects (including H.M.) show normal WSC priming with common nouns (e.g., [Gabrieli et al., 1994; Graf et al., 1984; Warrington and Weiskrantz, 1970]). The sparing of WSC priming in amnesia indicates that the medial temporal-diencephalic system is not critical for WSC priming. Subjects with Alzheimer's disease (AD), however, whose pathology relatively spares primary sensory and motor cortices but disrupts high-order cortex in the temporal and parietal lobes (Arnold, et al., 1991), can be impaired on tests of WSC priming (Shimamura et al., 1987; Salmon et al., 1988; Heindel, et al., 1989; Keane et al., 1991; Gabrieli et al., 1994; Chertkow et al., 1996; but see Downes et al., 1996), suggesting that high-order (heteromodal) cortical areas may be an important neural substrate for this type of priming.

PI priming is demonstrated when subjects can identify previously studied words or pictures at shorter exposure durations than unstudied words or pictures. Research by Keane and colleagues (Keane et al., 1995) suggests that PI priming is mediated by posterior cortical areas: A patient with lesions in bilateral peristriate cortex, but with relatively intact heteromodal cortex in the parietal lobes, showed impaired performance on this task. In contrast, subjects with AD perform normally on tests of PI priming (Keane et al., 1991), suggesting that peristriate visual cortex can support learning on this task. Subsequently, Gabrieli et al. (Gabrieli et al., 1995) reported impaired PI priming, but largely spared WSC priming, in a patient with a right occipital-lobe lesion.

Some researchers have posited that WSC priming, like PI priming, is a perceptually based phenomenon (Haist et al., 1991; Hamann and Squire, 1996, Rajaram and Roediger, 1993; Roediger, 1990; Schacter, 1992). For example, Squire and colleagues (Haist et al.; 1991, Squire et al., 1992) have argued that this kind of priming relies on transient change in perceptual circuits in posterior visual cortex when the task is administered in the visual modality. This view is consistent with reports from PET studies of decreased blood flow in occipital cortex when subjects performed WSC priming tasks (Squire et al., 1992; Petersen and Fiez, 1993; Buckner, et al., 1995; Schacter et al., 1996). These findings have been interpreted as suggestive that the processing of repeated presentations of a stimulus requires less neural activity than was required for the initial processing. Similarly, Schacter (Schacter, 1992) has proposed that WSC priming is supported by a presemantic perceptual representation system that is housed in posterior cortex. Investigators in our laboratory have argued, however, that in addition to perceptual mechanisms, WSC priming relies on a lexical-semantic memory system localized in temporal and parietal circuits (Keane et al., 1991; Gabrieli et al., 1994).

An early model of WSC priming, the trace activation model, proposed a lexical explanation of WSC priming (Diamond and Rozin, 1984; Graf et al., 1984; Shimamura and Squire, 1984). According to this view, activation of the mnemonic representations of words in a study session (Atkinson and Juola, 1974; Rozin, 1976; Morton, 1970) would bias subsequent WSC by increasing the probability that the studied stimulus would be retrieved during the test session (a "hot tubes" effect [Rozin, 1976]). Recently, Bowers (1996) has argued that "modification" is a more appropriate characterization of this theorized mechanism than "activation," and I will use the term "modification" in this report. This modification hypothesis would predict that amnesic subjects would need a premorbid representation of a word in order to prime with that word in a WSC priming test.

The modification explanation of WSC priming may seem inconsistent with recent reports of intact repetition priming in H.M. and other amnesic patients with novel stimuli, including priming of perceptual grouping tendencies with novel geometric patterns (Gabrieli et al., 1990; Musen and Squire, 1992; Gooding et al., 1993; Postle et al., 1996 [and Experiment 8]), PI priming with pseudowords (e.g., [Gabrieli et al., 1990; Haist et al., 1991; Keane et al., 1994]), and priming of "possible/impossible" judgments with novel objects (Schacter et al., 1991). These examples of intact repetition priming in amnesia employ stimuli that cannot have been represented in memory prior to the testing session, and therefore must arise from the establishment of new perceptual representations by the study episode (for examples of this argument, see (Smith and Oscar-Berman, 1990; Haist et al., 1991; Schacter 1992; Squire et al., 1992). However, the repetition priming paradigms that reveal intact priming in amnesia with novel stimuli -- PI, patterns completion, 3-dimensional object judgment -- all rely on low-level[2] perceptual processing of stimuli.

A considerable body of evidence suggests that the mechanisms underlying WSC priming have an important lexical component. Reports of robust cross-modal WSC priming (e.g., Bassili et al., 1989; Carlesimo, 1994; Gabrieli et al., 1995; Graf et al., 1985; Marsolek et al., 1992) and of robust WSC priming when studied words were inferred by the subjects from clues or from definitions (i.e., the studied words were neither visually nor auditorily presented) (Bassili, 1989; Schwartz, 1989), indicate that the WSC priming effect does not rely exclusively on perceptual continuity of stimuli between study and test[3]. Another study has suggested that semantic elaboration of words at study enhances the WSC priming effect (Carlesimo, 1994) (although other groups have reported the opposite result [e.g., Roediger et al., 1992; Hamann and Squire, 1996]). Finally, the evidence of impaired WSC priming (but intact PI priming) in AD (Keane et al., 1991; Gabrieli et al., 1995), is

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[2] Throughout this document I make the assumption that a meaningful functional distinction can be drawn between *low-level* visual processing -- early stages of visual processing in striate and peristriate cortex that treats meaningful and nonmeaninful letter strings comparably -- and *high-level* processing, in which visual information interacts with mental representations (e.g., when the visual percept of a word triggers access of the lexical representation of that word).

[3] The results from this type of study also indicate that WSC priming can have an important perceptual component, because changing case, font, or modality between study and test does reduce significantly the WSC priming effect (e.g., [Graf et al., 1985; Bassili et al., 1989; Marsolek et al., 1992; Carlesimo, 1994; Gabrieli et al., 1995]).

consistent with the idea that WSC priming depends upon non-perceptual (perhaps lexical) processes. The empirical evidence reviewed in this paragraph is consistent with a modification model of WSC priming.

In an approach orthogonal to this debate, Gabrieli, Keane and colleagues (Gabrieli et al., 1994; Keane et al., 1991; Keane et al., 1992; Monti et al., 1996) have argued that there are at least two distinct classes of repetition priming phenomena, *perceptual* and *conceptual*, whose operations are governed by distinct mechanisms operating in distinct brain areas. This position stems from dissociations among different repetition priming tasks revealed in tests of memory impaired patients. (See, also, Blaxton [1989] for a discussion of the perceptual/conceptual distinction.) The evidence reviewed above suggests that the perceptual/conceptual model is a more accurate characterization of repetition priming than a strong interpretation of either the acquisition or the modification models. The perceptual/conceptual formulation does not specify the mechanisms that underlie different types of priming, however, and thus lacks predictive power. In this chapter and in Chapter 3 I will seek to make a theoretical extension of the perceptual/conceptual model by specifying with more precision the cognitive processes that support two different types of repetition priming.

The hypothesis that many examples of nondeclarative memory are byproducts of the plasticity that is intrinsic to much of the nervous system leads one to analyze carefully the processes (cognitive and/or neural) that are engaged by a task if one seeks to understand the mechanisms that support nondeclarative learning expressed through that task. In the case of WSC priming, the modification model is compelling because it takes into account the processes engaged by the WSC priming task: When asked to complete a three-letter stem to a word, a subject must engage in a lexical search and select an exemplar from among the lexical entries in this word-initial cohort (Marslen-Wilson and Tyler, 1981). Because lexical search is an important component of the WSC task, it is reasonable to hypothesize that the priming that can be expressed in the WSC task results from the biasing of this lexical search procedure. The modification model posits just such a mechanism.

In order to test the modification hypothesis, I studied WSC priming in the amnesic patient H.M., using words that came into common usage after the onset of his anterograde amnesia, and thus were novel to him. This hypothesis predicted that H.M. would fail to show learning in this experiment because pre-existing lexical representations of the test stimuli would be necessary for priming to occur. In contrast to the modification hypothesis, perceptually oriented explanations of WSC priming (Rajaram and Roediger, 1993; Roediger et al., 1992; Schacter, 1992; Squire et al., 1992) would predict that amnesic subjects should perform normally on a test of WSC priming with unfamiliar words, because low-level perceptual mechanisms would be engaged equally by familiar and by unfamiliar letter strings. All previous experiments finding intact WSC priming in amnesic subjects (e.g., (Gabrieli et al., 1994; Graf et al., 1984; Warrington and Weiskrantz, 1970) used words that were familiar to the subjects. Therefore, the results of these experiments are equally consistent with the modification model and with the perceptual models. The present experiment was designed to provide a definitive test between these two models because they predicted different results.

Experiment 1.a.: Word-Stem Completion Priming with Post-1965 Words

One earlier study has been performed to test a modification model by investigating WSC with unfamiliar words in amnesia and dementia (Diamond and Rozin, 1984). This study employed a cued-recall procedure, and found impaired performance with pseudowords in the memory-impaired group. These results have no bearing on models of WSC *priming,* however, because control subjects in this study undoubtedly used declarative memory retrieval strategies when performing the WSC test (Haist et al., 1991). The present study therefore represents the first methodologically clean test of the modification model of WSC priming.

Methods

Subjects

Two amnesic subjects, H.M. and P.N., and 10 NCS participated in this study (Table 1). H.M. underwent bilateral medial temporal lobectomy in 1953, at age 27, to alleviate intractable epilepsy (see Corkin, 1984 ; Corkin et al., in press) for a summary of H.M.'s clinical and research history). P.N. was diagnosed with herpes simplex encephalitis in 1992, at age 58. In 1994 (approximately four months prior to testing), seizure activity and an associated hypoxic episode resulted in damage to both medial temporal-lobe regions; this episode has been linked to the onset of dense anterograde amnesia in P.N. The severity of P.N.'s amnesia was comparable to that of H.M. as indexed by the difference between the Full Scale I.Q. and the Memory Quotient or General Memory Score. For P.N. the difference was 38 (WAIS - R, F.S.I.Q. = 121; WMS - R, General Memory Score = 83; tested 5/94), and for H.M. the difference was 38.6 (Wechsler-Bellevue, II, F.S.I.Q. = 111.6; WMS, Memory Quotient = 73; tested 10/90). Like H.M., P.N. denied any familiarity with the testing procedures and apparatus despite repeated testing. None of the NCS had a history of neurological or psychiatric disorders, and all had a normal neurological examination at the time of testing. All subjects were born in the United States and were native English speakers.

Stimuli

The stimuli were 156 words that first appeared after 1965 in *Webster's Third New International Dictionary* or in *The American Heritage Dictionary* (assembled from the publication *12,000 Words: A supplement to the Webster's Third New International Dictionary*) (see Appendices). These words were presumed to be novel to H.M. because they came into popular usage after the onset of his amnesia. In contrast, these words were presumed to be familiar to P.N. because her amnesia was of recent onset. The words were chosen so as to be familiar to any native English speaker who had lived in the United States and had obtained a high school diploma there. The three-letter stem corresponding to each of the words could be completed to at least five common words. Of the 156 stimuli, 120 were divided randomly into six lists of 20 words each; each list was balanced for word length and for alphabetical

Table 1. Subject Characteristics for Experiment 1.a.

Group	Number of Subjects [M/F]	Age (Mean [and *SD*] for NCS)	Education (Mean [and *SD*] for NCS)	Vocabulary subsection of WAIS-R (Mean [and *SD*] for NCS)	Snellen Acuity (Range for NCS)
NCS	10 [4/6]	68 [2.8]	12.4 [.8]	11.6 [1.3]	20/20 - 20/30
H.M.	1 (M)	67	12	10	20/40
P.N.	1 (F)	60	16	16	20/30

position of the first letter. The mean frequency of the words was 16.9 per 44 million[4], and the mean length was 7.1 letters. The remaining 36 words were used as filler words. Each NCS, as well as P.N., was tested for priming on two lists, and for cued recall on two others; for the NCS, the lists were counterbalanced for both tests. H.M. was tested for priming using four of the lists, and for cued recall using the remaining two. To reduce the likelihood that NCS could invoke declarative memory strategies, we: a) used long study and test lists; b) gave only brief presentation(s) of stimuli at the study phase, and just single presentations of each stem at test phase; and c) administered all nondeclarative memory tests before testing declarative memory. (H.M. was administered two additional priming tests after taking the Cued Recall and Vocabulary Recognition Tests.)

Procedure

Subjects participated in two priming tests, followed by a test of cued recall and a test of recognition of the definitions of the words in our stimulus set (H.M. participated in additional testing, as discussed below). The WSC Priming Tests and WSC Cued Recall Test differed only in the instructions that were delivered immediately before the WSC portion of each test.

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[4] Word frequency was determined using a database of every wire story issued by the Associated Press during the period February, 1988 - December, 1988, using a stochastic part-of-speech analyzer (Church, 1988). We used this database rather than more conventional published corpora because the post-1965 words do not appear in corpora that were published several years prior to the the appearance of these words.

Study Session
Subjects read words aloud as they were presented one-by-one for 5 sec. each on a computer screen. If a subject mispronounced a word, the experimenter gave the correct pronunciation and instructed her to repeat the correct pronunciation aloud. Half of the words of a 20-word list occurred once, and half occurred three times. We included this manipulation of study-repetitions because if has been used successfully in previous studies to draw inferences about the processes underlying the creation and strengthening of memory traces (Feustel et al., 1983; Salasoo et al., 1985). Additionally, three filler words (taken from the remaining 36 stimuli) were inserted at the beginning and three filler words at the end of each list to control for primacy and recency effects, giving a total of 46 stimuli in each study list.

WSC Priming Test 1
Approximately 1 min following the study session, subjects viewed 40 three-letter stems one-by-one on a computer screen. Half of the stems corresponded to words in the study list, and half to words in another of the six lists that served as unstudied words. Word stems corresponding to the two lists were interleaved randomly. Subjects were asked to complete each stem with the first word that came to mind. Each stem remained on the screen until the subject responded, and response latency was recorded.

WSC Priming Test 2
The stimuli, study procedure, and test procedure for WSC Priming Test 2 were identical to those for WSC Priming Test 1, except that the studied and unstudied lists were reversed. In this way, each of the two lists served as a priming list and as an unstudied control list for each subject. This test followed WSC Priming Test 1 by at least 4 weeks (with the exception of subject P.N., who, 24 hours after WSC Priming Test 1, performed WSC Priming Test 2). This delay minimized the likelihood that NCS would remember the procedure from the previous test, and thus minimized the likelihood that they would employ declarative retrieval strategies.

WSC Cued Recall Test
The study procedure was identical to that for the priming tests, except that new lists were used. The testing procedure differed from the priming tests in one respect only: After the study procedure, subjects were instructed to remember the words from the study list and to complete the word stems to the studied words. This test followed WSC Priming Test 2 by at least 4 weeks (with the exception of P.N., who performed the WSC Cued Recall Test 24 hours after WSC Priming Test 2).

Vocabulary Recognition Test
Immediately following the WSC Cued Recall Test, subjects were administered a 4-alternative forced-choice vocabulary test, measuring their understanding of the meanings of the 120 words used as test stimuli. An example of a

Vocabulary Recognition Test question is: "***biathlon:*** *a) a marathon held annually in Boston; b) a river with two tributaries; c) a mansion with columns and arches characteristic of Roman architecture; d) a composite athletic contest consisting of cross-country skiing and rifle sharp shooting.*"

Additional Testing with H.M.
To gather more data from H.M., he received WSC Priming Test 3 and WSC Priming Test 4 after he performed the WSC Cued Recall Test and the Vocabulary Recognition Test. For these additional priming tests, we used the two word lists that had not been used previously in priming tests with H.M., but had been included in the Vocabulary Recognition Test, which preceded the administration of WSC Priming Test 3 by 14 weeks, and the administration of WSC Priming Test 4 by 21 weeks. H.M. also performed a test of Recall-of-Definitions of all 114 words used in this experiment. In this test, he viewed each word individually and gave the definition of that word. He performed this test the day after he performed WSC Priming Test 3, i.e., 7 weeks before he performed WSC Priming Test 4.

Scoring
We calculated priming and cued recall scores as the number of stems completed to studied words minus the baseline score of stems completed to unstudied words from the word list (completions to words other than those on the studied and unstudied list were not scored). In order to assess the subjects' familiarity with the words, the experimenter noted whether they pronounced the words in the study lists correctly, before receiving assistance from the experimenter.

After the experiment was concluded, we discarded six words from the analysis, one from each list. Most NCS (and in some cases H.M.) completed stems to five of these words in several unstudied trials, and thus decreased our confidence that we were measuring nondeclarative memory for these words in priming trials. We discarded an additional word when we realized, after the administration of the tests, that the three-letter stem of that word was itself a word ("codon").

Results
Vocabulary

NCS achieved 84.8% correct on the Vocabulary Recognition Test, which was significantly higher than H.M.'s score of 43.9% ($t = 19.12$; $p = .0001$)[5], and significantly lower than P.N.'s score of 95.6% ($t = -5.13$; $p < .001$). NCS recognized significantly more definitions of correctly pronounced (89.3% correct) than of mispronounced (73.4% correct) words ($t = 2.64$; $p < .05$). When

[5] Throughout this document I follow the convention that statistical significance is achieved with the demonstration that the probability of Type I error is less than or equal to .05. On occasion, *p* values that are slightly larger (but always < .1) are accepted as "marginally" significant if the result was predicted *a priori*.

subsequently asked to provide the definitions of the 114 words used in this experiment, H.M. correctly gave the definition of 13.2% of them.

WSC priming vs. WSC cued recall

In order to establish that NCS completed more stems to studied words on the WSC Cued Recall Test than on the WSC Priming Tests, we analyzed the NCS data with a factorial repeated measures ANOVA, with the factors of session (WSC Priming Test 1, WSC Priming Test 2, Cued Recall) and repetitions-at-study (0, 1, 3); the dependent measure was percentage of stems completed to target words. A significant Session x Repetition interaction (F = 6.24; $p < .001$) indicated that the difference between the number of completions to target words for 0 repetitions versus 1 and 3 repetitions for the Cued Recall session was significantly greater than that for the Priming sessions (F = 23.96; $p < .001$). Similarly, repetition of words at study had a stronger effect on the WSC Cued Recall Test than on the Priming Tests. The mean score for the 3-repetition study condition was significantly higher than that for the 1-repetition study condition (F = 6.31; $p < .05$) The mean scores for the 0-repetition condition, i.e., the unstudied condition, were virtually identical across sessions. We then performed separate ANOVAs to examine performance in the Priming Tests and the Cued Recall test separately.

WSC priming

NCS showed a repetition priming effect by completing 16.1% more word stems to studied words than to unstudied words (mean total completions to studied words, collapsed across sessions and repetitions, = 20.8%; mean total completions to unstudied words, collapsed across sessions, = 4.8%) (Figure 1). A factorial repeated-measures ANOVA with the factors of session (WSC Priming Test 1 and WSC Priming Test 2) and repetitions-at-study (0, 1, 3) revealed a main effect of repetition (F = 20.71; $p < .0001$). The absence of a main effect of session and of an interaction indicated that priming levels did not differ between WSC Priming Test 1 and WSC Priming Test 2, so subsequent comparisons of NCS with the amnesic subjects in this study employed NCS priming scores collapsed across the two priming tests. NCS completed significantly more stems to studied words (1 and 3 repetitions) than to unstudied words (0 repetitions) (F = 45.09; $p < .0001$) and significantly more stems to words with 3 repetitions than with 1 (F = 9.48; $p < .05$).

An additional analysis of NCS performance examined the percentage of stems completed to studied words by whether the words were pronounced correctly during the Study Session. Paired t tests indicated that completion of stems to correctly pronounced 1-repetition words (mean completion score = 16.7%) was significantly greater than completion of stems to mispronounced 1-repetition words (mean completion score = 3.3%), (t = 2.34; $p < 0.05$), and that completion of stems to correctly pronounced 3-repetition words (mean completion score = 32.6%) was significantly greater than completion of stems to mispronounced 3-repetition words (mean completion score = 0%), (t =

13.00; p = .0001) (Figure 2). Many of the 3-repetition words that were mispronounced by NCS were mispronounced more than once: NCS made a total of 90 pronunciation errors over the total of 900 single-word reading trials of three repetition words; 51% of the errors occurred on just one exposure of the word; 28% of errors occurred on two exposures of the word; and 21% of errors occurred on three exposures of the word.

H.M. completed only 1.3% more word stems to studied than to unstudied words (mean total completions to studied words = 2.6%; mean total completions to unstudied words = 1.3%) (Figure 1). A t test indicated that H.M.'s mean priming score did not differ from 0 (t = .4; p > .7). We compared H.M.'s performance with the performance of NCS by subtracting H.M.'s mean priming score from the score of each NCS, and then performing a t-test to determine whether the mean of these difference scores was significantly different from 0. This analysis indicated that the mean net priming score of NCS differed significantly from the value for H.M. (t = 6.58; p = .0001). H.M. mispronounced a study word on 49% of the 228 reading trials presented to him in the course of his testing.

P.N. completed 15.8% more stems to studied than to unstudied words (mean total completions to studied words = 18.4%; mean total completions to unstudied words = 2.6%) (Figure 1). The mean net priming score for P.N. did not differ significantly from the mean score for NCS. She did not mispronounce any words.

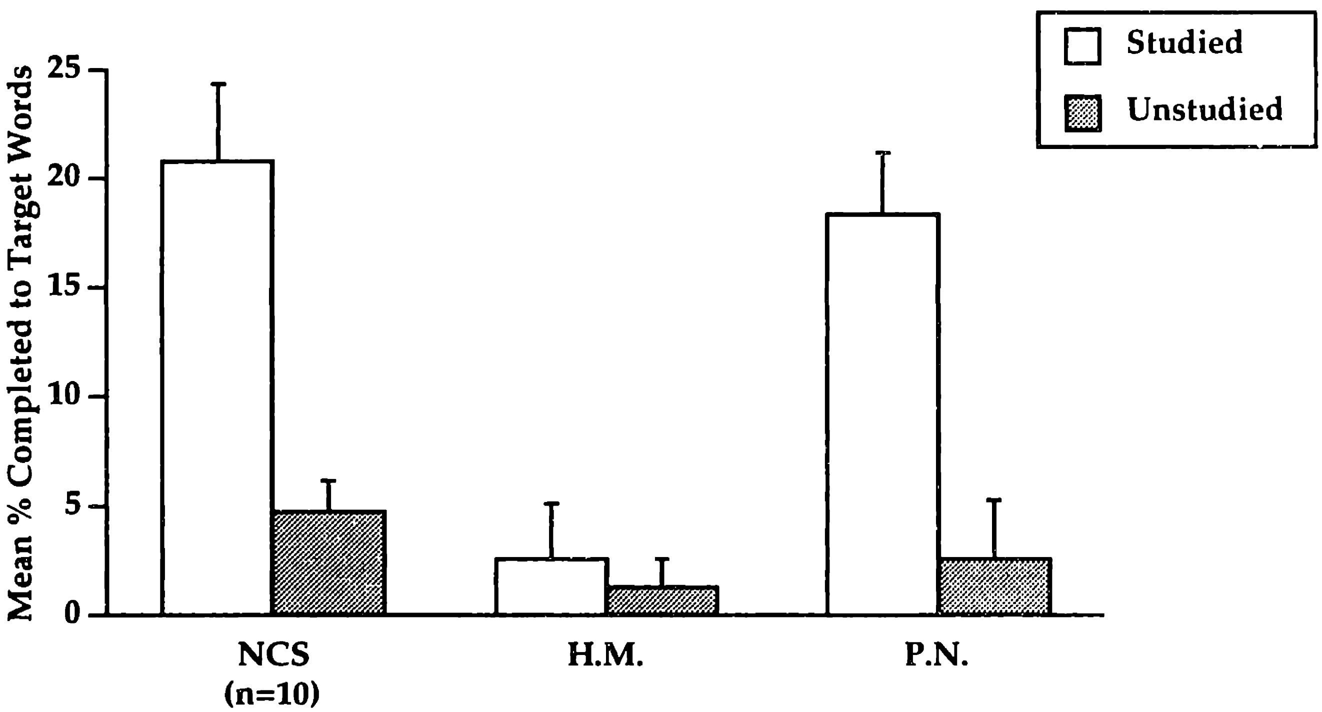

Figure 1. WSC priming performance with post-1965 words by NCS, P.N., and H.M.; H.M. was significantly impaired compared to NCS.

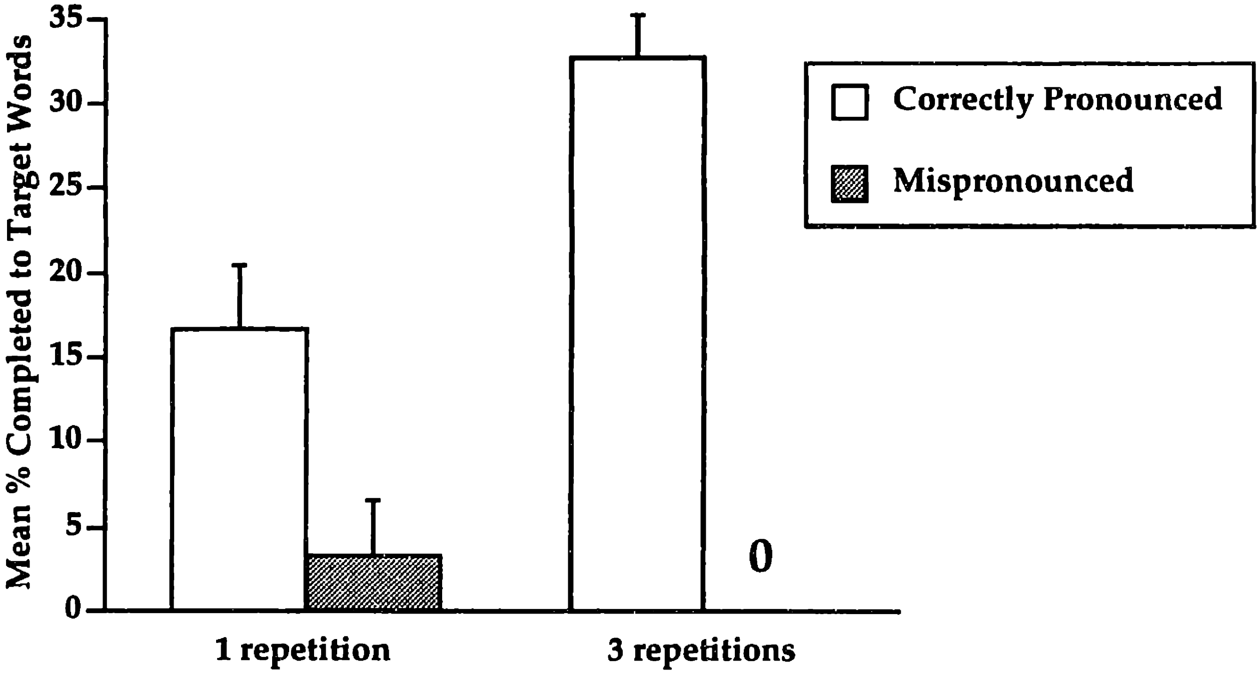

Figure 2. Post-1965 WSC priming: NCS correctly completed significantly more correctly pronounced one-repetition words than mispronounced one-repetition words, and they correctly completed significantly more correctly pronounced three-repetition words than mispronounced three-repetition words.

WSC Cued Recall

On the WSC Cued Recall Test, NCS benefited from study by completing 35.3% more word stems to studied words than to unstudied words (mean total completions to studied words, collapsed across repetition, = 39.5%; mean total completions to unstudied words = 4.2%) (Figure 3). A factorial repeated-measures ANOVA examining performance on the WSC Cued Recall Test with the factor of repetitions-at-study (0, 1, 3) revealed a main effect of repetition ($F = 45.79$; $p < .0001$). NCS completed significantly more stems to studied words (1 and 3 repetitions) than to unstudied words (0 repetitions) ($F = 55.48$; $p = .0001$), and significantly more stems to words with 3 repetitions than with 1 ($F = 32.93$; $p < .0005$).

NCS correctly completed 3-letter stems to 57.9% of correctly pronounced 3-repetition words and to 30.2% of mispronounced words; they correctly completed 3-letter stems to 24.1% of correctly pronounced 1-repetition words and to 10% of mispronounced 1-repetition words. During the WSC Cued Recall Test only 5 NCS made pronunciation errors while studying 1 repetition words, and only 8 NCS made pronunciation errors while studying 3 repetition words, so significance tests comparing the results for correctly pronounced vs. mispronounced words were not carried out.

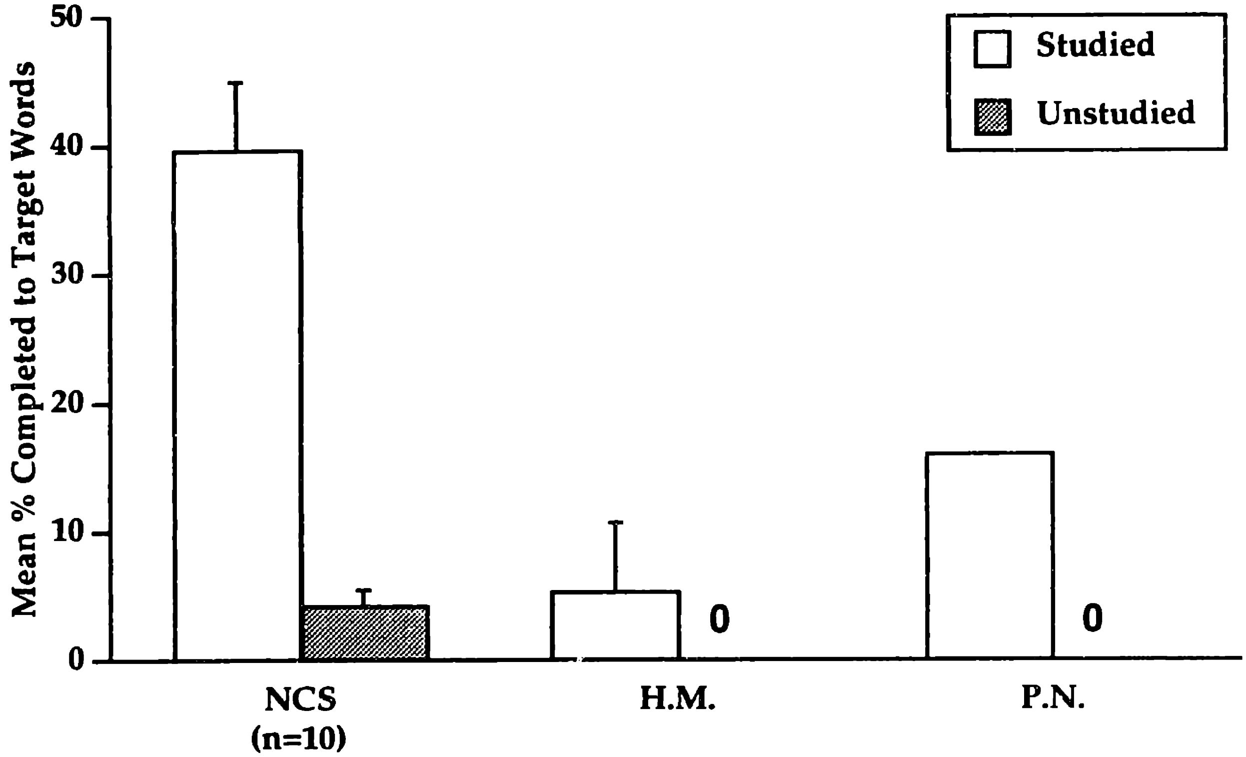

Figure 3. Post-1965 cued recall performance of NCS, P.N., and H.M.; H.M. and P.N. were significantly impaired compared to NCS.

H.M. showed only a slight advantage of study on the WSC Cued Recall Test, correctly completing 5.3% more word stems to studied words than to unstudied words (mean total completions to studied words = 5.3%, mean total completions to unstudied words = 0%) (Figure 3). P.N. completed 15.8% more word stems to studied words than to unstudied words (total completions to studied words = 15.8%; total completions to unstudied words = 0%) (Figure 3). A nonparametric Wilcoxon Signed Rank test indicated that H.M.'s value and P.N.'s value were significantly lower than that for NCS ($p < .005$ for both).

Discussion

We tested the hypothesis that WSC priming in amnesia depends upon modification of premorbid representations of the stimuli with which priming is tested, and thus that it depends upon lexical memory. Using words that entered the dictionary a minimum of 12 years after the onset of H.M.'s amnesia, we compared his priming performance to that of a group of NCS and to a patient with amnesia of recent onset (P.N.). H.M. did not prime with the post-1965 material, as contrasted with robust priming for the NCS and for P.N. P.N.'s normal WSC priming performance indicates that dense amnesia alone cannot explain H.M.'s results. H.M. was also significantly impaired relative to NCS on a declarative memory test of WSC, as well as on a test of the meanings of the 114 words in the post-1965 stimulus set. His multiple-choice Vocabulary Recognition Test score of 43.9%, which was well above chance, illustrates his use of his intelligence when he didn't know the meanings of words. For example, when asked to define the words, he said *biathlon* is : "A Greek word for a foot race between two people;" and that *psychedelia* is: "Study of the mind -- *psyche* is the mind, *delia* is the study of it." These responses suggest that, when he did not know the meaning of a word, H.M. attempted to derive it by analyzing the components of the word. We believe that H.M.'s score of 13.2% correct on the test of recall of the definitions of the 114 post-1965 words is a more accurate index of his familiarity with them. P.N. was also impaired relative to NCS on the WSC Cued Recall Test. She scored significantly higher than NCS on the Vocabulary Recognition Test, a reflection of her higher overall intelligence.

The results of Experiment 1.a. were consistent with the modification hypothesis of WSC priming, but inconsistent with strong versions of perceptual hypotheses of WSC priming. We concluded from this result that modification of pre-existing lexical representations is partly responsible for the WSC priming effect, and necessary for this effect to be expressed. This conclusion was prompted by our task analysis, which indicated that the WSC task requires subjects to engage in lexical retrieval. Because our conclusions relied so heavily on the failure of H.M. to display WSC priming with post-1965 words, however, it was important for us to establish that this result was caused by our experimental manipulation of word familiarity, rather than by a simple inability on the part of H.M. to produce priming in the WSC task. This important control experiment constituted Experiment 1b.

Experiment 1.b.: Word-Stem Completion Priming with Pre-1953 Words

Although previous research had demonstrated that H.M. can exhibit normal WSC priming with words that are familiar to him (Gabrieli et al., 1994), I sought with this experiment to confirm that H.M. could show WSC priming with familiar words that were matched for length and frequency with the post-1965 words used in Experiment 1.a., and presented with the same testing procedures. The modification model and the perceptual models of WSC priming each predicted that H.M. would show normal WSC priming with words for which he *did* have a premorbidly acquired lexical representation.

Methods

Subjects

H.M., and 10 NCS participated in this study (Table 2). None of the NCS had a history of neurological or psychiatric disorders, and all had a normal neurological examination at the time of testing. All subjects were born in the United States and were native English speakers. Four of the NCS had participated in Experiment 1.a.

Table 2. Subject Characteristics for Experiment 1.b.

Group	Number of Subjects [M/F]	Age (Mean [and *SD*] for NCS)	Education (Mean [and *SD*] for NCS)	Vocabulary sub-section of WAIS-R (Mean [and *SD*] for NCS)	Snellen Acuity (Range f or NCS)
NCS	10 [4/6]	68.9 [2.4]	11.8 [.7]	12.0 [1.9]	20/20 - 20/30
H.M.	1 (M)	67	12	10	20/40

Stimuli

The stimuli were 80 words that had been in common usage in the United States long before 1953 (first appearance of each word was determined from its entry in *Webster's Third New International Dictionary* or The *American Heritage Dictionary*) (Appendix B). The words were matched closely for frequency (mean = 16.7/44 million) and length (mean = 6.8 letters) to the post-1965 words used in Experiment 1.a., and were judged to be familiar to any native English speaker who had lived in the United States and had obtained a high school diploma there. These words were presumed to be familiar to H.M. because he would have learned them before the onset of his amnesia. The three-letter stem corresponding to each of the words could be completed to at least five common words. The 80 words were divided randomly into four lists of 20 words each; each list was balanced for word length and for alphabetical position of the first letter. An additional 24 "pre-1953" words were used as filler words. Each NCS was tested for WSC priming with one list.

Procedure

The procedures for administering and scoring the WSC priming test were identical to those used for the WSC priming tests in Experiment 1.a.

Additional Testing with H.M.

To gather more data from H.M., he was administered 10 WSC priming tests.

Vocabulary Recognition Test

Immediately following the WSC priming test, subjects were administered a 4-alternative forced-choice vocabulary test, measuring their understanding of the meanings of the 80 words used as test stimuli. H.M. was administered the test upon completion of the 10th WSC priming test.

Results

Vocabulary

NCS achieved a mean score of 97.5% correct on the Vocabulary Recognition Test; H.M. achieved 80.2% correct. Although H.M.'s score with pre-1953 words was lower than the mean score for NCS, it was considerably higher than his score for post-1965 words, confirming that the majority of the pre-1953 words were familiar to him.

WSC priming

NCS showed a repetition priming effect by completing significantly more word stems to studied words (mean = 28.5%) than to unstudied words (mean = 10%) ($t = 6.2$, $p < .0005$) (Figure 4). H.M. showed a repetition priming effect by completing significantly more word stems to studied words (mean = 35%) than to unstudied words (mean = 14.2%) ($t = 4.3$, $p < .01$) (Figure 4). The mean net priming score of NCS (18.5%) did not differ significantly from the value for H.M. (20.8%) (Wilcoxon Rank Sums test $p > .6$).

Discussion

The results of Experiment 1.b. confirmed that H.M. shows normal WSC priming when tested with words that are familiar to him. This result strengthens our conclusions from Experiment 1.a. that WSC priming arises from the modification of lexical representations because H.M. showed normal WSC priming on words for which he had a lexical representation,

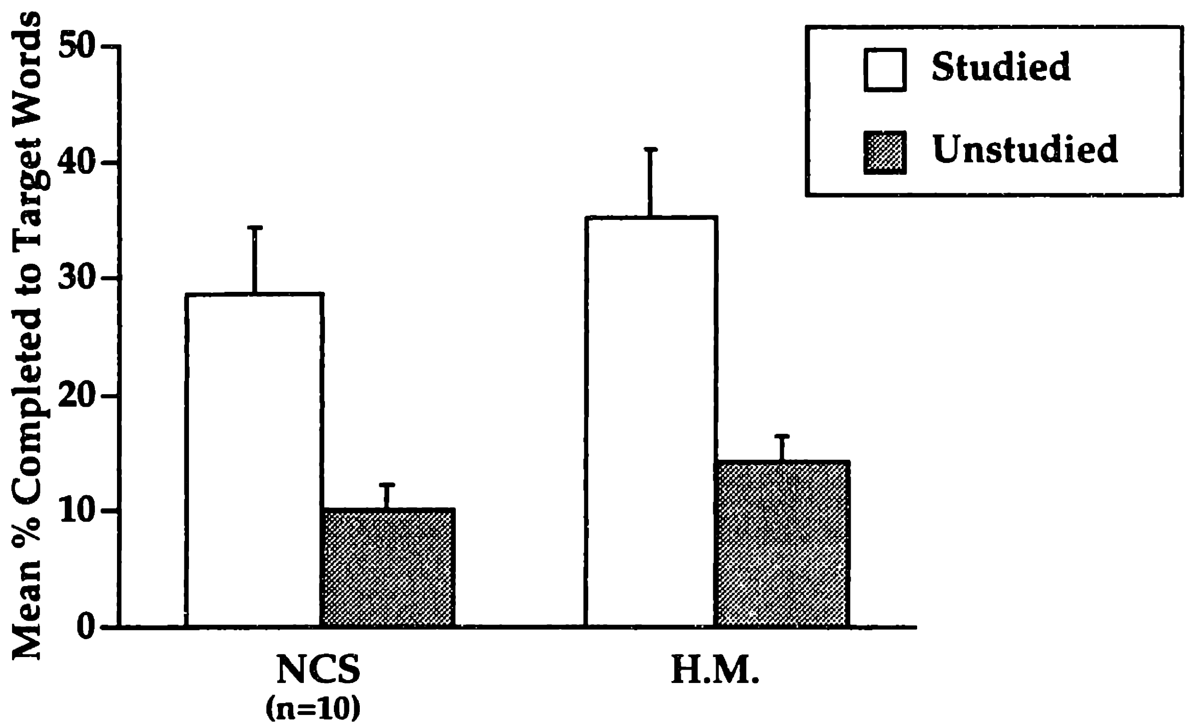

Figure 4. WSC priming performance with pre-1953 words was comparable for NCS and H.M.

and showed no WSC priming with words for which he lacked a lexical representation.

Experiment 2: Perceptual Identification Priming with pre-1953 and post-1965 words

After finding a clear dissociation in H.M.'s WSC priming performance with pre-1953 and post-1965 words, we sought to measure his performance with the same words using a repetition priming task that relied on perceptual mechanisms: perceptual identification (PI) priming. Task analysis suggested to us that the PI task, in which subjects are asked to identify visually presented words whose perception is rendered difficult by a short exposure duration or visual noise, places heavy demands on early (pre-lexical) stages of the visual system. We reasoned that, because subjects participating in such a test typically either perceive the word immediately or cannot discern it at all, an active, deliberate search of the lexicon is never required. We hypothesized, therefore, that the learning that is expressed in PI priming experiments results from plastic changes that occur at a locus different from the locus of the WSC priming effect. The preponderance of published data supports the view that the learning observed in PI priming experiments depends on unambiguously perceptual mechanisms. For example, the PI priming effect is largely abolished when the modality of stimulus presentation is changed between study and test (e.g., Jacoby and Dallas, 1981; Keane et al., 1991; Rajaram and Roediger, 1993). Additionally, intact PI priming is found in normal and memory impaired subjects tested with pseudowords (e.g., Soloman and Postman, 1952; Whitlow and Cebollero, 1989; Rueckl, 1990; Cermak et al., 1991; Haist et al., 1991; Bowers, 1994; Keane et al., 1994; Bowers, 1996; Postle and Corkin, in revision [and Chapter 3]), indicating that the learning is supported by the biasing of pre-semantic perceptual mechanisms (i.e., the learning *cannot* take place at the level of lexical representations). Preserved PI priming by H.M. with the post-1965 words used in Experiment 1.a. would demonstrate a dissociation from WSC priming, and would be consistent with our hypothesis that the two types of priming rely on different mechanisms. Intact PI priming with pseudowords by H.M. in earlier experiments from our laboratory (Gabrieli et al., 1990a; Keane et al., 1995) led us to predict that H.M. should show robust PI priming with post-1965 words.

Methods

Subjects

Two amnesic subjects, H.M. and P.N., and 19 NCS participated in this study (Table 3). None of the NCS had a history of neurological or psychiatric disorders, and all had a normal neurological examination at the time of testing. All subjects were born in the United States and were native English speakers. Three of the NCS had participated in Experiments 1.a. and 1.b.; 2 had participated in 1.a., and 2 had participated in 1.b.

Table 3. Subject Characteristics for Experiment 2.

Group	Number of Subjects [M/F]	Age (Mean [and SD] for NCS)	Education (Mean [and SD] for NCS)	Vocabulary sub-section of WAIS-R (Mean [and SD] for NCS)	Snellen Acuity (Range for NCS)
NCS	19 [10/9]	68.5 [2.8]	12.4 [.9]	11.4 [1.3]	20/20 - 20/30
H.M.	1 (M)	69	12	10	20/40
P.N.	1 (F)	62	16	16	20/30

Design

The experimental design of Experiment 2 was formally identical to the design of the WSC priming experiments, with the exception that each subject was tested in both conditions (pre-1953 and post-1965), permitting repeated measures analyses of the data. Testing sessions for NCS were separated by at least 4 hr for all subjects, and the order of testing was counterbalanced across NCS. Additional dependent measures for the PI priming experiment were threshold exposure duration by word length ("short" words were < or = 8 letters; "long" words were > 8 letters) and priming score by word length. The Vocabulary Recognition Test was not administered in Experiment 2.

Materials

The word stimuli used in Experiment 2 were the same as those in the previous experiments.

Procedure

Apparatus. The words were presented sequentially using 2 high speed random access slide projectors (Kodak EktaPro 7000) fitted with high speed shutters (Gerbrands G1166) that were controlled by a computer (Macintosh IIcx). The words were flashed on a rear projection screen in a dimly lit room. Word stimuli were presented in the same font and the same size as in Experiments 1.a. and 1.b., as well as at the same level contrast. Each subject sat approximately 24 in from the screen.

Threshold Session. This session determined for each subject the stimulus exposure duration that would result in 50% correct identification performance with unstudied words. An unstudied baseline performance of approximately 50% correct would insure that the performance of subjects on the PI priming test would not be contaminated by floor or ceiling effects. Subjects were told that each word would appear briefly on the screen, and they were asked to read each word aloud. Each trial consisted of a fixation cross (+) signaling the beginning of the trial (1000 msec), followed by a 900 msec blank interval, followed by a word presented for a variable exposure duration, followed immediately (ISI = 0 msec) by a pattern mask of 250 msec in duration. During the Threshold Session we determined the 50% correct performance exposure threshold for each subject at each word length (long and short) by using an adaptive staircase procedure (the Step Method [Simpson, 1989]). After each trial, the experimenter entered a score of "correct" or "incorrect" into the computer that controlled the shutters on the slide projectors, and the Step Method algorithm governing the computer used this information to adjust the exposure duration for the subsequent trial. Each block contained 45 trials, and the mean of the results of two threshold blocks yielded the exposure duration that was used to test subjects during the Priming Test. Two threshold blocks used short words and two used long words. The word stimuli used in the Threshold Session in both conditions were pre-1953 words (different from the words used in the priming tests). Because these words were familiar to H.M., the Step Method underestimated his 50% thresholds for words in the post-1965 condition, particularly for long words. We determined the long word exposure duration for H.M. in the post-1965 condition by increasing the estimate from the Threshold Session by approximately 190%, a factor that we determined during pilot testing.

Study Session. The study session was identical to that described in Experiment 1.

Priming Test. Subjects were shown 40 words one-by-one on the screen using the same presentation procedure as in the Threshold Session. The exposure durations for short words and for long words had been determined for each subject during the Threshold Session. Half of the words in each test had been presented in the previous study session. The other half were words that had not been studied. The priming effect was the number of correctly identified studied words minus the baseline score of correctly identified unstudied words. We discounted data from tests in which baseline scores were < 20% or >80% correct in order to avoid floor and ceiling effects. In these instances, subjects were retested (with a different test form) during a later session.

Additional testing for amnesic subjects

To increase the number of observations with the amnesic subjects, H.M. was tested 11 times in the pre-1953 condition and 14 times in the post-1965 condition; P.N. was tested 4 times in the pre-1953 condition and 4 times in the post-1965 condition. For each subject, each testing session was separated by at least 6 hours, and each test in the same condition was separated by at least one day. Because H.M.'s testing was performed during 4 separate multi-day visits to our laboratory over a period of 13 months, I considered each of his PI priming scores to be an independent observation for the purpose of our analyses.[6]

Results

Threshold Session

All subjects required longer exposure durations in the post-1965 condition than in the pre-1953 condition. Analysis of the NCS mean exposure durations with a 2 x 2 mixed factors ANOVA revealed main effects of condition ($F(1, 18) = 9.9$; $p > .005$) and word-length ($F(1, 18) = 29$; $p < .001$), and a tendency toward an interaction ($F(1,18)) = 3$; $p = .1$) (Table 4). H.M.'s mean exposure duration data were also submitted to a 2 x 2 mixed factors ANOVA, that revealed main effects of condition ($F(1,24) = 120.3$; $p > .0001$) and word-length ($F(1,24) = 116.4$; $p < .0001$) and an interaction ($F(1,24)) = 70.9$; $p < .0001$). Because P.N. was only tested 4 times in each condition, her data were not analyzed with inferential statistics (Table 4).

Table 4. Mean Exposure durations for Experiment 2 (msec)

	Pre-1953		Post-1965	
Group	Short [*SD*]	Long [*SD*]	Short *SD*	Long [*SD*]
NCS	53.1 [19.8]	75.5 [36.4]	68.5 [27.8]	99.7 [49.5]
H.M.	74.1 [19.7]	99.9 [40.3]	126.6 [29.5]	336.1 [66.4]
P.N.	25.8 [3.0]	33 [7.4]	49.5 [7.9]	69.0 [15.1]

Priming Test

The NCS, in both conditions, correctly identified more studied words (pre-1953 mean = 75.2%; post-1965 mean = 69.2%) than unstudied words (pre-1953 mean = 50.5%; post-1965 mean = 35.3%) (Figure 5). The priming effect was significant: A 2 x 2 between- and within-factors ANOVA, with the factors of study-type and condition, revealed a main effect of study ($F(1, 18) = 154.9$; $p < .0001$), a main effect of condition ($F(1, 18) = 7.6$; $p < .05$), and an interaction ($F(1, 18) = 5.2$; $p = .05$. Planned comparisons confirmed that there was a significant priming effect with pre-1953 words (24.7%) (t (18) = 7.8; $p < .0001$) and with post-1965 words (33.9%) (t (18) = 11.8; $p < .0001$). A post-hoc t test

[6] The autoregressive-moving average (ARMA; Locascio et al., in press) analysis that could be used to remove the autocorrelative component from multiple scores obtained from one subject requires a minimum of 50 observations.

indicated that the source of the interaction was the difference in baseline scores for the two conditions (post-1965 baseline score = 37.2; pre-1953 baseline score = 49.5) (t (18) = 3.4); p < .005) (Figure 5). The difference in baseline scores, which also appeared in the data of the two amnesic subjects, will be considered in the Discussion section.

The NCS data also revealed a significant effect of repetitions-at-study (pre-1953: 3 repetitions = 81.8%, 1 repetition = 68.7%; post-1965: 3 repetitions = 7[illegible], 1 repetition = 64.7%): A 2 x 2 between- and within-factors ANOVA with factors of condition and repetitions-at-study revealed a main effect of repetition (F(1,18) = 5.8; p < .05), a borderline significant effect of condition (F(1,18) = 3.3; p = .09), and no interaction.

Pronunciation errors during the Study Session were made by 10 NCS in the pre-1953 condition (total of 20 words mispronounced), and by 13 NCS in the post-1965 condition (total of 44 words mispronounced). In the pre-1953 condition, NCS correctly identified 79.8% of studied words that were pronounced correctly at study, and identified correctly 60.4% of studied words that were mispronounced at study; in the post-1965 condition, NCS correctly identified 78% of studied words that were pronounced correctly at study, and 46.6% of studied words that were mispronounced at study. These percentages, however, are skewed by the small number of observations in the "mispronounced" category. In the pre-1953 condition, 7 of the 10 subjects who mispronounced at study made just one pronunciation error, and thus their percentage identification of mispronounced words was either 100% (n = 4) or 0% (n = 3). Similarly, in the post-1965 condition, 4 of the 13 subjects who mispronounced at study made just one pronunciation error, and thus their percentage identification of mispronounced words was either 100% (n = 1) or 0% (n = 3). The small number of observations and high degree of variability in these data prevented meaningful statistical analysis.

H.M., in both conditions, correctly identified more studied words (pre-1953 mean = 67.4%; post-1965 mean = 55.9%) than unstudied words (pre-1953 mean = 52.1%; post-1965 mean = 42.9%). A 2 x 2 between- and within-factors ANOVA, with the factors of condition and study, confirmed that this priming effect was significant, and revealed that H.M.'s performance did not differ between the two conditions (main effect of study (F(1,24) = 18.9; p < .0005), and main effect of condition (F(1,24) = 6.2; p < .05), with no interaction (Figure 5). H.M.'s mean priming score was significantly lower than the NCS mean priming score in the pre-1953 condition (t (17) = 3.1; p < .001) and in the post-1965 condition (t(17) = 7.3; p < .0001).

Analysis of H.M.'s mean correct identification of studied words by repetitions-at-study (pre-1953: 3 repetitions = 65.5%, 1 repetition = 66.5%; post-1965: 3 repetitions = 62.1%, 1 repetition = 49.6%) with a 2 x 2 between- and within-factors ANOVA with factors of condition and repetitions-at-study revealed no significant effects, although the main effect of condition (F(1,22) = 2.6; p = .12), and the interaction (F(1,22) = 2.5; p = .13) approached significance. Because the results of an earlier study (Postle et al., submitted) predicted a significant interaction, we performed planned t-tests to compare H.M.'s performance b, repetition category across conditions. The across-conditions difference in 1-repetition performance was marginally significant ($t\ (22) = 1.9$; $p = .07$) and there was no suggestion of a difference in 3-repetition performance.

The limited number of observations with P.N. precluded statistical analysis of her data. Inspection of her results, however, indicated that she displayed comparable levels of priming in the two conditions (pre-1953 studied completions = 65%; unstudied completions = 50%; post-1965 studied completions = 65%, unstudied completions = 42.5%) (Figure 5).

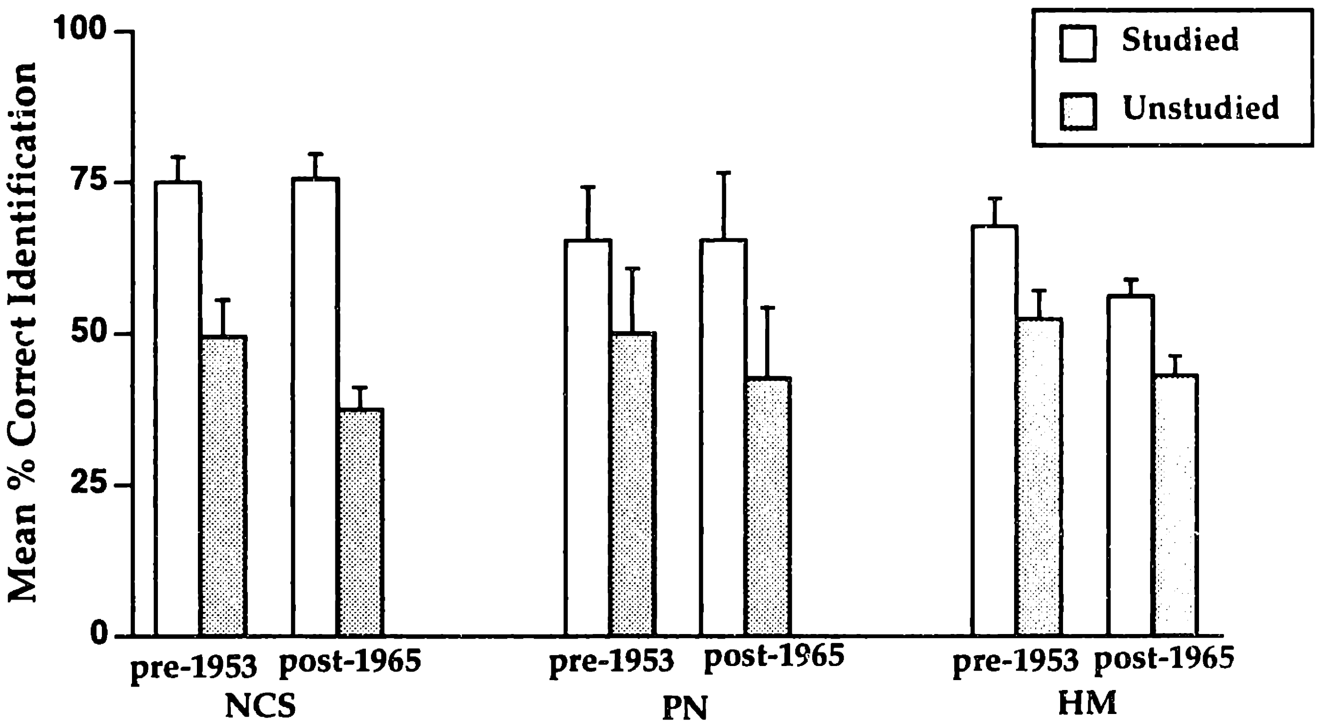

Figure 5. PI priming by NCS, P.N., and H.M.; H.M. was significantly impaired compared to NCS in both conditions, and H.M.'s corrected priming scores did not differ across conditions.

Discussion

The result from Experiment 2 with the most theoretical importance, that H.M.'s PI priming performance was insensitive to the manipulation of familiarity, stands in stark contrast to the clear effect that this manipulation had on his WSC priming performance (reported in Experiments 1.a. and 1.b.). This result, confirming many previous reports of comparable PI priming with familiar and unfamiliar stimuli (e.g., [Bowers, 1996; Bowers, 1994; Gabrieli et al., 1990b; Haist et al., 1991; Keane et al., 1994; Postle and Corkin, in revision [and Chapter 3]; Rueckl, Soloman and Postman, 1952; 1990; Whitlow and Cebollero, 1989]), is consistent with the claim that the learning observed in PI priming arises primarily from plasticity in perceptual, pre-lexical mechanisms. We believe that we found comparable PI priming in H.M. with pre-1953 and post-1965 words because the early visual system treats meaningful and nonmeaningful letter strings in the same way.[7] The fact that H.M.'s mean PI priming score in the post-1965 condition was significantly lower than the NCS mean score does not weaken our interpretation, because H.M.'s mean PI priming score was also significantly lower than the NCS mean score in the pre-1953 condition. H.M. also required longer exposure durations than NCS at both word lengths in both conditions.

The NCS' performance on the priming test also suggests differences from WSC priming. In the post-1965 condition of the WSC priming test, NCS completion rate for studied words that were mispronounced was lower than baseline completion rates. In the post-1965 PI priming test, in contrast, NCS identified correctly words that had been mispronounced at study at a rate that was numerically higher than the unstudied identification rate.

The (nonsignificant) trend in H.M.'s data of study repetitions affecting PI priming with post-1965 words but not with pre-1953 words is similar to data that we have gathered in tests of PI priming with unfamiliar and familiar words in young normal subjects (Postle and Corkin, in revision [and Chapter 3]). In those data, we interpreted a significant Repetitions x Condition interaction to suggest that more than one mechanism may mediate the PI priming effect, and that these mechanisms contribute differently depending on the familiarity of the stimuli. H.M.'s data are consistent with this interpretation: The same process of facilitation of perceptual processing through the establishment of new perceptual representations is responsible for priming in each condition, but familiar word PI priming gets an additional boost from the modification of lexical representations (Feustel et al., 1983; Kirsner et al., 1983). We further propose that the modification mechanism that contributes to the pre-1953 PI priming effect with H.M. is the same mechanism that is responsible for WSC priming. Support for the latter position comes from the differential levels of word identification for 1-repetition words that we found in H.M.'s data. The lower mean identification score for 1-repetition words in the post-1965 condition suggests that the new perceptual representation established by a single exposure to an unfamiliar word did not support priming to the same extent as the coupling of a perceptual representation and an activated lexical representation, a phenomenon only possible with pre-1953 words for which a long-term representation already existed. The equivalent levels of priming for pre-1953 and post-1965 *3-repetition* words, however, suggest that multiple exposures to a stimulus quickly strengthened this perceptual representation to the point where the influence of lexical mechanisms could no longer be detected. Salasoo and colleagues (1985) reported repeated-exposure effects similar to what we have reported here, and argued that the repeated-exposure effect is a manifestation of the "codification" of a representation.

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[7] The model of PI priming proposed by Bowers [Bowers, 1996], although concurring that a low-level perceptual mechanism supports PI priming with unfamiliar words, would posit that a *modification* mechanism supports PI priming with familiar words.

A distinctive pattern of the PI priming results for all subjects was that baseline identification was lower in the post-1965 condition than in the pre-1953 condition. We believe that this pattern in the data is an artifact resulting from the fact that 50% performance thresholds were determined using pre-1953 words. Although the two groups of words were matched carefully for frequency and for length, results of the Vocabulary Recognition Tests in Experiment 1.a. and 1.b. indicated that the pre-1953 words were more familiar to *all* subjects than the post-1965 words (dramatically so for H.M., subtly so for NCS). This difference in familiarity resulted in inaccuracies in estimating the exposure duration needed to achieve 50% baseline performance in the post-1965 condition (even though we took steps to account for this in determining post-1965 exposure durations for H.M.). This methodological complication does not detract from the result of principal theoretical importance of this study, however, because H.M.'s priming scores did not differ significantly across conditions.

General Discussion

The finding with H.M. of impaired WSC priming, but robust PI priming, with novel stimuli is consistent with the view that different mechanisms support the learning that can be measured in each task. Although preserved PI priming with pseudowords has been reported previously in H.M. (Gabrieli et al., 1990b; Keane et al., 1995) in patients with Alzheimer's disease (Keane et al., 1991), in Korsakoff's amnesics (Cermak et al., 1991), and in a group of amnesic subjects with mixed etiologies (Haist et al., 1991), our study represents the first methodologically clean investigation of WSC priming in amnesia. A dissociation between these two tasks has also been reported in patients with Alzheimer's disease by Gabrieli, Keane, and colleagues (Gabrieli et al., 1994; Keane et al., 1991). They proposed that WSC priming relies on a lexical-semantic system, whereas PI priming relies on a structural-perceptual system, both of these memory systems operating in the domain of nondeclarative memory (Gabrieli et al., 1994; Keane et al., 1991). In contrast, we propose that a modification process (Atkinson and Juola, 1974; Diamond and Rozin, 1984; Graf et al., 1984; Morton, 1970; Rozin, 1976) may be the lexical mechanism underlying WSC priming. Our reasoning is prompted by a consideration of the demands of the WSC priming task.

In the WSC test, subjects are asked to produce "the first word that comes to mind" that completes a three-letter stem. Subjects are thus confronted with a lexical retrieval task that, from their perspective, has little to do with "memory." As they search their lexicons for a word beginning with a particular combination of three letters, the probability that they will first retrieve the target word increases if the lexical representation of that word was recently modified by exposure to the word during a study session. If the target word was not presented during the study session (i.e., if it is an unstudied word), then that word's representation in the subject's lexicon has *not* been modified, and the word's stem is less likely to be completed to that word. (At the present time we can only speak of "modification" metaphorically because the neural mechanisms underlying lexical retrieval are not understood.) This model is consistent with the results routinely obtained from healthy and amnesic subjects on tests of WSC priming with *familiar* words. If, however, a representation of the word in question does *not* exist in the subject's lexicon, or exists in a degraded form, then no modification can take place during the study session, and the word will not be retrieved during the subsequent word-finding procedure in which the subject engages during the priming test. This reasoning can explain H.M.'s impaired performance with the unfamiliar stimulus set employed in our experiment. We interpret the robust repetition effect that we see in the NCS results to indicate that the state of modification of a lexical entry may be a graded quality, depending in part on the number of times that the word corresponding to the entry is read during the study session. Additional support for this view comes from Carlesimo (Carlesimo, 1994), who has reported a level-of-processing effect in WSC priming (although other studies, e.g., [Hamann and Squire, 1996; Roediger et al., 1992] have not found this effect). In this respect, our view departs from that of Graf and Mandler (1984), who argued that activation of a lexical representation is an all-or-none state, and who therefore predicted that there would be no level-of-processing effect in WSC priming. Alternatively, the repetition effect in WSC priming may reflect a strengthened contribution of perceptual learning with increased repetitions.

Task analysis suggests that a different procedure is critical in the PI task. In PI, subjects are asked to read words (or pseudowords) whose perception is rendered difficult by a short exposure duration or visual noise. Because subjects participating in such a test either perceive the word immediately or cannot discern it at all, an active, deliberate search of the lexicon is never required. Clearly, lexical access plays an important role in the PI task, because baseline identification thresholds are lower with familiar words than with unfamiliar words. The learning that is expressed in PI priming, however, must result from facilitation at a low, pre-lexical level, because the priming effects with unfamiliar words are comparable to those with familiar words (see Bowers [1996] for an alternative view). Thus, in our conception of the requirements of the WSC task and the PI task, subjects follow different procedures in order to perform successfully, and the priming that can be observed in each task arises from the biasing of two different processes. Further, previous studies from our laboratory (Gabrieli et al., 1994; Keane et al., 1991; Keane et al., 1994) propose that these two types of priming also arise from two disparate parts of the brain: The neural mechanisms for WSC priming are located in high-order temporal and parietal cortex (likely candidate brain areas for lexical memory); whereas the putative neural substrate for PI priming is peristriate cortex.

The proposition that the WSC priming effect arises primarily from lexical retrieval procedures is supported by evidence from AD. When Keane and colleagues (1991) found impaired WSC priming but intact PI priming in AD, they observed that WSC priming, but not PI priming, was correlated with verbal fluency performance. This finding supports a view that WSC priming relies on intact lexical retrieval, and, indeed, the authors suggested that "the mechanism underlying impaired verbal fluency in AD is related to the mechanism underlying impaired word-completion priming in AD but is unrelated to the mechanism supporting perceptual priming" (Keane et al., 1991, p. 335). Consistent with this claim is the well-documented deficit of subjects with AD on tests of lexical retrieval, such as confrontation naming tests (e.g., Huff et al., 1986; Locascio et al., 1995; Chertkow et al., 1989). Chertkow and colleagues have recently reported that AD subjects showed reduced priming with words that they had failed to produce during a naming test (Chertkow et al., 1996). These results suggest that impaired lexical retrieval predicts impaired WSC priming, an observation consistent with the modification hypothesis.

Further support for our conception of the mechanisms underlying WSC priming (and for our interpretation of H.M.'s performance in this study) comes from the performance of our NCS. They primed at a robust level with words that they pronounced correctly during the study sessions in the post-1965 condition, but showed virtually no priming with words that they mispronounced at study. In the test of PI priming, however, NCS showed enhanced identification of words that they had mispronounced at study in comparison to unstudied words. We assume that mispronouncing a word indicates a lack of familiarity with that word, i.e., the word is not represented in the subject's lexicon or is only weakly represented. Our finding of no WSC priming with mispronounced suggests one of two possibilities: (a) that NCS did not show WSC priming with words that they did not know, or (b) that mispronouncing words at study interfered with the process of "modifying" the lexical representation of those words (despite the fact that when subjects mispronounced a word, they were given the correct pronunciation and were subsequently asked to repeat it). The first possibility is supported by our observation that NCS recognized the correct definitions of words that they pronounced correctly at study more often than of words that they mispronounced.

This pattern in the NCS data in the present study is reminiscent of other work by our group using unfamiliar words (Postle and Corkin, in revision [and Chapter 3]) and pseudowords (Gabrieli et al., 1990b). These two studies indicated that NCS do not show WSC priming with unfamiliar stimuli, but, when a cued recall (declarative) testing procedure is used, they can complete stems to these novel stimuli. These results are consistent with the claim that, for NCS as well as for amnesic subjects, the modification of a pre-existing lexical representation of a word is necessary in order for study of that word to enhance the subject's ability to complete its three-letter stem to the word.

The differing pattern of results obtained by testing amnesic subjects on WSC and PI priming tests is inconsistent with theoretical models suggesting that both of these priming paradigms rely solely on perceptual mechanisms (e.g., Haist et al., 1991; Roediger, 1990; Schacter, 1992; Squire et al., 1992). These models depend heavily on the fact that most experiments demonstrating intact repetition priming with novel verbal information in amnesia have been tests of perceptual priming, and have not included WSC priming in their testing protocols (see Bowers and Schacter, 1993) for a review). Based on the results reported here, we propose that pre-existing lexical representation of words in a stimulus set is a *sine qua non* of exhibiting normal WSC priming, and thus that a modification mechanism makes a critical contribution to this kind of nondeclarative memory. I will examine this proposal further in Chapter 3.

CHAPTER 3

Manipulation of Familiarity Dissociates Word-Stem Completion Priming from Perceptual Identification Priming

The experiments presented in this chapter, like those in Chapter 2, are motivated by the theory that repetition priming results from the biasing of the mechanisms whose primary function is nonmnemonic. In these experiments repetition priming with familiar and unfamiliar word stimuli is tested in healthy young subjects. Specifically, the experiments presented in this chapter, like those in Chapter 2, tested the hypothesis that an important component of the learning observed in WSC priming takes place at the level of the lexical search, whereas PI priming reflects plasticity at relatively low levels of the visual system. These experiments represent an important test of the generalizability of the results reported in Chapter 2, which were obtained from a single patient with an idiosyncratic history. For a theory of memory to shed the qualifier of "tentative" or "preliminary" the data supporting it must be reproducible and should derive from studies of normal subjects, as well as of amnesic subjects. The strategy of performing experiments of WSC priming and PI priming in young subjects also permitted me to perform important control experiments that were not practical to perform with H.M.

In the terminology of Bowers (1994), I hypothesized that WSC priming relies on a mechanism consistent with modification theories, and PI priming on a mechanism consistent with acquisition theories. I tested this hypothesis by manipulating the familiarity of the verbal stimuli in these two repetition priming tasks. Common-perceptual-mechanism models predicted that the two repetition priming tasks would be affected in the same way by this manipulation, because unfamiliar words do not differ perceptually from familiar words. My hypothesis, however, predicted that the two tasks would be affected differently by this manipulation.

Experiment 3: Word-Stem Completion Priming

To test the hypothesis that WSC priming relies on a modification mechanism, I manipulated the familiarity of the stimuli that I presented to our subjects. The modification hypothesis predicted that subjects would need a preexisting lexical representation of a word in order to show priming with that word on a WSC priming test. (A corollary prediction of this lexical access-based hypothesis is that baseline WSC to unfamiliar target words would be considerably lower than baseline WSC to familiar target words, because subjects would not be expected to complete word-stems to words that they did not know.) Common-perceptual-mechanism explanations of WSC priming (e.g., Haist et al., 1991; Roediger et al., 1992; Squire et al.; 1992, Schacter, 1992; Rajaram and Roediger, 1993), however, predicted that subjects would perform normally on a test of WSC priming with unfamiliar words, because low-level perceptual mechanisms would be engaged equally by unfamiliar and familiar letter strings.

Methods

Subjects

The 49 subjects were members of the MIT community (mean age = 20.8 [*SD* = 2.2]; mean Vocabulary score on the Wechsler Adult Intelligence Scale-Revised [WAIS-R] = 12.9 [*SD* = 4.0]). They were college graduates or actively working toward a college degree, learned English as their first language, and had normal or corrected to normal vision (Snellen visual acuity range = 20/20-20/25). We divided subjects randomly into four groups: familiar WSC priming (n = 13); unfamiliar WSC priming (n = 14); familiar WSC cued recall (n = 11); and unfamiliar WSC cued recall (n = 11). The groups did not differ significantly in age or WAIS-R Vocabulary score.

Design

The independent variables were condition (familiar or unfamiliar) and test-type (WSC priming or WSC cued recall). The principal dependent variable was memory score (priming or cued recall). I performed separate analyses for completions to 1-repetition words and to 3-repetition words (see Procedure). Subjects were randomly assigned to one of the four cells of this 2 x 2 study design. I employed a between-subjects design to avoid declarative memory contamination of the data because previous experience indicated that young subjects quickly realize that their memory is being tested when they are given multiple priming tests.

Materials

To assemble an unfamiliar word stimulus set, we selected 104 English language words from Bowler (1992), Evans and Berent (1993), and The American Heritage Dictionary (1991) (Appendix C) that were judged to be unfamiliar to native English speaking college undergraduates. The mean frequency of the unfamiliar words was 0 per 44 million[1], and the mean length was 8.2 letters. To confirm that these words were low-usage words, we distributed a list of 104 3-letter stems corresponding to the 104 words to 102 subjects, aged 18-35 (different from those whose data are presented in this report), instructing them to complete each stem to the first word that came to mind. None of the words from the unfamiliar list was used to complete a stem. To assemble a familiar stimulus set, we selected 104 English language words that were judged to be familiar to native English speaking college undergraduates (Appendix D). The mean frequency of the familiar words was 16.9 per 44 million, the mean length was 7.9 letters. Of the 104 words in each stimulus set, 80 were divided into four lists of 20 words each. Each list contained roughly the same number of "short" words (8 letters or less) and "long" words (more than 8 letters). The remaining 24 words were used as buffer words, with 3 placed at the beginning and 3 at the end of each 20 word list to dampen primacy and recency effects.

Procedure

Subjects participated in either a WSC priming test or a WSC cued recall test, followed in all cases by a test of recognition of the definitions of all the words in the stimulus set corresponding to the condition in which the subject was tested. The WSC priming and WSC cued recall tests differed only in the instructions that were delivered immediately before the word-stem completion portion of each test.

The Study Session, Test Session, Vocabulary Recognition Test, and scoring procedures were all the same as those used in Experiment 1.a.

Results

Nonnormal distributions of dependent variables in some of the cells of our study precluded analysis with ANOVA. I therefore performed separate repeated measures analyses with nonparametric statistics to test for significant levels of priming or cued recall in each test, then performed the relevant planned between-group comparisons.

Vocabulary Recognition Test

The Vocabulary Recognition data confirmed that the "familiar" words were more familiar to our subjects than were the "unfamiliar" words: The familiar WSC priming group scored significantly higher on the Vocabulary Recognition Test (mean = 84.2%) than did the unfamiliar WSC priming group (mean = 41.2%) ($t = 4.8$; $p = .001$); similarly, the familiar WSC cued recall group scored significantly higher on the Vocabulary Recognition Test (mean = 95.4%) than did the unfamiliar WSC cued recall group (mean = 41.9%) ($t = 15.5$; $p < .0001$). Chance performance on the Vocabulary Recognition Test was 25%.

Priming tests

Subjects who performed the familiar WSC priming test completed significantly more stems to studied words (mean completions = 30.6) than to unstudied words (mean completions = 4.6) ($t = 6.8$; $p < .0001$). Each of the subjects in this group showed a priming effect. In the unfamiliar WSC priming test, however, the difference between mean studied completions (4.4%) and mean unstudied completions (0%) did not achieve statistical significance. Only 2 of the 14 subjects in this group showed a priming effect. In the familiar WSC priming test, mean completions to 3-repetition words (31.2%) was not significantly different from mean completions to 1-repetition words (29.2%). In the unfamiliar WSC priming test, 5 word-stems were completed to 3-repetition words and 1 word-stem was completed to a 1-repetition word. A Wilcoxon Rank Sums test indicated that familiar WSC priming (mean = 25.9%) was significantly greater than unfamiliar WSC priming (mean = 4.4%) ($p < .0001$) (Figure 6).

Cued recall tests

Subjects in both WSC cued recall tests completed significantly more stems to studied words than to unstudied words (familiar studied mean completions = 60.5%; familiar unstudied mean completions = 6.0%; $t = 17.4$; $p < .0001$); unfamiliar studied mean completions = 14.3%; unfamiliar unstudied mean completions = 0%; $p = .001$, Mann-Whitney Sign Rank test). In the familiar WSC cued recall test, mean completions to 3-repetition words (72.7%) were significantly higher than mean completions to 1-repetition words (48.2%) ($t = 3.1$; $p = .01$). In the unfamiliar WSC cued recall test, mean completions to 3-repetition words (22.3%) was significantly superior to mean completions to 1-repetition words (6.5%) ($t = 6.2$; $p < .0001$). A Wilcoxon Rank Sums test indicated that familiar WSC cued recall (mean = 54.4%) was significantly greater than unfamiliar WSC cued recall (mean = 14.3%) ($p < .0001$) (Figure 6). Within condition comparisons of tests indicated that, within each condition, WSC cued recall scores were significantly greater than WSC priming scores (familiar: $t = 5.8$, $p < .0001$; unfamiliar: $p < .0005$, Wilcoxon Rank Sums test).

Discussion

Experiment 3 produced a striking dissociation in WSC priming scores when I manipulated word familiarity: WSC priming with unfamiliar words was not statistically different from 0, whereas WSC priming with familiar words that were closely matched to the unfamiliar words for word length was robust. In both conditions, WSC cued recall scores were significantly higher than WSC priming scores. In the familiar condition, WSC cued recall performance was sensitive to a manipulation of repetitions at study, whereas WSC priming performance was not. Although a similar statistical analysis for the unfamiliar condition was not possible, due to low stem completions for studied words in the WSC priming test, the data suggest a trend toward higher rates of stem completions to target words for 3-repetition words.

These results are consistent with the modification model of WSC priming, because this model posits that WSC priming requires preexisting

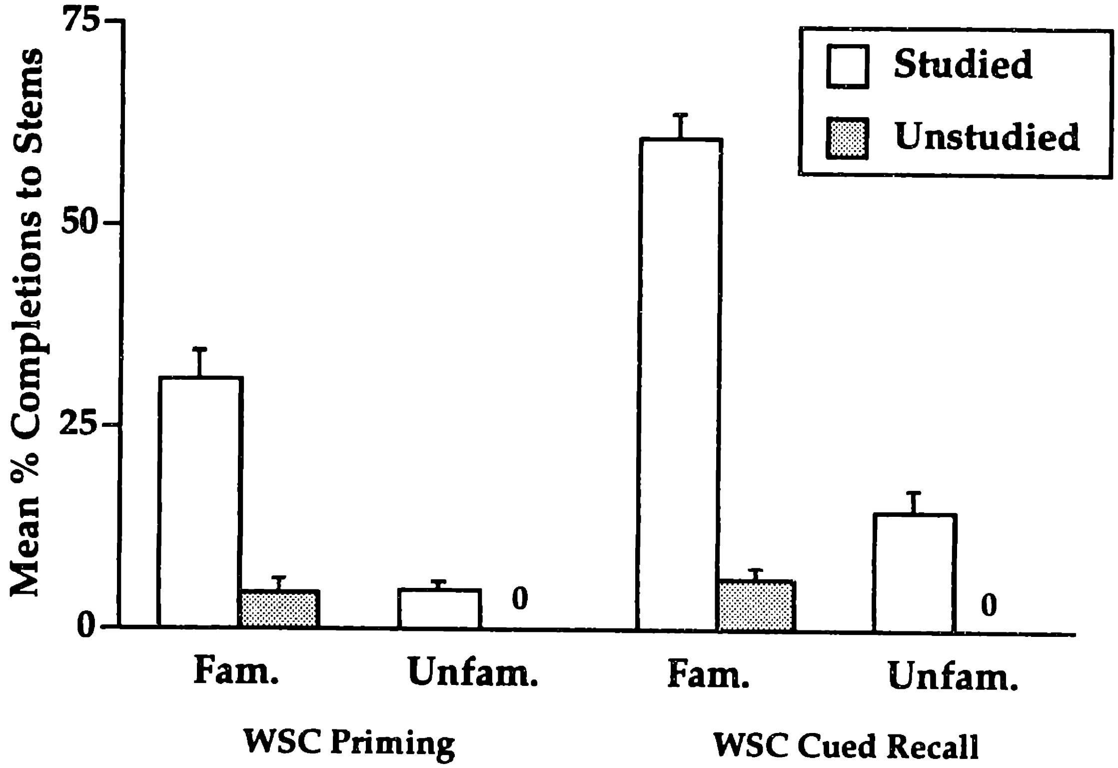

Figure 6. WSC priming and WSC cued recall with familiar and unfamiliar stimuli.

lexical representations of the stimulus material. I found no evidence for WSC priming with words that were unfamiliar to subjects, words for which I assume that subjects had no lexical representations. Diamond and Rozin (1984) employed a similar experimental approach and reported impaired WSC cued recall in amnesic subjects with pseudoword stimuli. This earlier result was inconclusive about the role of modification in WSC *priming,* however, because subjects were given cued recall instructions prior to the stem completion test. Other studies manipulating familiarity of letter strings have reported robust levels of PI priming with pseudowords (Haist et al., 1991; Bowers, 1994). These results, when contrasted with the results of our Experiment 3, suggest that PI priming and WSC priming rely on different mechanisms: one that supports learning with novel stimuli, and one that does not. I will describe a study of PI priming with unfamiliar words in Experiment 6. Our interpretation of these results is not weakened by the floor effect in the unfamiliar-word condition (baseline score of 0). Indeed, this result illustrates our assertion that disrupted lexical access (the process on which modification relies) is predicted when performance is scored on completion of word-stems to words for which subjects have no lexical representations.

I feel confident that the two WSC priming tests were valid measures of nondeclarative memory, because performance on these two tests dissociated in important ways from performance on the WSC cued recall tests, our measures of declarative memory in this experiment. First, WSC cued recall scores were significantly higher than WSC priming scores in both conditions. Second, WSC cued recall was sensitive to the manipulation of study repetitions of stimulus items, whereas WSC priming was not.

Because the theoretical arguments presented in this paper rely heavily on the dissociation between familiar WSC priming and unfamiliar WSC priming, I conducted two additional experiments to confirm the reliability of this result.

Experiment 4: "Phonological" Stem Completion Priming

Although the results of Experiment 3 were predicted by the modification hypothesis, it was possible that the absence of WSC priming with unfamiliar words in Experiment 3 was an artifact of the priming test instructions to "complete each stem to the first *word* that comes to mind." That is, studied unfamiliar words may have been the first words to come to mind for our subjects, but if they treated the unfamiliar words as nonwords (despite our instructions that these words were real, but likely to be unfamiliar), they may have opted instead to complete stems with words with which they were familiar. We therefore investigated whether WSC priming can be supported by low-level phonological representations by modifying the instructions preceding the stem completion (SC) phase of the WSC priming test to encourage subjects to rely on phonology to complete the 3-letter stems, and by deemphasizing the need to complete the stems to familiar words. Again, the modification hypothesis predicted that subjects would fail to show priming with unfamiliar words (and that baseline performance in the unfamiliar condition would be low), but common-perceptual-mechanism hypotheses predicted normal priming with unfamiliar words.

Methods

Subjects

The 31 subjects were members of the MIT community (mean age = 19.0 [*SD* = 1.3]; mean WAIS-R Vocabulary score = 14 [*SD* = 1.8]). They were college graduates or actively working toward a college degree, learned English as their first language, and had normal or corrected to normal vision (Snellen acuity range = 20/20-20/25). We divided subjects randomly into two groups (familiar phonological SC priming [n = 16], and unfamiliar phonological SC priming [n = 15]). The groups did not differ significantly in age or WAIS-R Vocabulary score.

Design

The independent variable in Experiment 4 was condition (familiar or unfamiliar), and subjects were randomly assigned to one of two groups (between-subjects design). The principal dependent variable, priming score, was calculated as in Experiment 3.

Materials

Materials in Experiment 4 were the same as those in Experiment 3.

Procedure

The procedure for Experiment 4 was identical to that of the WSC priming portion of Experiment 3, with one exception: The instructions that preceded the test phase directed subjects to complete each 3-letter stem to the "first *sound* that comes to mind" (rather than to the "first *word* that comes to mind"), and did not specify completion of stems to words. If a subject asked whether the stem completions needed to be words, the experimenter indicated that words, nonsense words, or nonverbal sounds were all acceptable, so long as the beginning of the spoken stem completion corresponded to the 3-letter stem.

Scoring

Scoring for Experiment 4 was identical to scoring for Experiment 3.

Results

As in Experiment 3, these data indicated that the "familiar" words were more familiar to our subjects than were the "unfamiliar" words: The familiar phonological stem completion (SC) group scored significantly higher on the Vocabulary Recognition Test (mean = 89.4%) than did the unfamiliar phonological SC priming group (mean = 36.8%) ($t = 16.8$; $p < .0001$). Subjects who performed the familiar phonological SC priming test correctly completed significantly more stems to studied words (mean completions = 25.2%) than to unstudied words (mean completions = 7.2%) ($t = 6.8$; $p < .0001$). Of the 16 subjects in this group, 15 showed a priming effect. For subjects who performed the unfamiliar phonological SC priming test, the difference between mean studied completions (2.3%) and mean unstudied completions (0%) also achieved statistical significance. Of the 15 subjects in this group, 6 showed a priming effect. An item analysis of unfamiliar SC priming (restricted to the 6 subjects who showed a priming effect) revealed that, for the 7 trials in which stems were completed to studied words, 72.2% of the definitions of these studied words were correctly selected in the Vocabulary Recognition Test. By contrast, for the 291 trials in which stems were not completed to studied words, 43.7% of the definitions of these studied words were correctly selected in the Vocabulary Recognition Test. In the familiar phonological SC priming test, the number of mean completions to 3-repetition words (33.0%) differed significantly from the number of mean completions to 1-repetition words (17.4%). In the unfamiliar phonological SC priming test, 7 word-stems were completed to 3-repetition words and 0 stems were completed to 1-repetition words. A Wilcoxon Rank Sums test indicated that familiar WSC priming (mean = 18.0%) was significantly greater than unfamiliar WSC priming (mean = 2.3%) ($p < .0001$) (Figure 7).

Discussion

The results for Experiment 4 differed from those for Experiment 3 in two ways: First, there was a small (numerically smaller than in Experiment 3) but statistically significant priming effect in the unfamiliar SC condition, although the priming score in the familiar SC condition was significantly greater than that in the unfamiliar condition. Second, the manipulation of repetitions at study did have a significant effect on priming performance.

There are two possible interpretations of the results from the unfamiliar condition of Experiment 4. The first is that the stems that were

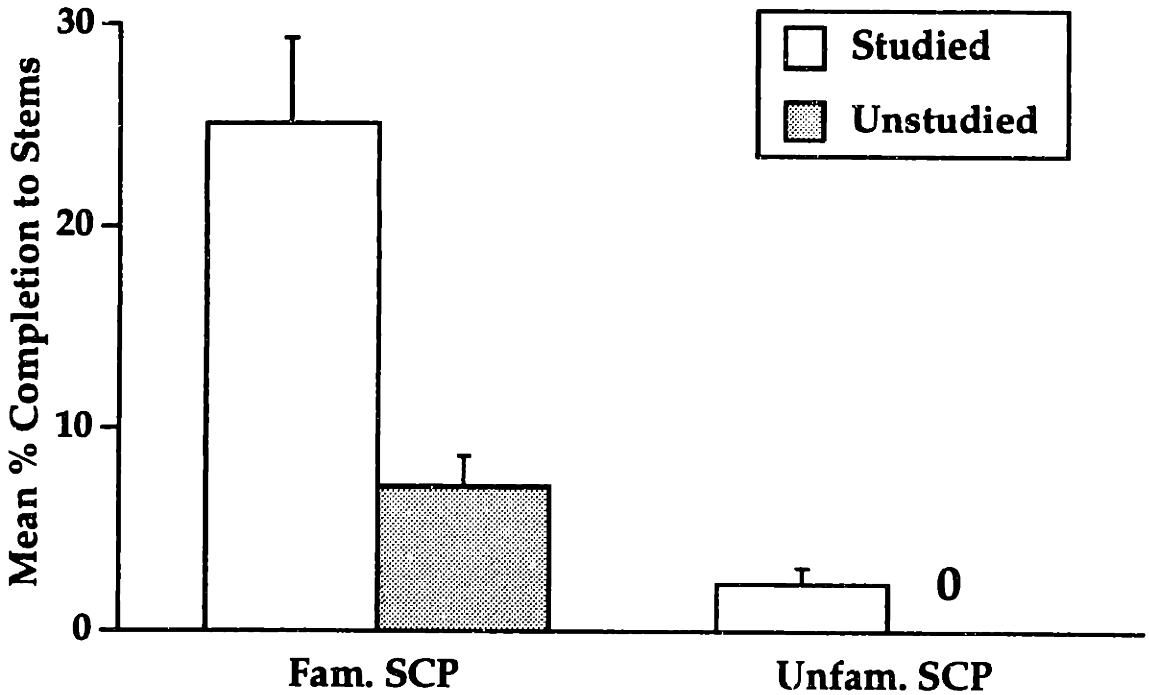

Figure 7. "Phonological" SC priming with familiar and unfamiliar words.

completed to studied words corresponded to words that were actually familiar to subjects. This interpretation is suggested by the item analysis, which indicated that Vocabulary Recognition Test performance was dramatically higher for stems completed to target words than for stems that were not completed to target words. The second interpretation of the results is that perceptual codes can support a modest amount of SC priming. This interpretation finds support from a strong repetition effect. Our procedures required subjects to convert visual, orthographic word stimuli into phonological output during the study session, and also presented the stem stimuli as visual, orthographic information during the test session. Therefore, although the experiment was intended to measure the contribution of *phonological* perceptual representations to SC priming, I cannot discount an alternative explanation that a visual or orthographic perceptual code supported the small amount of SC priming that we found in the unfamiliar condition. As in Experiment 3, our interpretations of these data are not vulnerable to criticism based on a scaling artifact in the unfamiliar-word data because subjects were not expected to complete word-stems to unfamiliar words in the baseline condition.

Our data do not permit us to rule out either of these two alternative hypotheses. The second interpretation of the results is inconsistent with a strict interpretation of the modification hypothesis, which predicted that there would be no unfamiliar SC priming. Because the unfamiliar SC priming effect was minute, however, I maintain that the results of Experiment 4 are consistent with the assertion that the modification mechanism is the principal contributor to the WSC priming effect. Indeed, the unfamiliar SC priming effect in Experiment 4 was numerically smaller than the unfamiliar WSC priming effect in Experiment 3, but differences in variance in the two data sets resulted in the former being significantly different from 0. The dramatic difference between familiar phonological SC priming and unfamiliar phonological SC priming was clearly qualitatively different from the subtle differences between familiar and unfamiliar conditions that have been reported in tests of PI priming (Bowers, 1994; Bowers, in press; Haist et al., 1991; see also Experiment 6 in this report).

Experiment 5: "Orthographic" Stem Completion Priming

Experiment 5 was also intended to establish the reliability of the results of Experiment 3. In this experiment, we investigated whether WSC priming can be supported by low-level *orthographic* representations by modifying the procedures and instructions of the standard SC priming experiment to encourage subjects to rely on orthography to complete the 3-letter stems, and, again, by deemphasizing the need to complete the stems to words. Similar to the two previous experiments, the modification hypothesis predicted that subjects would fail to show priming with unfamiliar words, but common-perceptual-mechanism hypotheses predicted normal priming with unfamiliar words.

Methods

Subjects

The 33 subjects were members of the MIT community (mean age = 21.3 [*SD* = 2.4]; mean WAIS-R Vocabulary score = 14.1 [*SD* = 1.8]). All were college graduates or actively working toward a college degree, learned English as their first language, and had normal or corrected to normal vision (Snellen acuity range = 20/20-20/25). We divided subjects randomly into two groups (familiar orthographic SC priming [n = 17], and unfamiliar phonological SC priming [n = 16]). The groups did not differ significantly in age or WAIS-R Vocabulary score.

Design

The independent variable in Experiment 5 was condition (familiar or unfamiliar), and subjects were randomly assigned to one of two groups (between-subjects design). The principal dependent variable, priming score, was calculated as in Experiment 3.

Materials

The words used in this experiment were the same as those used in Experiment 3, but, unlike Experiment 3, all stimuli (words and stems) were printed individually on 8 1/2" x 11" sheets of paper.

Procedure

The procedure for Experiment 5 was formally similar to that of the WSC priming portion of Experiment 3, with the exception of the method of administration and instructions. During the study session, each word was presented to the subject on a sheet of paper for 5 sec, and the subject was instructed to read the word aloud. Immediately following the study session the subject was given a pen, and instructed to complete, by writing, the 3-letter stem appearing on each sheet of paper with the first letter or letters coming to mind that could follow the stem to make a longer letter string. As in Experiment 4, if a subject asked whether the stem completions needed to be words, the experimenter indicated that words, nonsense words, or nonverbal strings of letters were all acceptable.

Scoring

Scoring for Experiment 5 was identical to scoring for Experiment 3.

Results

As in Experiments 1 and 2, the Vocabulary Recognition Test data indicated that the "familiar" words were more familiar to our subjects than were the "unfamiliar" words: The familiar orthographic SC group scored significantly higher (mean = 94.5%) than did the unfamiliar orthographic SC priming group (mean = 40.9%) ($t = 24.1$; $p < .0001$). Subjects who performed the familiar orthographic SC priming test completed significantly more stems to studied words (mean completions = 26.2%) than to unstudied words (mean completions = 2.4%) ($t = 5.7$; $p < .0001$). Of the 17 subjects in this group, 15 showed a priming effect. For subjects who performed the unfamiliar orthographic SC priming test, the difference between mean studied completions (2.3%) and mean unstudied completions (0%) also achieved statistical significance ($p < .05$, Mann Whitney Signed Rank test). Of the 16 subjects in this group, 6 showed a priming effect. An item analysis of unfamiliar orthographic SC priming (restricted to these 6 subjects) revealed that, for the 8 trials in which stems were completed to studied words, 72.2% of

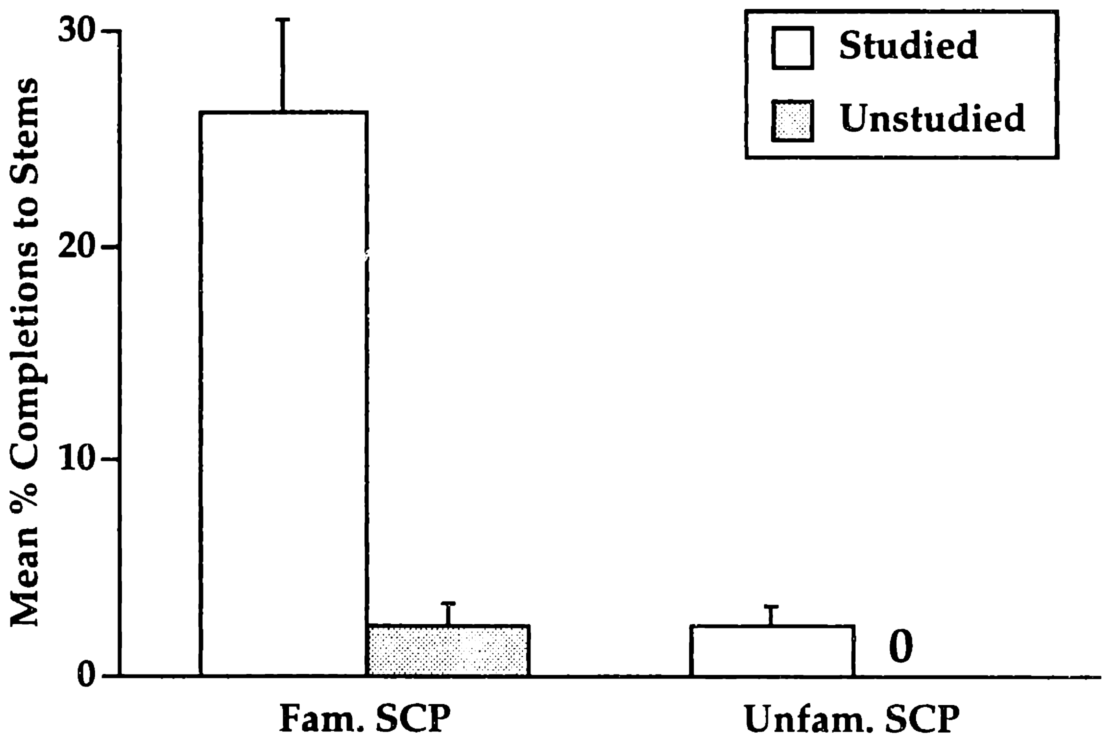

Figure 8. "Orthographic" SC priming with familiar and unfamiliar words.

the definitions of the studied words were correctly selected in the Vocabulary Recognition Test. In contrast, for the 312 trials in which stems were not completed to studied words, 43.9% of the definitions were correctly selected in the Vocabulary Recognition Test. In the familiar orthographic SC priming test, mean completions to 3-repetition words (27.6%) were not significantly different from mean completions to 1-repetition words (24.7%). In the unfamiliar orthographic SC priming test, 8 word-stems were completed to 3 repetition words and 0 word-stems were completed to 1-repetition words. A Wilcoxon Rank Sums test indicated that familiar orthographic SC priming (mean = 23.8%) was significantly greater than unfamiliar orthographic SC priming (mean = 2.5%) ($\underline{p} < .0001$) (Figure 8).

Discussion

Results from the orthographic SC priming experiment indicated that, as in the phonological SC priming experiment, the unfamiliar SC priming effect was numerically smaller than the unfamiliar WSC priming effect from Experiment 3, but was statistically different from 0. Also, as in the previous two SC priming experiments, the priming score in the familiar SC condition was significantly greater than the priming score in the unfamiliar condition. Similar to Experiment 3, but at variance with Experiment 4, the manipulation of repetitions at study did not have a significant effect on familiar SC priming performance. Similar to Experiment 4, this manipulation did have a strong effect on unfamiliar word-stem completions.

As in Experiment 4, the results of Experiment 5 can be interpreted in two ways. The item analysis again suggested that subjects may have been familiar with the words to which they completed stems. Alternatively, these data may indicate that perceptual codes can support a modest amount of SC priming. As in the previous experiment, however, the level of priming in the unfamiliar condition, while detectable, was dramatically less than priming with familiar words. The unfamiliar orthographic SC priming effect was so small that I can again reconcile these results with the predictions of the modification model by noting that low-level, prelexical codes may support a modest level of SC priming.

Experiment 6: Perceptual Identification Priming

PI priming is demonstrated when subjects identify previously studied stimuli at shorter exposure durations than unstudied stimuli. Considerable evidence supports the view that the learning observed in PI priming experiments depends unambiguously on perceptual mechanisms. For example, intact PI priming is found in normal and memory-impaired subjects tested with pseudowords and unfamiliar words (Bowers, 1994; Bowers, in press; Haist et al., 1991; Keane et al., 1994; Postle and Corkin, submitted; Rueckl, 1990; Soloman and Postman, 1952; Whitlow and Cebollero, 1989), indicating that the learning is supported by the biasing of pre-semantic perceptual mechanisms (i.e., the learning *cannot* take place at the level of lexical representations). Intact PI priming with the unfamiliar words used in the previous experiments would demonstrate a dissociation from WSC priming, suggesting that the two types of priming rely on different mechanisms. This result would also indicate that the absence of a WSC priming effect with these same stimuli (Experiments 1, 2, and 3) was not due to an idiosyncratic "non-learnability" inherent in this stimulus set.

Methods

Subjects

We tested 37 subjects who were members of the MIT community (mean age = 20.7 [*SD* = 3.0]; mean WAIS-R Vocabulary score = 13.0 [*SD* = 1.9]). All subjects were college graduates or actively working toward a college degree, learned English as their first language, and had normal or corrected to normal vision (Snellen acuity range = 20/20-20/25). We divided subjects randomly into two groups (familiar n = 20; unfamiliar n = 17). The groups did not differ significantly in age or WAIS-R Vocabulary score.

Design

The experimental design of Experiment 6 was formally identical to that of the SC priming experiments. Additional dependent measures for the PI priming experiment were threshold exposure duration and priming-score-by-word-length ("short" < or = 8 letters; "long" > 8 letters).

Materials

The word stimuli used in Experiment 6 were the same as those in Experiments 3, 4, and 5, but each word was presented with a slide projector.

Procedure

The procedure was identical to that used in Experiment 2.

Results

Vocabulary Test

The results of the Vocabulary Recognition Test confirmed that the familiar words were more familiar than the unfamiliar words to our subjects: The mean score for familiar words was 87.7%, and the mean score for unfamiliar words was 34.3% (t = 19.2, p < .0001).

Threshold Session

The mean exposure duration was shorter for short words than for long words for both groups: A 2 x 2 mixed factors ANOVA revealed main effects of condition ($F(1,35) = 232.4$; $p > .0001$) and word-length ($F(1,35) = 70.9$; $p < .0001$) and an interaction ($F[1,35]) = 167.2$; $p < .0001$) (Table 5).

Table 5. Mean exposure duration determined by PI threshold test (msec).

Condition	Short Words *M*	Short Words *SE*	Long Words *M*	Long Words *SE*
Familiar	63.2	13.4	95.7	23.8
Unfamiliar	149.1	14.7	544.1	39.7

Priming Test

Both groups demonstrated significant PI priming effects by correctly identifying more studied words (familiar mean = 87%; unfamiliar mean = 81.8%) than unstudied words (familiar mean = 48.6%; unfamiliar mean = 52.9%). The significance of this priming effect was confirmed with a 2 x 2 between- and within-factors ANOVA, with the factors of condition and study, revealing a main effect of study ($F(1,35) = 206.9$; $p < .001$) and an interaction ($F(1,35) = 4.2$; $p < .05$). Post hoc t tests confirmed that there was a significant priming effect for familiar words (38.4%) (t =12.2; p < .0001) and for unfamiliar words (28.8%) (t = 8.0; p < .0001), and that the baseline scores of the two groups did not differ significantly. A post hoc t test confirmed that the source of the interaction was a significant difference between familiar word priming and unfamiliar word priming (t = 2.0; p < .05) (Figure 9).

An analysis of priming effects by word length (familiar: short = 36.6%, long = 40.2%; unfamiliar: short = 26.5%, long = 32.4%) with a 2 x 2 between- and within factors ANOVA with factors of condition and priming-score-by-word-length revealed a borderline main effect of condition ($F(1,35) = 3.4$; p = .07), no main effect of word length, and no interaction.

An analysis of mean correct identification of studied words by repetitions-at-study, with a 2 x 2 between- and within-factors ANOVA with factors of condition and repetitions-at-study, revealed a borderline main effect of condition ($F(1,35) = 3.7$; p = .06), a main effect of repetition ($F(1,35) = 45.5$; p

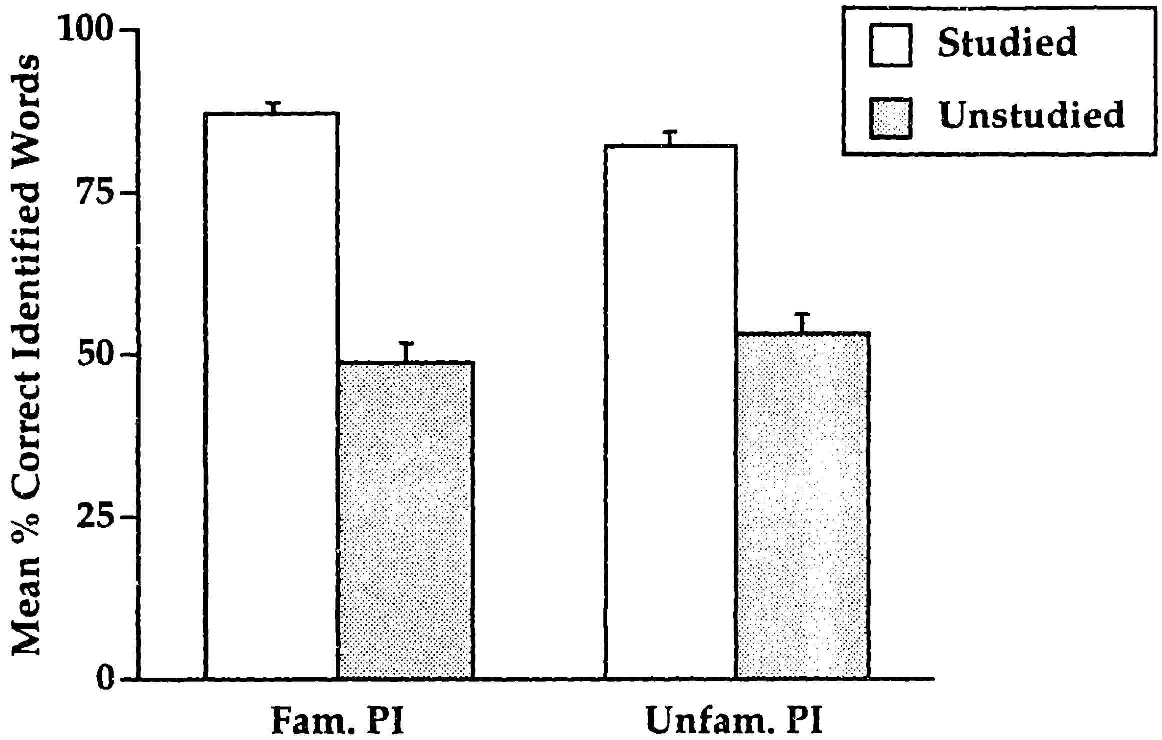

Figure 9. PI priming with familiar and unfamiliar words.

< .0001), and an interaction ($F(1,35) = 20.2$; $p < .0001$). Post hoc t tests confirmed that the source of the interaction was a significant difference between the mean identification score for 1-repetition familiar words (85%) and for 1-repetition unfamiliar words (71.8%) ($t = 4.0$; $p < .0005$), but no difference between the mean identification score for 3-repetition familiar words (89%) and the mean score for 3-repetition unfamiliar words (91.8%) (Table 6).

Table 6. PI priming: mean percentage completions to studied words by repetitions-at-study

Condition	1 repetition	3 repetitions
Familiar	85	89
Unfamiliar	71.8	91.8

Discussion

Although we observed robust PI priming with familiar and unfamiliar words, priming with familiar words was significantly higher than priming with unfamiliar words. Baseline identification levels for the two conditions were comparable. The manipulation of word length affected both subject groups in the same way, resulting in slightly (but not significantly) higher priming for long words than for short words. The manipulation of repetitions at study, however, affected the two conditions differently: Subjects identified correctly more 1-repetition familiar words than 1-repetition unfamiliar words.

The Study-Repetition x Condition interaction in PI priming suggests that different mechanisms mediate PI priming with familiar and unfamiliar words. A strong interpretation of this view is that PI priming with familiar words may work on a principle of "modification" of graphemic representation units, while PI priming with unfamiliar words would result from interaction of the test stimuli with newly formed perceptual representations that were established by the study episode (an acquisition mechanism) (Bowers, in press; Whitlow, 1990). A less-strong interpretation, derived from Feustel et al. (1983) and Kirsner et al., (1983), posits that the same process of facilitation of perceptual processing through the acquisition of new perceptual representations is responsible for priming in each condition, but that familiar word PI priming gets an additional boost from the activation of lexical representations, i.e., the same modification mechanism that is responsible for WSC priming[8]. Support for the latter position comes from the differential levels of word identification for 1-repetition words that I found in the present study. The lower mean identification score for 1-repetition words in the unfamiliar condition suggests that the new perceptual representation established by a single exposure to an unfamiliar word does not support priming to the same extent as the coupling of a perceptual representation and an activated lexical representation, a phenomenon only possible with familiar words for which a long-term representation already exists. The equivalent levels of priming for familiar and unfamiliar 3-repetition words, however, suggest that multiple exposures to a stimulus quickly strengthen this perceptual representation to a point at which behavioral evidence for perceptual facilitation is at ceiling, and neither the benefit of modification of lexical representations nor of further study exposures serves to increase the priming effect. Salasoo et al. (1985) reported repeated-exposure effects similar to what I have reported here, and argued that the repeated-exposure effect is a manifestation of the "codification" of a representation. This model of one process mediating PI priming with familiar and with unfamiliar words (Feustel et al., 1983) offers a more parsimonious explanation of our results. This model also illustrates the theoretical point of this paper, that a study episode can result in plastic change at several levels of information processing. A third possible source of the difference in priming with familiar and unfamiliar words, a difference in the levels of baseline performance between the two conditions that would have

[8] Kirsner et al. (1983) posited that PI priming results from facilitation at two levels of word representation, a modality-specific level and a modality-independent level. The former corresponds to perceptual facilitation that would support PI priming with familiar and unfamiliar words, the latter to the interaction with the lexicon that can only occur with familiar words. Evidence from their study suggests that word frequency effects in PI priming are restricted to the modality-independent level.

left more room for priming in one group than in the other group, is not supported by our data.

In spite of the between-condition difference in priming score, the robust priming in the unfamiliar condition is evidence that PI priming relies on a pre-semantic, perceptual mechanism. That is, I observed near normal priming effects with words for which our subjects did not have lexical representations. These results, consistent with previous reports of largely intact PI priming with pseudowords in normal subjects and in memory impaired subjects (e.g., Bowers, 1994; Bowers, in press; Haist et al., 1991; Keane et al., 1994; Postle and Corkin, submitted; Rueckl, 1990; Soloman and Postman, 1952; Whitlow and Cebollero, 1989), indicate that the mechanisms that underlie PI priming are different from the modification mechanism, and therefore different from the mechanism that is primarily responsible for the WSC priming effect.

Experiment 7: Recognition Memory for Unfamiliar Words

The experiments presented thus far in this chapter have tested SC in declarative and nondeclarative memory tests, and PI in a nondeclarative memory test. In addition to the conditions of memory type (declarative/nondeclarative), nondeclarative memory test type (WSC/PI), and familiarity that have been manipulated in these experiments, there is another independent variable whose manipulation I have not emphasized: completeness of word stimuli (words/word-stems). The SC tests have presented subjects with 3-letter word-stems at test, and have done so in nondeclarative (priming) and declarative (cued recall) testing conditions. The PI test, in contrast, presents complete words at test. Thus far, the interaction that I have emphasized is the effect of manipulating familiarity on nondeclarative memory test performance. But because manipulations of the nondeclarative memory test type also manipulate word completeness, it is important to consider whether the interaction that has emerged from Experiments 3-6 (and also from Experiments 1.a., 1.b., and 2) arises from the manipulation of word-completeness rather than from the manipulation of nondeclarative memory test type. That is, although I have interpreted the differential effect of the familiarity manipulation as evidence that WSC priming and PI priming rely on different mechanisms, an alternative interpretation could posit that this effect arises from the fact that WSC priming presents subjects with 3-letter word-stems at test, whereas PI priming presents subjects with complete words at test.

This alternative interpretation gains some support from the results of Experiment 3, in which the familiarity manipulation had a dramatic effect on WSC cued recall, as well as on WSC priming. This result could be interpreted to suggest that the familiarity effect that I have described in WSC priming is a reflection of the fact that tests that probe memory with partial word cues are generally more difficult than are tests that probe memory with complete words. This "difficulty" interpretation of my results runs as follows: Tests with unfamiliar words are more difficult than tests with familiar words, and tests that present partial-word cues are more difficult than tests that present complete words. In a 2 x 2 design, therefore, the cell that pairs the difficult unfamiliar words with the difficult partial-word cue task would be predicted to produce the lowest performance (Figure 10).

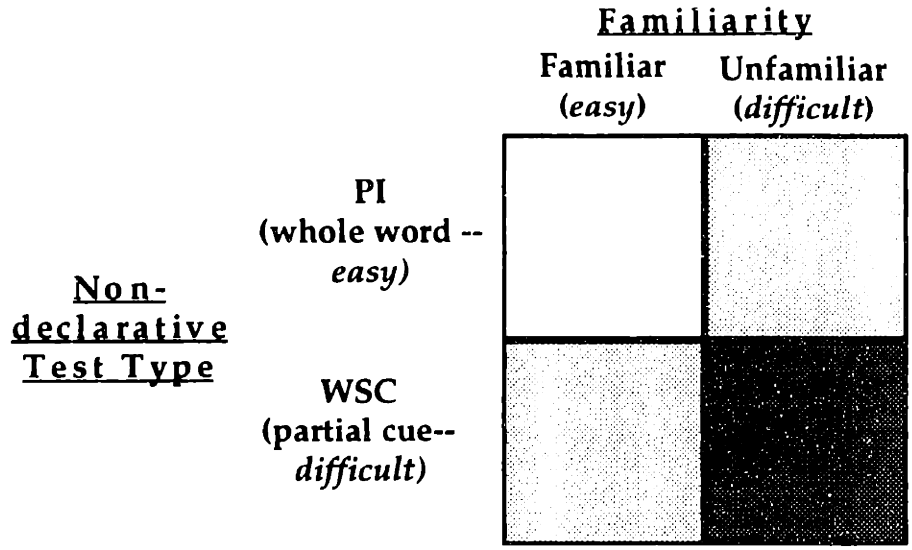

Figure 10. Schematic illustration of "difficulty" hypothesis of the difference between WSC and PI priming. Increasing difficulty is illustrated by darker shading.

The data for this 2 x 2 design were already gathered for nondeclarative memory tests in Experiments 3 and 6. Although direct comparison of WSC and PI results is difficult because of important methodological differences (e.g., in baseline determination) a qualitative examination of the data indicates that they are consistent with the difficulty hypothesis (Figure 11)[9].

Non-declarative Test Type	Familiarity: Familiar	Familiarity: Unfamiliar
PI	38.4%	28.8%
WSC	25.9%	4.4%

Figure 11. Data from Experiments 3 and 6.

This presentation of the data, however, represents a post-hoc analysis, and therefore remains only suggestive. Experiment 7 assessed the "difficulty"

[9] It is important to emphasize that these results are also consistent with the predictions of the proceduralist hypothesis.

hypothesis in a direct way, in the domain of declarative memory. Experiment 3, as well as testing WSC priming, also tested WSC cued recall, a test of declarative memory. The data from these cued recall tests fill out, for declarative memory, 2 of the cells of the 2 x 2 design illustrated in Figure 10. To fill in the other two cells, which require a declarative memory test that presents complete words to subjects, I performed a test of recognition memory, manipulating word familiarity as I did in Experiment 3[10].

Methods

Subjects

The participants in this study were 30 MIT students, who were divided randomly into two groups (familiar $\underline{n}$ = 15; unfamiliar $\underline{n}$ = 15).

Design

The experimental design of Experiment 7 was formally identical to the design of the experiments described earlier in this chapter.

Materials

One half of the word stimuli used in Experiment 7, 20 familiar words and 20 unfamiliar words, were drawn from those used in Experiments 3, 4, 5, and 6. In addition, each of these target words, which were presented in the study session, was paired with an unstudied "foil" stimulus that shared many of the same initial letters as the target words. Each familiar foil stimulus was a real word that was selected because its initial letters (a mean of 3/5 of the letters in the word) and its length were similar to a matched target word (Appendix E). Each unfamiliar foil stimulus was a pseudoword that was created by using the initial letters of its matched target word, and adding a suffix that would create a plausible facsimile to an unfamiliar word.[11] The unfamiliar foils also shared 3/5 of the same letters as the unfamiliar target words (Appendix F).

Procedure

The study session was identical to that of Experiments 3, 4, and 6. The interval between study and test was approximately 20 min. Pilot testing had indicated that the recognition test produced ceiling effects when the delay was 1 min. During this interval subjects performed a different test (nonverbal pattern priming, described in Chapter 4) and their blood pressure and body temperature were measured (procedures required by the MIT Clinical Research Center). During the test session, studied and unstudied stimuli were presented in random order, and subjects indicated for each whether it

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[10] A similar experiment was described by Jacoby and Witherspoon (1982), but this report did not disclose the recognition memory scores from this experiment.

[11] This process relied on the assumption that the unfamiliar words were equivalent to pseudowords for our subjects.

had appeared on the study list. The dependent measure was hit rate corrected for false alarms.

Results

To test whether there was a difference in recognition memory for familiar vs. unfamiliar words, I performed a Wilcoxon Signed-Rank test, which indicated that the mean corrected hit rate for the familiar group (92.7%) was significantly higher than the mean corrected hit rate for the unfamiliar group (82.3%) ($p = .01$) (Figure 12). A ceiling effect was evident in the familiar data.

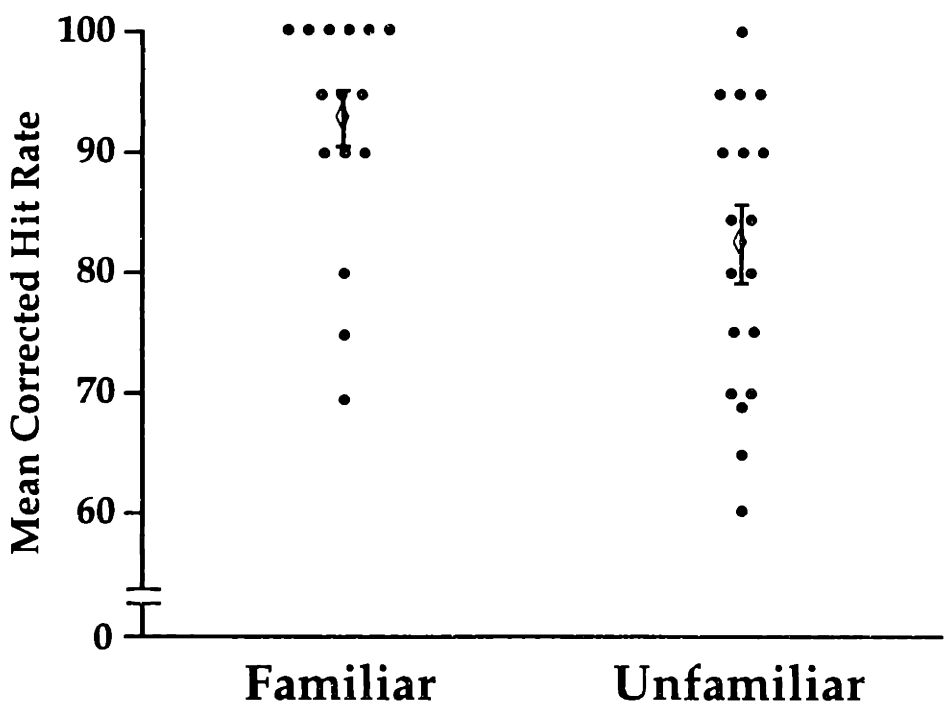

Figure 12. Group means and standard errors of the mean are represented by an open diamond and error bars. Individual data points are also plotted.

Discussion

These results permit me to complete the declarative memory 2 x 2 design prompted by the "difficulty" hypothesis (Figure 13). These results do not permit the rejection of either the proceduralist or the "difficulty" hypothesis. Although the unfamiliar group performed significantly worse than the familiar group, this difference was qualitatively much smaller than the difference between familiar and unfamiliar WSC cued recall in Experiment 3 (Figure 13). This type of experiment could have provided less equivocal results if the procedures of the recognition test were modified to make it more difficult. Efforts to increase difficulty by increasing the study-test delay and by filling the delay with unrelated tasks were unsuccessful. The

Declarative Test Type	Familiarity: Familiar	Familiarity: Unfamiliar
Recognition	92.7%	82.3%
WSC cued recall	54.4%	14.3%

Figure 13: Results from Experiment 7 paired with WSC cued recall results from Experiment 3.

presence of a ceiling effect in the familiar data leaves open the possibility that the real difference between recognition memory in the two conditions is much greater, but simply undetectable with the test as I administered it. If the modest difference between conditions seen in Experiment 7 were to hold up in a more difficult recognition memory test, this result would strengthen the interpretation that the familiarity effect may indeed be a general phenomenon that is mediated by task difficulty. This result would weaken the effectiveness of the familiarity manipulation as a test of the mechanisms underlying different repetition priming effects, because familiar/unfamiliar dissociations could be interpreted as reflections of differing task difficulty, rather than of differing underlying mechanisms.

This second possibility would not permit decisive rejection of the proceduralist hypothesis, however, because the degree of homology between PI priming and recognition memory is unclear. The procedure for testing the "difficulty" hypothesis that was used in Experiment 7 relies on the assumption that declarative and nondeclarative versions of the same (or similar) tests share enough common characteristics that parallel behavior of the two measures on a particular manipulation can be interpreted as evidence that they share common mechanisms (or, at a minimum, that the effect of the manipulation on each test is due to the same factor). Although recognition memory can be influenced by manipulations perceptual variables at encoding (Jacoby and Dallas, 1981), the two tests dissociate in at least three important ways. First, recognition memory and PI differ in their sensitivity to manipulations of level-of-processing or difficulty at encoding. These empirical results led Jacoby and Dallas to assert the two tests have different informational requirements: Recognition memory relies on a "more distinctive memory trace" than does PI priming, which requires only "the visual pattern and the name of the word" (Jacoby and Dallas, 1981; p. 317). A memory trace is made more "distinctive" by making the encoding task more meaningful or more difficult (Jacoby and Craik, 1979), but a "richer memory trace is of no benefit" to PI priming (Jacoby and Dallas, 1981; p. 317). Second, recognition memory and PI priming demonstrate independence (Jacoby and Witherspoon, 1982). Third, tests of memory impaired subjects have demonstrated that recognition memory, but not PI priming, is vulnerable to amnesia (Keane et al., 1991; 1994). These results indicate that PI priming and recognition memory are readily dissociable, and therefore similar effects of the familiarity manipulation on PI priming and recognition memory would be of limited relevance to the resolution of this debate. A more direct test of the "difficulty" hypothesis would be to test PI priming with 3-letter word-stems; this hypothesis would predict that the familiarity manipulation would have the same effect on PI priming with word-stems as it does on WSC priming.

General Discussion

I interpret the dissociation of WSC priming and PI priming as a reflection of the procedural differences of the two tasks. Rather than invoking two "memory systems" (e.g., *perceptual* and *conceptual*), I emphasize that the two tasks engage different cognitive mechanisms: lexical search and visual perception, respectively. The locus of learning in WSC priming is the lexical search process, which is biased by the modification mechanism. The locus of learning in PI priming is the visual perceptual mechanism(s) that permits detection of letter strings presented near the limits of temporal resolution of the visual system. Neuropsychological studies of WSC priming and PI priming suggest that the brain areas corresponding to these two different processes are heteromodal temporal-parietal cortex and posterior visual cortex, respectively (Keane et al., 1991; 1994; 1995; Gabrieli et al., 1994).

One difficulty in interpreting the WSC priming data from Experiments 1.a., 3, 4, and 5 arises from the presence of low baseline scores in the unfamiliar condition. An alternative interpretation of my data is that these low baseline scores reflect a floor effect, and that the absent (or low) SC priming with unfamiliar words therefore simply reflects a scaling artifact caused by the increased difficulty of pairing a SC task with unfamiliar stimuli. Because it is not possible to boost baseline performance in an unfamiliar SC priming test, an approach to solving this problem might be to bring baseline performance in the PI test down to the floor. If WSC priming and PI priming do indeed rely on a common perceptual mechanism, increasing the difficulty of the PI test (e.g., by decreasing exposure duration) should have the effect of making PI priming performance resemble WSC priming performance, and the PI priming effect would be abolished when tested with unfamiliar words. If, on the other hand, the modified proceduralist hypothesis is correct, PI priming with unfamiliar words would be relatively preserved when baseline performance was brought down to 0. Preliminary results from this experiment are consistent with the modified proceduralist hypothesis.

The results presented in this chapter, together with those presented in Chapter 2, challenge the assumptions of several memory researchers that many types of repetition priming rely on the same perceptual mechanisms (e.g., Rajaram and Roediger, 1993; Schacter, 1994; Bowers, 1994; Hamann and Squire, 1996; Hamann, 1996). These results are consistent with our hypothesis that the proceduralist principle that has been observed in motor learning (Brashers-Krug et al., 1995; Grafton, 1995; Karni et al, 1995a) and in visual skill learning (Karni et al., 1995b) also applies to repetition priming. The dissociation of different repetition priming tests (and, therefore, of different kinds of nondeclarative memory) does not, however, challenge the importance of the declarative/nondeclarative distinction. Although many different types of repetition priming may rely on distinct mechanisms and distinct neural substrates, all share the common property that they do not rely on the medial temporal-diencephalic system that is specialized for declarative memory.

CHAPTER 4

The Properties and Neural Substrates of Pattern Priming

Previous work in our laboratory has demonstrated that H.M. exhibits preserved pattern completion priming (a type of *nonlinguistic* repetition priming) with novel, abstract patterns (Gabrieli et al., 1990a). Subsequent studies by other groups have replicated this result in amnesic patients of diverse organic etiologies (Musen and Squire, 1992; Verfaellie et al., 1992; Gooding et al., 1993; Gooding et al., 1994). Because the stimuli employed in these studies were presumed to be novel to the subjects, the studies suggested that repetition priming with nonlinguistic stimuli relies on a low-level, perceptual mechanism. These studies, however, gave no clues about the neural substrate for this type of nondeclarative memory, beyond the fact that it did not rely on the medial temporal lobe-diencephalic system that is compromised in amnesia.

Although this paradigm has been employed in several studies with amnesic patients, very little attention has been devoted to the functional properties of this mnemonic phenomenon. Work by Musen, who was among the first to use this paradigm, has indicated that the pattern priming effect can last as long as one week in young subjects (Musen and Treisman, 1990), and that the effect, like many other types of nondeclarative memory, is insensitive to encoding manipulations that typically affect declarative memory (Musen, 1991). Both of these studies were conducted with healthy young subjects. This chapter presents a series of experiments of pattern priming in Alzheimer's disease (AD). These experiments were designed to elucidate (a) the neural substrates of this effect, (b) the extent to which the properties of pattern priming that have been described in young subjects (Musen and Treisman, 1990; Musen, 1991) are preserved in AD, and (c) the boundary conditions of nonverbal perceptual nondeclarative memory in AD.

Experiment 8: Intact Implicit Memory for Novel Patterns in Alzheimer's Disease

Patients with AD provide a useful model for investigating the neural substrate of pattern priming because AD pathology relatively spares low-level, unimodal sensory areas in neocortex while targeting the high-level, heteromodal cortical regions of frontal, temporal, and parietal cortex (Arnold et al., 1991). A finding of intact pattern priming in AD would suggest that this kind of *nonverbal* mnemonic processing, like that seen in repetition priming tasks that employ words (Squire et al., 1992; Buckner et al., 1995; Gabrieli et al., 1995; Keane et al., 1995; Schacter et al., 1996), relies on peristriate cortex, the belt of unimodal visual cortex (areas 18 and 19) surrounding area 17 (Braak, 1980; Mesulam, 1985). I predicted, *a priori*, that pattern priming relies on the posterior cortex that is responsible for relatively early ("pre-semantic") visual processing. In spite of the fact that the pattern priming task that we employed in this experiment required fine motor control of the hand, we assumed that motor areas were not candidate loci for the learning observed on this task because the learning takes place in a single trial, and motor learning requires many repetitions of a movement for learning to be expressed (Corkin, 1965; Corkin, 1968; Gabrieli et al., 1993). The relative contributions of sensory and motor processes to the pattern priming effect were examined in Experiment 9, described below. Previous work in our laboratory indicates that AD subjects show normal learning on a test of perceptual identification priming with pseudowords, which are presumed to be novel to the subjects (Keane et al., 1994), although earlier work by Corkin (1982) suggested that AD patients have difficulty learning the Gollin Incomplete-Pictures test. I predicted in the present experiment that I would find intact pattern priming in AD.

Methods

Subjects

The participants in this study were 23 subjects with AD and 26 NCS (Table 7). The AD subjects, referred from the Memory Disorders Unit at the Massachusetts General Hospital, met established criteria for the clinical diagnosis of probable AD (McKhann et al., 1984; Khachaturian, 1985). All AD subjects received a neurological examination, either magnetic resonance or computed tomography brain scan, and laboratory tests to rule out other causes of dementia. The severity of dementia in the AD subjects was assessed with the information, memory, and orientation section of the Blessed Dementia Scale (BDS [IMC]; Blessed et al., 1968). AD subjects and NCS did not differ in mean age or mean years of education. Although abnormalities in visual perception can accompany AD (Katz and Rimmer, 1989; Mendez et al., 1990; Kurylo et al., 1994a; Cronin-Golomb et al., 1995; Kurylo et al., 1996), recent work suggests that AD subjects are not impaired on a task requiring synthesis of a shape from a sparse amount of information (Kurylo et al., 1994b), the principal demand of our task. Many researchers have observed that a subset of AD subjects have visuospatial deficits disproportionately severe in comparison to their cognitive deficits (e.g., Martin et al., 1986; Martin, 1990; Mendola et al., 1995). A small number of AD subjects had a visuospatial impairment that was so severe they were unable to execute the simple "copying" procedure required by this experiment. They were, therefore, excluded from the study on the grounds that they were untestable.

Table 7. Subject characteristics for Experiment 8

Group	N [M,F]	Mean Age [*SD*]	Mean Education [*SD*]	Mean BDS: IMC* [*SD*]	Mean Duration of Disease [*SD*]
NCS	26 [13, 13]	68.8 [8.4]	15.1 [2.9]	.4 [.6]	---
AD	23 [11,12]	71.7 [7.1]	15.2 [3.0]	11.6 [6.8]	3.5 [3.1]

*Blessed Dementia Scale: Information, Memory, and Concentration Section (Blessed et al., 1968)

Stimulus Materials

The stimuli were derived from six dot patterns, each consisting of five dots of the possible nine in a 3 x 3 square matrix (Garner and Clement, 1963). We created three target stimuli from each dot pattern by connecting the dots with straight lines, and selected one stimulus from each dot pattern to create three test forms of six stimuli each. An additional 54 stimuli (9 from each dot pattern) served as unstudied foils for the Recognition Test (Figure 12).

Procedure

The experiment consisted of four sessions: *Baseline, Priming Test 1, Priming Test 2,* and *Recognition Test.* The inter-session interval was at least 5 hours. The two priming tests measured nondeclarative memory; the recognition test measured declarative memory. We administered two priming tests in an effort to increase the power of our priming measure because the learning effect seen with pattern priming is small. In the *Baseline Session* subjects viewed each pattern of dots and drew the first figure that came to mind by connecting the dots of each pattern with straight lines (Figure 12). In *Priming Test 1* subjects copied each of the 6 target figures onto dot patterns, followed by a 3-min distractor task (naming items within the categories of politicians, entertainers, or athletes). Subjects then performed the test phase by drawing the first figure that came to mind onto each of the same 6 dot patterns (Figure 12). The percentage of target figures drawn identically to the copied figures yielded a measure of studied completions. If subjects completed a dot pattern to a target figure during the *Baseline* session, that trial was scored as a baseline completion. The measure of priming was the difference between studied completions and baseline completions. In this way, I insured that any learning observed during the priming tests was not confounded by a subject's natural predisposition to complete a dot pattern in a particular way. *Priming Test* 2 followed the same procedure (and used the same dot patterns) as *Priming Test 1*, but used a different test form and a different fluency category for the distractor test (Figure 12). The *Recognition Test* employed the same copy and distractor procedures as the priming tests, but with a different test form and a different fluency category. At test, subjects viewed each of the six patterns of dots and indicated by pointing, in a four-alternative forced-choice paradigm, which of four possible completions

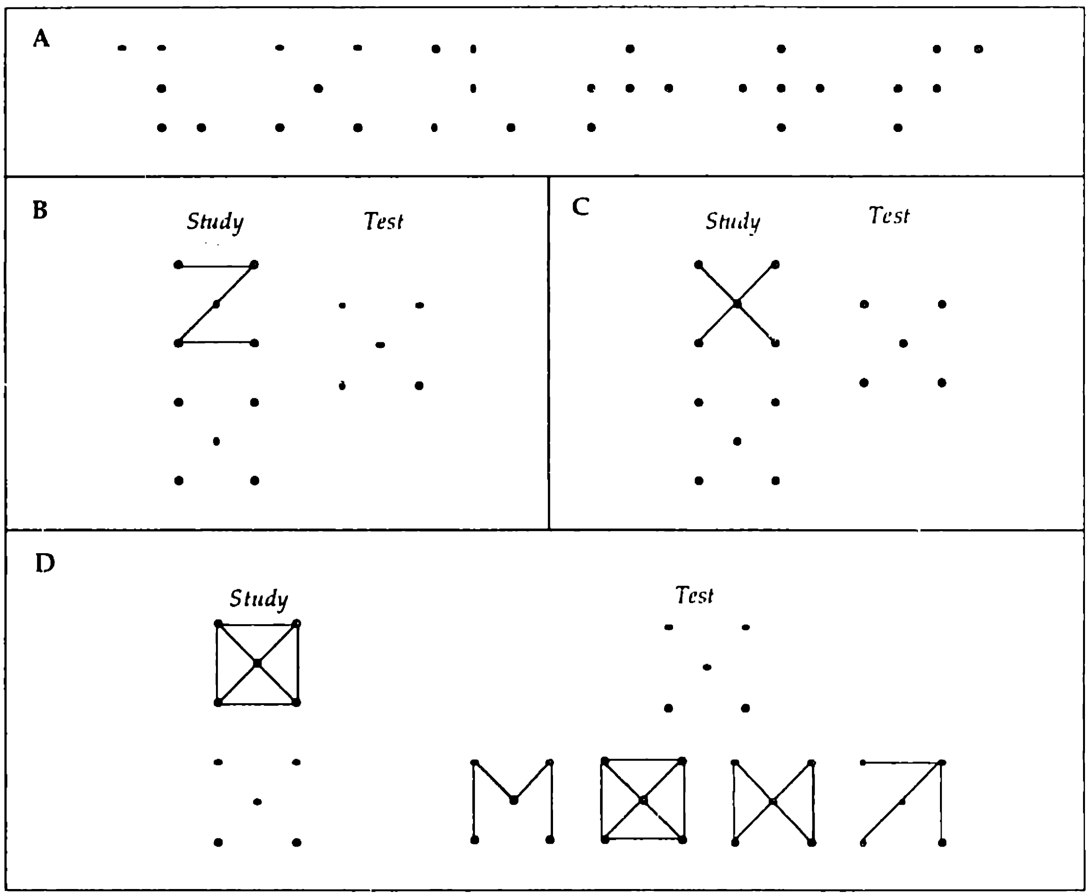

Figure 12. a. The six dot patterns used in Experiment 8.
b. An example of the stimuli used on a single trial of *Priming Test 1*.
c. An example of the stimuli used on a single trial of *Priming Test 2*.
d. An example of the stimuli used on a single trial of the *Recognition Test*.

corresponded to the figure they had copied 3 minutes earlier (Figure 12). Test forms were counterbalanced across subjects, so that each of the three forms was used in equal proportions for Priming Test 1, Priming Test 2, and the Recognition Test with each group.

Results

Statistical tests confirmed a priming effect in each group: For NCS, the mean number of studied completions on *Priming Test 1* (21.4%) differed from the mean number of baseline completions (13.7%) at a marginally significant level ($p < .07$); For the AD group, the mean studied completions (20.4%) differed significantly from the number of mean baseline completions (11.7%) ($p = .01$). Mean studied completions on *Priming Test 2* (NCS = 12.9%; AD = 12.3%), however, did not differ significantly from mean baseline completions. The reduction of studied completions for both groups in *Priming Test 2* was due to interference from figures studied during *Priming Test 1*: NCS completed 12.7% of the dot patterns in *Priming Test 2* to figures studied in *Priming Test 1*, and AD subjects completed 13.8% of the dot patterns in *Priming Test 2* to figures studied in *Priming Test 1*. Because of these interference effects, scores from Priming Test 2 were not submitted to further analyses. Further discussion of pattern priming effects will refer to the results from *Priming Test 1*.

Because non-normal distributions precluded further analysis of the priming results with an ANOVA, I employed nonparametric tests (Wilcoxon Rank-Sum tests) to determine that NCS and AD scores did not differ in mean studied completions ($p > .8$) or in mean baseline completions ($p < .6$). I tested for an interaction by comparing the mean of the sum of NCS studied completions and AD baseline completions with the mean of the sum of AD studied completions and NCS baseline completions: A nonsignificant result indicated that there was no significant interaction (Figure 13).

Next, I calculated corrected priming scores by subtracting mean baseline completions from mean studied completions (NCS = 7.7% [*SD* = 14.5]; AD = 8.6% [*SD* = 20.0]) (Figure 11). The Spearman correlations between priming score and BDS (IMC) were not significant for either group, nor did a Wilcoxon Rank-Sum test indicate that the two groups differed significantly on the priming measure ($p > .7$). Because one cannot prove the null hypothesis, I sought to determine statistically the true difference between NCS and AD priming scores. The difference between the mean scores of the two groups in our study (AD - NCS) was .9%. A 95% confidence interval indicated that the true difference between the two groups was bounded by a lower confidence limit of -9.5% and an upper confidence limit of 11.4%. Thus, with 95% certainty, I can assert that the true values of the pattern priming scores of the two populations were such that the NCS value did not exceed the AD value by more than 9.5%, and the AD value did not exceed the NCS value by more than 11.4%

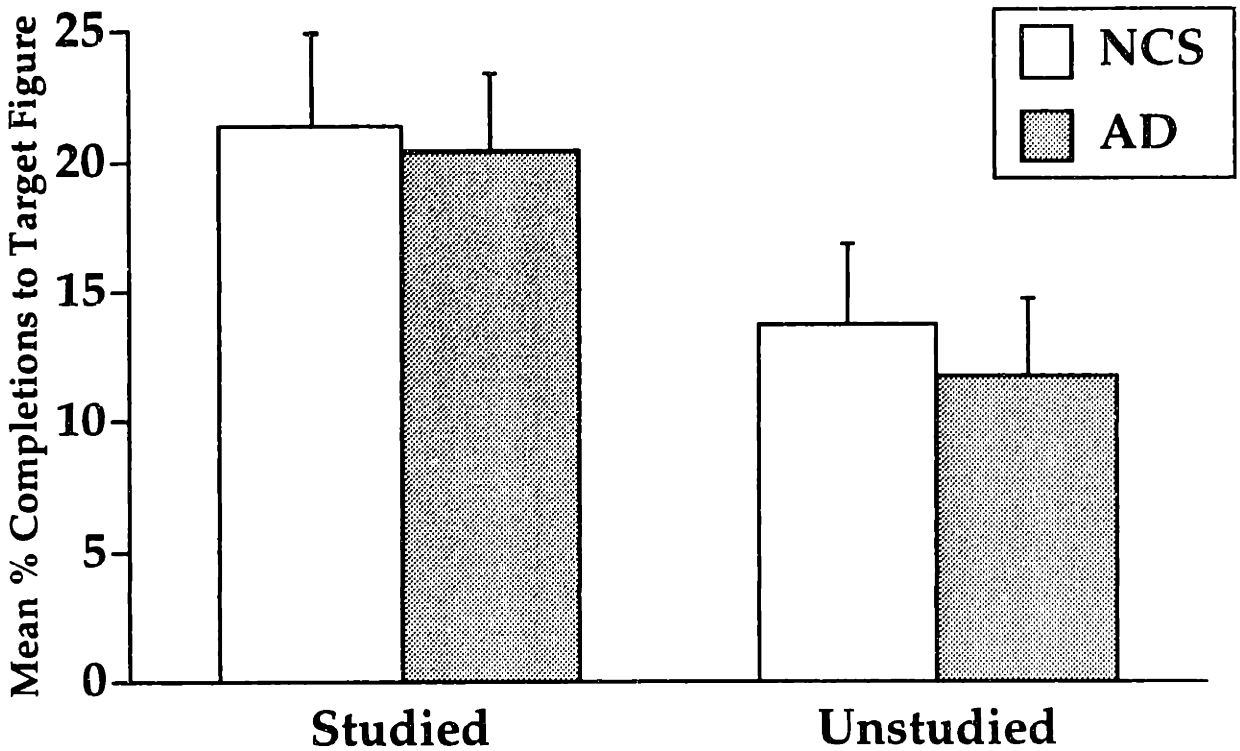

Figure 13. Mean percentage completion of patterns to target figures. The priming score for each group is the difference between studied completions and unstudied completions.

The NCS scored significantly higher on the *Recognition Test* (mean = 55.3%; *SD* = 26%) than the AD subjects (mean = 35.7%; *SD* = 25.3%), (t (47) = -2.6; p = .01) (Figure 14). The correlation between the recognition score and the BDS (IMC) score was not significant for either group.

The correlations between the priming and recognition scores within each group were nonsignificant: NCS r = .2 (p > .2); AD r = -.7 (p > .9). This result indicates that, for both groups, there was no tendency for subjects who did well on the *Recognition Test* to do well on the *Priming Tests,* nor vice versa.

Discussion

I investigated pattern priming in 23 AD subjects and 26 NCS to test the hypothesis that the neural substrate of this nonverbal repetition priming phenomenon is peristriate cortex. On the measure of nondeclarative memory (*Priming Test 1*), the AD and NCS groups achieved comparable performance. On the measure of declarative memory (the *Recognition Test*), the AD group was significantly impaired relative to NCS. This result indicates that pattern priming does not rely on the medial temporal-lobe memory system, which is compromised in AD, and is consistent with results from previous experiments that tested amnesic subjects with etiologies other than AD (Gabrieli et al., 1990a; Musen et al., 1992; Verfaellie et al., 1992;

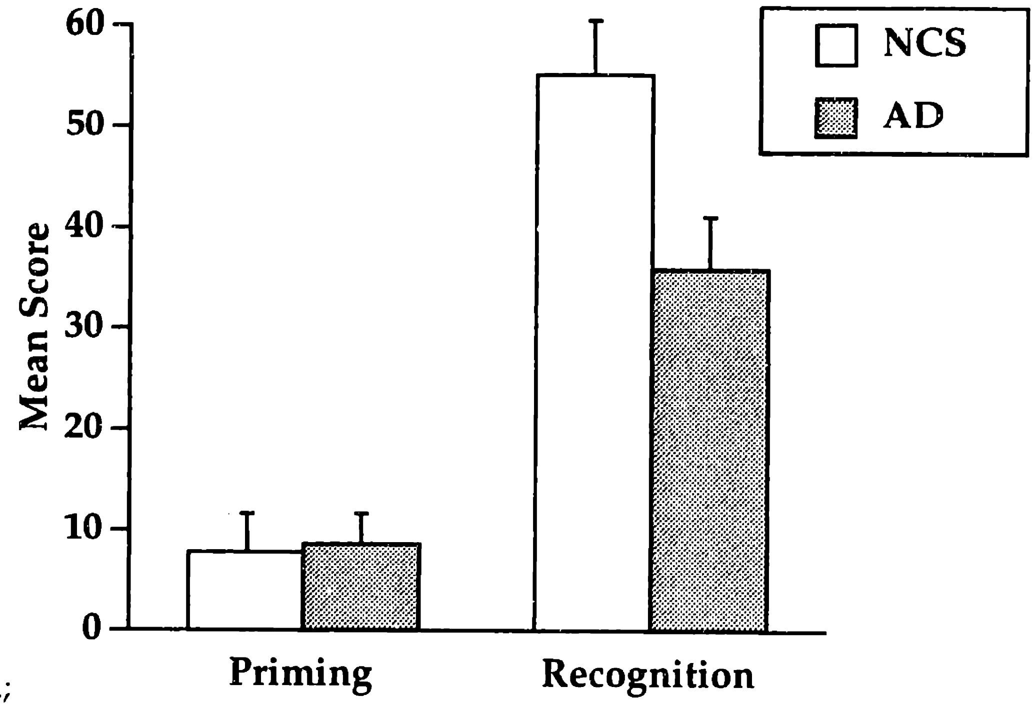

Figure 14. Mean performance, by group, on *Priming Test 1* and the *Recognition Test*.

Gooding et al., 1993; Gooding et al., 1994). Although demonstrations of stochastic independence are not definitive evidence for the existence of the operation of discrete mnemonic mechanisms (Hintzman, 1990), the absence of a significant positive correlation between priming and recognition scores for each group is consistent with the interpretation that subjects relied on different memory processes to perform the two tests in our experiment. A carry-over effect of priming from *Priming Test 1* to *Priming Test 2*, tests that were separated by a minimum of 5 hours, indicated that the pattern priming effect was long-lasting, a result that is consistent with a previous report that pattern priming effects can last for 1 week or longer (Musen and Treisman, 1990).

The priming results indicate that nondeclarative memory for novel nonverbal stimuli is preserved in AD subjects: Statistical analyses demonstrated that the priming performance of the two groups was comparable. This finding is consistent with previous studies from our laboratory in which AD subjects showed intact perceptual identification priming with words and pseudowords (Keane et al., 1991; Keane et al. 1994). In these studies, AD subjects and NCS studied a list of words or pseudowords, and were subsequently able, under tachistoscopic presentation conditions, to identify previously studied stimuli at shorter exposure durations than unstudied stimuli. Testing perceptual identification priming with pseudowords, meaningless combinations of letters that are presumed to be novel to the subjects, employed a similar logic to that employed in the present study. A finding of intact priming with novel stimuli indicates that the learning takes place at a perceptual level of processing, "upstream" (in information processing terms *and* in brain systems terms) from a level where interactions with representations in long-term memory would take place. Taken together, the findings of Keane and colleagues (1991; 1994) and those presented in this report indicate that perceptual priming, tested across a broad range of tasks and stimulus types, is preserved in AD.

The present finding of intact pattern priming in AD suggests that perceptual priming with *nonlinguistic* stimuli depends upon a brain area that is relatively spared in AD, possibly peristriate cortex. I have ruled out higher level, heteromodal cortical areas (e.g., inferotemporal and posterior parietal cortex) as candidate substrates for pattern priming because these areas are preferentially vulnerable to AD pathology (Arnold et al., 1991). Consistent with my reasoning are studies of word-stem completion priming that reveal significantly disrupted performance in AD (Keane et al., 1991; Gabrieli et al., 1994). Word-stem completion priming is a type of repetition priming that relies on lexical access (and thus on the integrity of heteromodal temporo-parietal cortex). If pattern priming relied on the same heteromodal temporo-parietal areas, I would also expect to see impaired performance in AD on this task. Also consistent with my hypothesis are the results of electrophysiological investigations of nonhuman primates showing plasticity in the response properties of neurons in low-level, unimodal sensory cortex in association with perceptual learning (Recanzone et al., 1992a; Recanzone et al., 1992b; Recanzone et al., 1993; Bertini et al., 1995), as well as neuroimaging research in humans that indicates that the neural substrate of structurally mediated verbal priming includes posterior visual cortex (Squire et al., 1992; Buckner et al., 1995; Schacter et al., 1996).

Although the brain mechanisms that underlie pattern priming in humans cannot be determined using the behavioral methods that I and other researchers have employed, physiological and pharmacological research using other experimental paradigms can shape our hypotheses. Positron emission tomography (PET) investigations of word-stem completion priming suggest a mechanism that may also underlie pattern priming. In addition to its lexical access component, word-stem completion priming has a perceptual component (e.g., the effect is reduced by shifts of modality between study and test) (Graf et al., 1985; Bassili et al., 1989; Postle and Corkin, 1994). These PET studies have revealed decreases in blood flow in peristriate cortex when subjects performed the priming phase of these tests, in comparison with baseline (unprimed) performance (Squire et al., 1992; Buckner et al., 1995; Schacter et al., 1996). These findings have been interpreted as suggesting that the processing of repeated presentations of a stimulus requires less neural activity than was required for the initial processing. Electrophysiological investigations in nonhuman primates have uncovered response properties of single cortical neurons that bear some similarity to these PET findings (Li et al., 1993; Fahy et al., 1993; Miller and Desimone, 1994). A recent PET study of nonverbal object priming, however, has found the opposite result. This study revealed blood flow increases in the inferior temporal and fusiform gyri in association with priming on a "possible/impossible" object decision task (Schacter et al., 1995). A double-blind study using the partial glycine agonist d-cycloserine, which is active at the NMDA-type glutamate receptor complex, has revealed enhanced perceptual identification priming in AD with the application of this putatively long-term potentiation-enhancing compound (Schwartz et al., 1996). Thus, although further physiological investigations coupled with careful experimental design need to be carried out, I can postulate that the phenomenon of pattern priming may result from an alteration in the activity of the networks of neurons in posterior regions of the visual system that are recruited to accomplish the perceptual grouping that is necessary to perceive a pattern of scattered dots as a coherent whole.

Experiment 9: Effects of Varied Encoding Time on Pattern Priming in AD and NCS

An unattended result of my initial study of pattern priming in AD (Postle et al., 1996; Experiment 8) was that AD subjects, although statistically impaired, performed better than expected on the test of recognition memory. I hypothesized that this result could be explained if the AD subjects took longer to draw each pattern during the study sessions, thereby benefiting from longer exposure to the stimuli (and therefore from higher quality encoding) than NCS. If this hypothesis were true, it could mean one of two things: 1) that pattern recognition benefits from longer exposure duration to stimuli at study, but pattern priming is relatively insensitive to this manipulation (because longer exposure times did not result in higher priming scores for AD patients); or, 2) that longer exposure duration to stimuli for the AD patients may have boosted their performance in *both* measures of memory. This second interpretation would suggest that AD subjects are in fact *impaired* at pattern priming, but that the seeming equivalence of performance between AD subjects and NCS in Experiment 8 arose artifactually because the AD subjects benefited from longer exposure to the stimuli than NCS.

The hypothesis that pattern priming is insensitive to manipulations of exposure duration is consistent with previous work by Musen (1991), indicating that pattern priming, as assessed by a tachistoscopic presentation method, was insensitive to exposure duration manipulations. PI priming has also been shown to be insensitive to this manipulation (Jacoby and Dallas, 1981; Hirshman and Mulligan, 1991). I tested the two hypotheses by investigating the effects of varying drawing time on the pattern priming effect in AD.

Methods

Subjects

We tested 13 NCS and 12 AD subjects (Table 8).

Procedure

Because this experiment was an follow-up investigation to the priming and recognition results in Experiment 8, I employed the same testing procedure from that experiment, rather than directly manipulating exposure duration as an independent variable. During the study session, we recorded the drawing time associated with each trial during the study sessions. Trials for each group were later binned into four groups, and I calculated the mean drawing time associated with *priming hits, priming misses, recognition hits,* and *recognition misses.* Because these data were analyzed separately by group with repeated measures statistical tests, planned post-hoc analyses of were restricted to the 12 NCS and 11 AD subjects who had at least one observation in each of the four cells of the experimental design.

Table 8. Subject characteristics for Experiment 9.

Group	N [M,F]	Mean Age [*SD*]	Mean Education [*SD*]	Mean BDS: IMC* [*SD*]
NCS	13 [6,7]	67.4 [6.8]	14.6 [3.0]	1.6 [2.6]
AD	12 [6,6]	71.2 [7.5]	16.5 [3.7]	10.9 [9.6]

*Blessed Dementia Scale: Information, Memory, and Concentration Section (Blessed et al., 1968)

Results

There was little variability in the NCS' drawing times associated with each of the four trial types, obviating a meaningful examination of the effect of drawing time variability on NCS performance (Figure 15). A mixed between (group) and within (test-type [priming/recognition]; success [hit/miss]) factors ANOVA indicated that the NCS' mean drawing time collapsed across test-type and condition was significantly shorter than the AD subjects drawing time ($\underline{F}(1,13) = 9.2$; $\underline{p} < .01$). No other effects were significant. Paired $\underline{t}$ tests of the AD data revealed no difference between mean drawing times associated with priming-hits and priming-misses, but a significant difference between recognition-hits and recognition-misses ($\underline{t} = 2.2$; $\underline{p} = .05$; $\underline{n} = 11$) (Figure 15).

Discussion

These results suggested that, in AD, pattern priming is insensitive to the duration of encoding time, whereas pattern recognition is not. These results confirm that the equivalence of AD and NCS pattern priming in Experiment 8 was not due to differential amounts of drawing time. These results may also have considerable theoretical significance germane to the nondeclarative/declarative dichotomy. There are two possible explanations of the dissociation between pattern priming and pattern recognition: 1) if the longer drawing time required by AD subjects reflects slowed attentional and/or motor processes in AD, then the dissociation reflects differential sensitivity of pattern priming and pattern recognition to encoding time (as suggested by Musen [1992]); 2) if the longer drawing time required by AD subjects reflects degraded perceptual processing of these stimuli, then the dissociation reflects differential sensitivity to the quality of perceptual

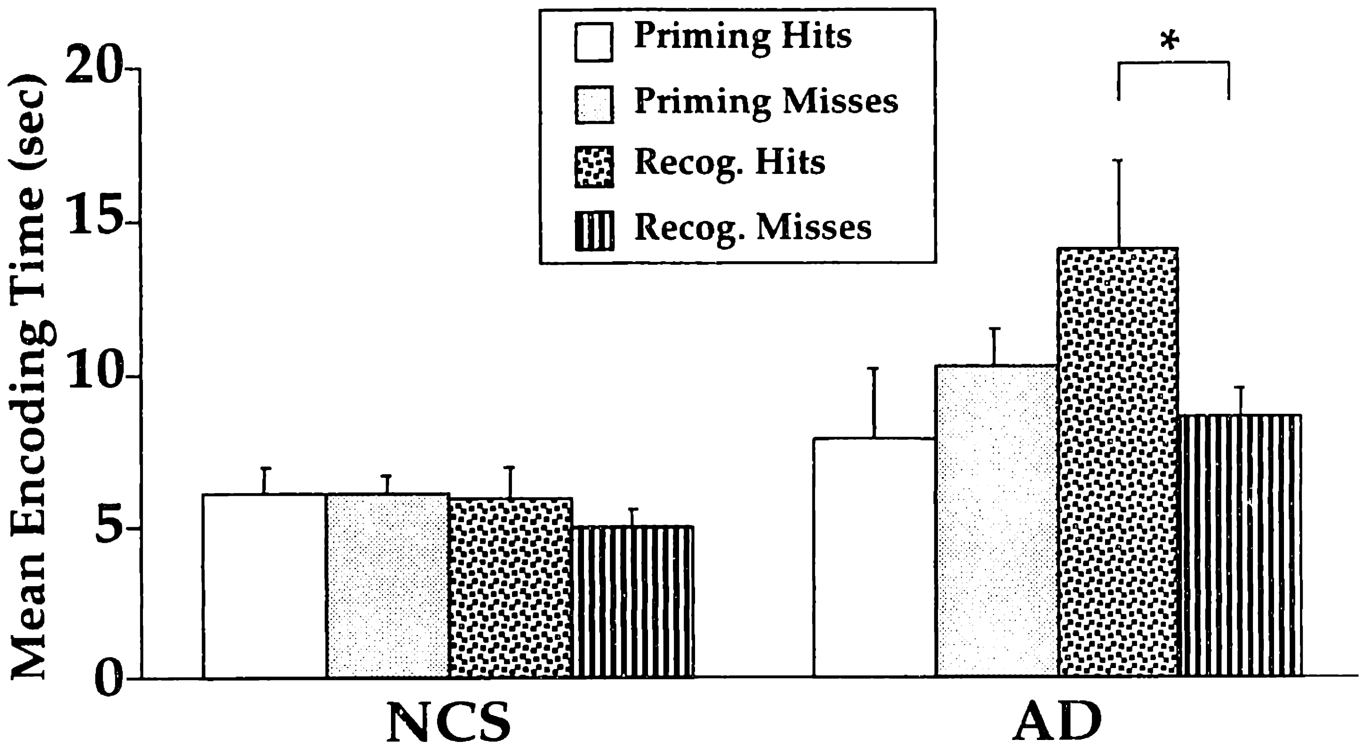

Figure 15. Significant difference between mean drawing time associated with recognition hits and recognition misses in the AD group, but no difference in the priming test.

processing at encoding. The dissociation could also reflect contributions from both of these sources. Future studies will pursue these issues.

Experiment 10: The Cognitive Mechanism Underlying Pattern Priming: Perceptual Learning or Motor Learning?

Early AD pathology relatively spares low-level, unimodal sensory and motor neocortices (Arnold et al., 1991). We have hypothesized, therefore, from our previous finding of intact pattern priming in AD (Experiment 8; Postle et al., 1996), that a critical neural substrate for pattern priming is peristriate cortex. This logic, however, does not permit us to rule out motor cortex as a candidate locus of this learning. Previous studies of pattern priming in college students (Musen and Treisman, 1990) and in amnesic subjects (Musen et al., 1992), have employed a tachistoscopic presentation procedure that yielded nondeclarative learning that was unambiguously perceptual. We designed Experiment 9 to confirm that the pattern priming effect that we have described in AD (Experiment 8; Postle et al., 1996), using our copy-and-draw procedure, also represents *perceptual* nondeclarative learning.

Methods

Subjects

We tested 5 NCS and 5 subjects with AD (Table 9).

Table 9. Subject characteristics for Experiment 9.

Group	N [M,F]	Mean Age [*SD*]	Mean Education [*SD*]	Mean BDS: IMC* [*SD*]
NCS	5 [1,4]	72.3 [9.2]	12.0 [0]	1.5 [1.3]
AD	5 [3,2]	72.5 [8.7]	15.3 [5.0]	11.5 [3.4]

*Blessed Dementia Scale: Information, Memory, and Concentration Section (Blessed et al., 1968)

Procedure

The testing methods for Experiment 10 were identical to those used in Experiment 8, except that we administered a single priming session and no recognition test. We videotaped the testing sessions to permit off-line motor learning analysis, and assigned a "Motor Index" score to priming hit trials by scoring each trial according to the direction and sequence of pen strokes.

Motor Index

The logic of this scoring procedure was that, if motor learning was the basis of the pattern priming effect that I observed in Experiment 8, the sequence and direction of pen strokes produced during priming hit trials would have to be identical to those that had been executed during the corresponding study trial. Analyses were restricted to priming hit trials. A Motor Index score for each hit trial was derived by awarding one point for each line segment that was drawn with a stroke in the same direction and occurring in the same sequence of strokes during the test session as during the study session, and dividing this number by the total number of line segments in that shape. A point was deducted for out-of-sequence strokes for only the first stroke that broke with the study sequence, if the subsequent strokes replicated the study sequence but were simply out of phase with it (Figure 16). Thus a motor index of 1 for a stimulus pattern would indicate complete correspondence of the sequence and direction of pen strokes between the study and test trials associated with that pattern. Such a score

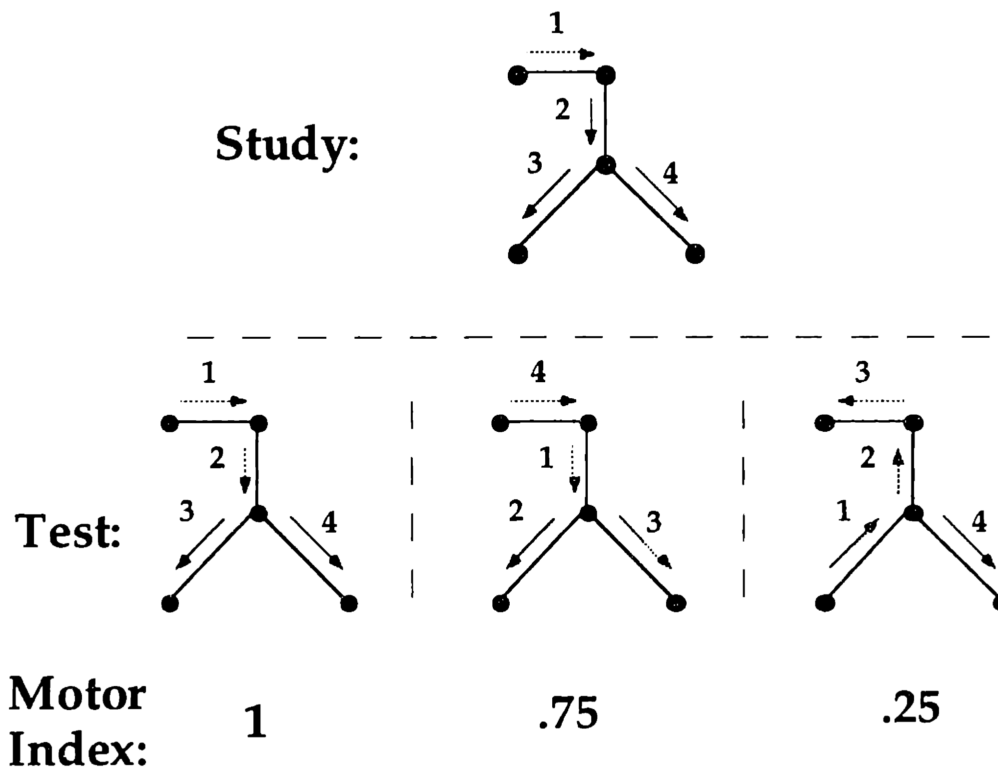

Figure 16. Motor Index scoring, illustrated by the sequence and direction of pen strokes in a study trial and three possible patterns (and their corresponding Motor Index) in the priming session.

would not unambiguously prove that motor learning was the phenomenon underpinning learning on that trial, merely that motor learning was a candidate mechanism. If, however, the score for a trial were less than 1, this outcome would indicate unequivocally that motor learning was *not* the sole basis of learning on that trial. I opted for this somewhat clumsy design because it permitted us to replicate the testing procedure that we had used in Experiment 8, and because of my strong *a priori* prediction that pattern priming is *not* primarily a motor learning phenomenon.

Results

The mean NCS Motor Index was .72; the mean AD Motor Index was .55, suggesting that a significant component of the pattern priming effect for both groups is perceptual.

Discussion

I interpret these results to be consistent with my hypothesis that the neural substrate of pattern priming is peristriate cortex. As discussed earlier, this cortical region has been hypothesized to be the locus of other types of nondeclarative perceptual learning, such as perceptual identification priming (e.g., Keane et al., 1995). Similarities between pattern priming and PI priming will be considered in the General Discussion of this chapter.

Experiment 11: The Effect of Size Translation on Pattern Priming

Computational analyses of the human visual system indicate that one characteristic of a high level of the visual system must be the stability of representations over changes in viewing conditions (i.e., the system must be able to be recognize an object regardless of its distance [and therefore retinal size], orientation, level of illumination, etc.) (e.g., [Marr, 1982; Plaut and Farah, 1990]). Considerable evidence exists that ensembles of neurons in inferotemporal (IT) cortex in the monkey demonstrate the property of size invariance (e.g., Sato et al., 1980; Perrett et al., 1982; Schwartz et al., 1983; Desimone et al., 1984). Clearly, advanced stations of the human visual system in ventral temporal cortex (e.g., Alexander and Albert, 1983; Kanwisher et al., in press) also subserve complex object recognition functions, such as the creation and storage of size invariant representations of objects. This knowledge has been exploited by researchers to probe the levels of information processing that support different types of visual memory. For example, Biederman and Cooper demonstrated with a partial presentation technique that priming of object naming takes place even when none of the features presented at test were presented at study (Biederman and Cooper, 1991), and that such priming is invariant to translations in size between study and test (Biederman and Cooper, 1992). Additionally, Cooper and colleagues (1992) demonstrated priming of possible/impossible judgments of 3-dimensional objects despite study-to-test transformations in size or reflection.

These studies point the way to a test of my interpretation of the results of Experiment 8, that intact pattern priming in AD indicates that this phenomenon can be supported in peristriate cortex: Because AD pathology targets the regions of ventral temporal cortex (i.e., areas 37, 20, and 21 [Arnold et al., 1990]) that are believed to support high-level, stable object representations, retinal translations in size of pattern stimuli between study and test should interfere with pattern primir g in AD. The results of previous object priming studies (Biederman and Cooper, 1992; Cooper et al., 1992) led us to predict that pattern priming should be relatively intact in NCS despite the size-translation manipulation.

Methods

Subjects

To date, we have tested 20 NCS and 15 AD subjects (Table 10). We plan to test 26 NCS and 23 AD subjects, the same number tested in Experiment 8.

Materials

The dot pattern stimuli used in the study session were those used in Experiment 8, plus six new stimuli that were generated in the same manner. Test stimuli were the same dot patterns, but translated in size by 300%.

Table 10. Subject characteristics for Experiment 11.

Group	N [M,F]	Mean Age [*SD*]	Mean Education [*SD*]	Mean BDS: IMC* [*SD*]
NCS	20 [6,7]	65.3 [12.6]	13.1 [2.5]	.6 [.9]
AD	15 [6,6]	75.1 [6.7]	14.0 [3.6]	10.9 [4.7]

*Blessed Dementia Scale: Information, Memory, and Concentration Section (Blessed et al., 1968)

Procedure

Testing was performed in one session, with subjects studying 6 shapes, followed by the 3-min distractor test, followed by pattern completion (priming) with 12 shapes, 6 corresponding to studied shapes, and 6 unstudied patterns serving as baseline stimuli.

Results

Analyses of these preliminary data with a 2 x 2 within (study-type) and between (group) subjects ANOVA revealed no significant effects, although there was a trend toward a main effect of study-type ($F(1,33) = 2.08$; $p = .15$) (Figure 16). Planned comparisons indicated that the priming effect was not significantly different from 0 in either group (NCS mean priming score = 6.0% [*SD* = 20.4]; AD mean priming score = 4.4% [*SD* = 22.2]). The difference between the mean scores of the two groups in our study (NCS - AD) was 1.6%. A 95% confidence interval indicated that the true difference between the two groups was bounded by a lower confidence limit of -13.2% and an upper confidence limit of 16.3%, a greater interval than that bounding the difference of mean scores in Experiment 8.

Discussion

Analyses of our preliminary data indicate that the size translation manipulation produced greater variability in the performance of both groups than the standard pattern priming experiment (Experiment 8), postponing conclusive interpretation of the results of this experiment until more data are collected. It is already evident, however, that our results diverge from those reported in previous size-translation object priming experiments (Biederman and Cooper, 1992; Cooper et al., 1992) because both of these experiments found

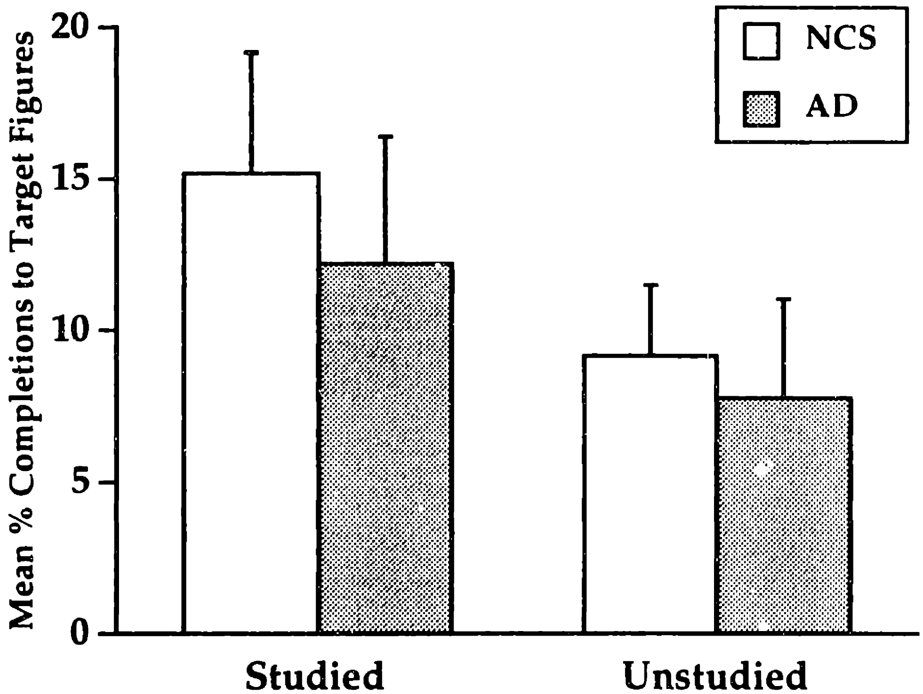

Figure 17. Preliminary results from Experiment 11. Error bars represent standard error of the mean.

that the size translation manipulation had no effect on the size of the priming effect. This discrepancy may be due to important methodological differences between the present study and these earlier studies: Biederman and Cooper (1992) measured priming as a function of RT in a same/different object judgment task, and Cooper et al. (1992) measured priming as a function of accuracy of a possible/impossible judgment about 3-dimensional objects. Our task, in contrast, was a completion paradigm, formally similar to WSC priming. It is possible that if we modified our procedure to make our task a perceptual judgment task, it would behave in a way more similar to the tasks of Biederman and Cooper (1992) and Cooper et al. (1992).

The preliminary trends in the data, however, do prompt speculation that the size translation has a greater effect on the AD subjects than on NCS, an observation consistent with my predictions. If these trends hold up across more testing they will suggest interesting parallels with PI priming. Future studies will investigate this homology by examining the effects of size manipulations on PI priming.

General Discussion

My investigations of pattern priming in AD have generated many empirical observations: Pattern priming is spared in AD; the effect is insensitive to differences in drawing time; it can be expressed through motor patterns that differ between study and test; and study-to-test translations in size disrupt the effect in NCS and in AD, possibly to differing degrees. An implication of these results for our understanding of cortical mechanisms of learning is that learning can be supported in low-level sensory cortices. At a theoretical level of analysis these observations indicate that the principles governing cortically based nondeclarative perceptual learning are different from those that mediate declarative learning that is supported by medial-temporal structures. They also prompt speculation that pattern priming may share common properties with verbal perceptual learning, such as PI priming. PI priming, like pattern priming, demonstrates insensitivity to the manipulation of encoding time (Jacoby and Dallas, 1981; Hirshman and Mulligan, 1991). This similarity is of interest because these two tasks are very different procedurally: PI priming is an identification task, whereas pattern priming is a completion task, formally similar to WSC priming. Thus the results of these studies raise the possibility that nondeclarative memory tasks that have important methodological differences might, nevertheless, rely on the same mechanisms of plasticity.

CHAPTER 5

CONCLUSIONS

The modified proceduralist theory that has guided the research presented in this thesis posits that nondeclarative memory is a byproduct of the plasticity intrinsic to the central nervous system and, thus, that it can be observed in virtually any process that the central nervous system carries out. I have argued that the most effective way to elucidate the mechanisms that underlie different kinds of repetition priming is to analyze carefully the cognitive processes that subjects must engage in order to accomplish the primary task. For example, task analysis indicated that word-stem completion requires subjects to engage in a lexical search, whereas perceptual identification requires subjects to parse a visually noisy scene. This analysis led to the hypothesis, tested in Chapters 2 and 3, that the two types of repetition priming that can be expressed through these tasks arise, at least in part, from plastic change in distinct cognitive processes. It is also likely the case that these two examples of repetition priming are supported by partially discrete neural substrates (Keane et al., 1991; 1995).

The modified proceduralist approach that I have espoused in this thesis differs in important ways from memory systems models of repetition priming, from transfer-appropriate processing models, and from strict interpretations of proceduralist models. Memory systems models posit that different types of repetition priming reflect the existence of different nondeclarative memory systems (e.g., Schacter and Tulving, 1994; Gabrieli, et al., 1994). Gabrieli and colleagues (1994), for example, have stated that a memory system is "the minimal neural network required to record, retain, and retrieve a form of knowledge" (p. 93). Sherry and Schacter (1987) have proposed a similar definition. By this definition, the motor system, vestibulo-ocular system, visual perceptual system, and many other brain systems qualify as memory systems. I believe that this approach makes the study of nondeclarative memory unnecessarily complicated. The modified proceduralist approach offers the alternative view that repetition priming arises from plasticity in systems whose primary function is not mnemonic. Guided by this heuristic, I characterize each of the above-listed systems as brain systems that have the capacity to demonstrate memory. This distinction is more than a terminological one, because the memory systems approach can lead to imprecise models, and thus to inaccurate empirical predictions, as I will demonstrate in the next paragraph. I have characterized my approach as a *modified* proceduralist view because it deviates from a strict interpretation of proceduralist theory (e.g., Crowder, 1993), as well as from transfer-appropriate processing theories (e.g., Blaxton, 1989; Roediger, 1990), in that it asserts the existence of a declarative memory system whose primary function *is* mnemonic. Declarative memory qualifies as a memory system by the principle of functional incompatibility (Sherry and Schacter, 1987), because it has adapted to serve a specialized function that makes it unable to serve nondeclarative memory functions. The importance of the declarative/nondeclarative distinction is highlighted by WSC priming, which is a type of nondeclarative memory that arises from plasticity in a declarative memory system: the mental lexicon. As explained by the modification model, plasticity in the lexical memory system is sufficient to account for Gabrieli's three requirements for a memory system (Gabrieli et al., 1994): 1) The act of reading a word is *recorded* through modification of that word's representation in the lexicon; 2) this level of modification is *retained* for a period of time[12]; and 3) the (nondeclarative) knowledge of the study experience is *retrieved* during the search of the lexicon for a word beginning with a particular three-letter stem. The nondeclarative feature of this process is the state of modification of certain elements in the lexicon. Subjects, if not deliberately thinking of the study episode, are not aware that certain lexical entries are modified, yet these states of modification bias the lexical retrieval procedure that subjects initiate consciously when asked to complete three-letter stems.

The memory systems approach has resulted in important contributions to our understanding of nondeclarative memory. For example, the dissociation of WSC priming and PI priming was first described in investigations of dissociations of the conceptual priming system (of which WSC priming has been characterized as an exemplar) and the perceptual priming system (of which PI priming has been characterized as an exemplar) (Keane, et al., 1991). This and subsequent studies also established that these two types of repetition priming rely on distinct neural substrates (Keane et al., 1991; 1995). But a shortcoming of memory systems analysis is that, although it provides a useful way to organize different types of priming into general categories, it gives no insight into the mechanisms that underlie different types of priming. This mechanistic vagueness can lead to problems when over interpretation of a memory systems organizational scheme leads to the assumption that all types of priming falling under a particular rubric rely on common mechanisms. In an illustration of this point, Maki and Knopman (1996) recently challenged the validity of the perceptual/conceptual distinction by comparing the performance of AD subjects and NCS on a "*perceptual*" rhyme exemplar general task and a *conceptual* category exemplar generation task. They noted that Keane and colleagues (1991) had proposed that AD subjects perform normally on perceptual priming tests, but are impaired on conceptual priming tests. The results of their experiment, in contrast, indicated that AD subjects performed as well as NCS on both tasks when they generated target items at study, but were impaired on both tasks when they repeated target items at study (Maki and Knopman, 1996). They concluded that methodological factors (type of processing at study) were more important than the conceptual or perceptual nature of the task in determining the results. I suggest, however, that the two tasks used in the Maki and Knopman experiment shared an important common characteristic: Each required subjects to engage in a search of stored representations of words (one search done by phonology, the other done by semantics). Therefore the status of the rhyme exemplar generation task as a perceptual task is insecure,

[12] The duration of modification of elements in the lexicon may be as brief as 2 hrs (Graf et al., 1984) or as long as several days (Roediger et al., 1992).

and it is not surprising that predictions based on strict adherence to the perceptual/conceptual organizational scheme were not born out. WSC priming is another task that does not fit easily into the perceptual/conceptual framework, because perceptual and lexical mechanisms can each contribute to the learning that is observed in this task. These examples suggest that careful analysis of the mechanisms and procedures that are engaged by a specific task yield greater analytic precision and predictive power than can memory systems models, such as the perceptual/conceptual model.

The results of Experiment 8 (intact pattern priming in AD), when paired with those of Keane et al. (1991), indicate that the neural substrate of pattern priming is similar to, and perhaps the same as, that of PI priming. The results of Experiment 9, when paired with those of Musen (1992), suggest that pattern priming may share important properties with PI priming. These similarities, particularly interesting in view of the methodological differences of these two tasks, suggest that similar mechanisms may mediate the learning on these two kinds of repetition priming. A possible physiological correlate of visuoperceptual repetition priming has been suggested by neuroimaging studies that have revealed a decrease in blood flow in posterior temporal and anterior occipital cortical regions in association with facilitated behavioral performance (Squire et al., 1992; Buckner et al., 1995; Schacter et al., 1996). A likely candidate for the information processing system(s) that gives rise to these two examples of repetition priming is the perceptual representation system (PRS), a "collection of cortically based perceptual systems that process and represent information about the form and structure, but not the meaning and associative properties, of words and objects" (Curran et al., 1996, p. 23; Schacter, 1990).

Sherry and Schacter (1987) have proposed that the anatomical dissociation of memory-supporting brain regions "need not imply the existence of multiple memory systems operating according to different rules" (p. 440). One illustration of this point comes from the fMRI studies of Karni and colleagues (1995a; 1995b), that have revealed similar temporal profiles for fMRI signal change in subjects as they learned two different kinds of tasks, a motor skill learning task and a visual skill learning task: a transient decrease of fMRI signal intensity followed by a slower developing, long-lasting increase in the area of activation. These changes were seen independently in two different experiments in two anatomically and functionally disparate regions of cortex. In this context, it would be imprudent to hypothesize forcefully that PI priming and pattern priming arise from plasticity in the same system, because the anatomical overlap of the cortical regions supporting them is neither a sufficient nor a necessary condition for hypothesizing that they arise from plasticity in the same system. Indeed, because object perception and word perception undoubtedly engage, at least partly, different perceptual mechanisms (Fodor, 1983), my results are consistent with the model that these two kinds of repetition priming represent the functioning of two PRS subsystems (Schacter, 1994).

The modified proceduralist theory is best viewed not as rejecting memory systems and transfer-appropriate processing theories, but as incorporating important ideas from each to assemble a stronger theory. Like the componential theory (Witherspoon and Moscovitch, 1989; Hintzman, 1990; Tenpenny and Shoben, 1991; Moscovitch, 1994), the modified proceduralist theory views different nondeclarative memory tests as "composed of various component processes" (McDermott and Roediger, 1996, p. 68), some shared and some unique. These component processes adhere to the principles laid out in transfer-appropriate processing theory, and they are often supported by discrete brain systems. The power of the modified proceduralist approach comes from its appreciation of the fact that plasticity is a characteristic of virtually every process and system in the brain, and thus that careful attention must be paid to the processes and systems that are engaged by tasks that can reveal nondeclarative memory.

References

12,000 Words. (1986) Merriam-Webster Inc., Springfield, MA.

Alexander, M.P. and Albert, M.L. (1983). The anatomical basis of visual agnosia. In: Localization in Neuropsychology, A. Kertesz, (Ed.), Academic Press, New York, 393-415.

Arnold, S. E., Hyman, B. T. , Flory, J., Damasio, A. R. and Van Hoesen, G. W. (1991). The topographical and neuroanatomical distribution of neurofibrillary tangles and neuritic plaques in the cerebral cortex of patients with Alzheimer's disease. Cerebral Cortex, **1**, 103-116.

Atkinson, R. C. and Juola, J. F. (1974). Search and decision processes in recognition memory. In: Contemporary Developments in Mathematical Psychology, D. H. Krantz, R. C. Atkinson, R. D. Luce and P. Suppes (Eds.), **vol. I**, Freeman, San Francisco, 243-293.

Bassili, J. N., Smith, M. C., and MacLeod, C. M. (1989). Auditory and visual word-stem completion: separating data-driven and conceptually driven processes. The Quarterly Journal of Experimental Psychology, **41A**, 439-453.

Bechterew, W. v. (1900). Demonstration eines gehirns mit zerstorung der vorderen und inneren theile der hirnrinde beider schlafenlappen. Neurologisches Zentralb., **19**, 990-991.

Bertini, G., Karni, A., De Weerd, P., Desimone, R., and Ungerleider, L.G. (1995). A behavioral and electrophysiological study of monkey visual cortex plasticity. Society for Neuroscience Abstracts, **21**, 276.

Biederman, I. and Cooper, E.E. (1991). Priming contour-deleted images: evidence for intermediate representations in visual object recognition. Cognitive Psychology, **23**, 393-419.

Biederman, I. and Cooper, E.E. (1992). Size invariance in visual object priming. Journal of Experiment Psychology: Human Perception and Performance, **18**, 121-133.

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

Blessed, G., Tomlinson, B.E., and Roth, M. (1968). The association between quantitative measures of dementia and of senile change in the grey matter of elderly subjects. British Journal of Psychiatry, **114**, 797-811.

Bowers, J. and Schacter, D. L. (1993). Priming of novel information in amnesic patients: issues and data. In: Implicit Memory: New Directions in Cognition, Development, and Neuropsychology, P. Graf and M. Masson (Eds.), Erlbaum, Hillsdale, N.J., 303-326.

Bowers, J. S. (1994). Does implicit memory extend to legal and illegal nonwords? Journal of Experimental Psychology: Learning, Memory, & Cognition, **20**, 534-549.

Bowers, J. S. (1996). Different perceptual codes support priming for words and pseudowords: Was Morton right all along? Journal of Experimental Psychology: Learning, Memory, & Cognition, **22**, 1336-1353.

Braak, H. (1980). Architectonics of the Human Telencephalic Cortex. Springer-Verlag, New York.

Brashers-Krug, T., Krebs, H. Rauch, S., Savage, C., Rubin, R., Alpert, N., Fischman, A., Hogan, N., and Bizzi, E. (1995). PET imaging of human motor learning. Society for Neuroscience Abstracts, **21**, 517.

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

Brown, S. and Schäfer, E. A. (1888). An investigation into the functions of the occipital and temporal lobes of the monkey's brain. Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences, **179**, 303-327.

Buckner, R. L., Petersen, S. E., Ojemann, J. G., Miezen, F. M., Squire, L. R. and Raichle, M. E. (1995). Functional anatomical studies of explicit and implicit memory retrieval tasks. Journal of Neuroscience, **15**, 12-29.

Carlesimo, G. A. (1994). Perceptual and conceptual priming in amnesic and alcoholic patients. Neuropsychologia, **32**, 903-921.

Cermak, L. S., Verfaellie, M., Milberg, W., Letourneau, L., and Blackford, S. (1991). A further analysis of perceptual identification priming in alcoholic Korsakoff patients. Neuropsychologia, **29**, 725-736.

Chertkow, H., Bub, D. and Seidenberg, M. (1989). Priming and semantic memory loss in Alzheimer's disease. Brain and Language, **36**, 420-446.

Chertkow, H., Beauregard, M., Murtha, S., Bergman, H., Leblanc, S. Benhamou, J. and Gold, D. (1996). The impact of semantic impairment on implicit memory function in Alzheimer's disease. Society for Neuroscience Abstracts, **22**, 2119.

Church, K. (1988). A stochastic parts program and nour phrase parser for unrestricted text. Second Conference on Applied Natural Language Processing, Austin, Texas, pp. 136-143.

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

Cooper, L.A., Schacter, D.L., Ballesteros, S., and Moore, C. (1992). Priming and recognition of transformed three-dimensional objects: effects of size and reflection. Journal of Experimental Psychology: Learning Memory and Cognition, **18**, 43-57.

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. (1982). Some relationships between global amnesias and the memory impairments in Alzheimer's disease. In: Alzheimer's Disease: A Report of Progress, S. Corkin et al. (Eds.), (Aging, Vol. 19), Raven Press, New York, 149-164.

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

Corkin, S., Cohen, N.J., Sullivan, E.J., Clegg, R.A., and Rosen, T.J. (1985). Analyses of global memory impairments of different etiologies. Annals of the New York Academy of Sciences, **444**, 10-40.

Corkin, S., Amaral, D.G., Gonzalez, R.G., Johnson, K.A., Hyman, B.T. (in press). H.M.'s medial temporal-lobe lesion: findings from MRI. Journal of Neuroscience.

Cronin-Golomb, A., Corkin, S., and Growdon, J.H. (1995). Visual dysfunction predicts cognitive deficits in Alzheimer's disease. Optometry and Vision Science, **72**, 168-176.

Crowder, R. G. (1993). Systems and principles in memory theory: another critique of pure memory. In: Theories of Memory, A. Collins, S. Gathercole, M. Conway, and P. Morris (Eds), Erlbaum, Hove (U.K.), 139-161.

Curran, T., Schacter, D.L., Bessenoff, G. (1996). Visual specificity effects on word stem completion: beyond transfer appropriate processing? Canadian Journal of Experimental Psychology, **50**, 22-33.

Desimone, R., Albright, T.D., Gross, C.G., Bruce, C. (1984). Stimulus selective properties of inferior temporal neurons in the macaque. Journal of Neuroscience, **4**, 2051-2062.

Diamond, R. and Rozin, P. (1984). Activation of existing memories in anterograde amnesia. Journal of Abnormal Psychology, **93**, 98-105.

Dorfman, J. (1994). Sublexical components in implicit memory for novel words. Journal of Experimental Psychology: Learning, Memory, & Cognition, **20**, 1108-1125.

Downes, J. J., Davis, E. J., Davies, P. D., Perfect, T. J., Wilson, K., Mayes, A. R., and Sagar, H. J. (1996). Stem-completion priming in Alzheimer's disease: the importance of target word articulation. Neuropsychologia, **34**, 63-75.

Fahy, F.L., Riches, I.P., and Brown, M.W. (1993). Neuronal activity related to visual recognition memory: long-term memory and the encoding of recency and familiarity information in the primate anterior and medial inferior temporal and rhinal cortex. Experimental Brain Research, **96**, 457-472.

Feustel, T.C., Shiffrin, R.M., and Salasoo, A. (1983). Episodic and lexical contributions to the repetition effect in word identification. Journal of Experimental Psychology: General, **112**, 309-346.

Fodor, J. (1983). The Modularity of Mind. MIT Press, Cambridge.

Gabrieli, J.D.E., Milberg, W., Keane, M.M. and Corkin, S. (1990a). Intact priming of patterns despite impaired memory. Neuropsychologia, **28**, 417-427.

Gabrieli, J. D. E., Keane, M. M., and Corkin, S. (1990b). Nonword priming may be robust despite global amnesia. Society for Neuroscience Abstracts, **16**, 26.

Gabrieli, J.D.E., Corkin, S., Mickel, S.F., and Growdon, J.H. (1993). Intact acquisition and long-term retention of mirror-tracing skill in Alzheimer's disease and in global amnesia. Behavioral Neuroscience, **107**, 899-910.

Gabrieli, J. D. E., Keane, M. M., Stanger, B. Z., Kjelgaard, M. M., Corkin, S. and Growdon, J. H. (1994). Dissociations among structural-perceptual, lexical-semantic, and event-fact memory systems in amnesia, Alzheimer's disease, and normal subjects. Cortex, **30**, 75-103.

Gabrieli, J. D. E., Fleischman, D. A., Keane, M. M., Reminger, S. L., and Morrell, F. (1995). Double dissociation between memory systems underlying explicit and implicit memory in the human brain. Psychological Science, **6**, 76-82.

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

Garner, W.R., and Clement, D.E. (1963). Goodness of pattern and pattern uncertainty. Journal of Verbal Learning and Verbal Behavior, **2**, 446-452.

Gooding, P.A., van Eijk, R., Mayes, A.R., and Meudell, P. (1993). Preserved pattern completion priming for novel, abstract geometric shapes in amnesics of several aetiologies. Neuropsychologia, **31**, 789-810.

Gooding, P.A., Mayes, A.R., and Meudell, P. (1994). Long lasting indirect memory performance for abstract shapes in amnesics and matched controls. Neuropsychologia, **32**, 1135-1143.

Graf, P. and Mandler, G. (1984). Activation makes words more accessible, but not more retrievable. Journal of Verbal Learning and Verbal Behavior, **23**, 553-568.

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

Graf, P. and Schacter, D.L. (1985). Implicit and explicit memory for new associations in normal and amnesic subjects. Journal of Experimental Psychology: Learning, Memory, and Cognition, **13**, 45-53.

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

Grafton, S.T., Hazeltine, E., and Ivry, R. (1995). Functional mapping of sequence learning in normal humans. Journal of Cognitive Neuroscience, **7**, 497-510.

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

Hamann, S. and Squire, L.R. (1996). Level-of-processing in word-completion priming: a neuropsychological study. Journal of Experimental Psychology: Learning, Memory, and Cognition, **22**, 933-947.

Hamann, S.B. (1996). Implicit memory in the tactile modality: evidence from braille stem completion in the blind. Psychological Science, **7**, 284-288.

Heindel, W. C., Salmon, D. P., Shults, C. W., Walicke, P. A. and Butters, N. (1989). Neuropsychological evidence for multiple implicit memory systems: A comparison of Alzheimer's, Huntington's, and Parkinson's disease patients. Journal of Neuroscience, **9**, 582-587.

Hintzman, D.L. (1990). Human learning and memory: Connections and dissociations. Annual Review of Psychology, **41**, 109-139.

Hirshman, E. and Mulligan, N.W. (1991). Perceptual interference improves explicit memory but does not enhance data-driven processing. Journal of Experimental Psychology: Learning, Memory, and Cognition, **18**, 255-265.

Huff, F. J., Corkin, S., and Growdon, J. H. (1986). Semantic impairment and anomia in Alzheimer's disease. Brain and Language, **28**, 235-249.

Jacoby, L.L. and Craik, F.I.M. (1979). Effects of elaboration of processing at endocing and retrieval: Trace distinctiveness and recovery of initial context. In: Levels of Processing and Human Memory, L.S. Cermak and F.I.M. Craik (Eds.), Erlbaum, Hillsdale, N.J.

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

Jacoby, L.L. and Witherspoon, D. (1982). Remembering without awareness. Canadian Journal of Psychology, **36**, 300-324.

Kanwisher, N., McDermott, J., and Chun, M.M. (in press). The fusiform face area: a module in human extrastriate cortex specialized for face perception. Journal of Neuroscience.

Karni, A., Meyer, G., Jezzard, P., Adams, M.M., Turner, R., and Ungerleider, L.G. (1995a). Functional MRI evidence for adult motor cortex plasticity during motor skill learning. Nature, **377**, 155-158.

Karni, A., Weisberg, J., Lalonde, F., and Ungerleider, L.G. (1995b). An fMRI study of human visual cortex plasticity. Society for Neuroscience Abstracts, **21**, 276.

Katz, B. and Rimmer, S. (1989). Ophthalmologic manifestations of Alzheimer's disease. Surv. Ophthalmol., **34**, 31-43.

Keane, M.M., Gabrieli, J.D.E., Fennema, A.C., Growdon, J.H., and Corkin, S. (1991). Evidence for a dissociation between perceptual and conceptual priming in Alzheimer's disease. Behavioral Neuroscience, **105**, 326-342.

Keane, M.M., Gabrieli, J.D.E., Growdon, J.H., and Corkin, S. (1994). Perceptual identification priming of pseudowords is normal in Alzheimer's Disease. Neuropsychologia, **32**, 343-356.

Keane, M. M., Gabrieli, J. D. E., Mapstone, H. C., Johnson, K. A., and Corkin, S (1995). Double dissociation of memory capacities after bilateral occipital-lobe or medial temporal-lobe lesions. Brain, **118**, 1129-1148.

Keane, M.M., Gabrieli, J.D.E., Monti, L.A., Fleischman, D.A. Cantor, J.M., and Noland, J.S. (1997). Intact and impaired conceptual memory processes in amnesia. Neuropsychology, **11**, 59-69.

Khachaturian, Z.S. (1985). Diagnosis of Alzheimer's disease. Archives of Neurology, **42**, 1097-1105.

Kirsner, K., Milech, D., and Standen, P. (1983). Common and modality-specific process in the mental lexicon. Memory and Cognition, **11**, 621-630.

Kurylo, D.D., Corkin, S., Dolan, R.P., Rizzo III, J.F., Parker S.W., and Growdon, J.H. (1994a). Broad-band visual capacities are not selectively impaired in Alzheimer's disease. Neurobiology of Aging, **15**, 305-311.

Kurylo, D.D., Corkin, S., and Growdon, J.H. (1994b). Perceptual organization in Alzheimer's disease. Psychology and Aging, **9**, 562-567.

Kurylo, D.D., Corkin, S., Rizzo III, J.F., and Growdon, J.H. (1996). Greater relative impairment of object recognition than of visuospatial abilities in Alzheimer's disease. Neuropsychology, **10**, 74-81.

Li, L., Miller, E.K., and Desimone, R. (1993). The representation of stimulus familiarity in anterior inferior temporal cortex. Journal of Neuropsyiology, **69**, 1918-1929.

Locascio, J. J., Growdon, J. H. and Corkin, S. (1995). Cognitive test performance in detecting, staging, and tracking Alzheimer's disease. Archives of Neurology, **52**, 1087-1099.

Locascio, J.J., Jennings, P.J., Moore, C.I., and Corkin, S. (in press). Time series analyses in the time domain and resampling methods for studies of magnetic rsonance brain imaging. Human Brain Mapping.

Maki, P. M., and Knopman, D. S. (1996). Limitations of the distinction between conceptual and perceptual implicit memory: a study of Alzheimer's disease. Neuropsychology, **10**, 464-474.

Marr, D. (1982). Vision. Freeman, San Francisco.

Marslen-Wilson, W. D. and Tyler, L. K. (1981). Central processes in speech understanding. Philosophical Transactions of the Royal Society of London (Biologic), **295**, 317-332.

Martin, A., Brouwers, P., Lalonde, F., Cox, C. Teleska, Pl, Fedio, P, Foster, N.L., and Chase, T.N. (1986). Toward a behavioral typology of Alzheimer's patients. Journal of Clinical and Experimental Neuropsychology, **8**, 594-610.

Martin, A. (1990). Neuropsychology of Alzheimer's disease: The case for subgroups. In: Modular Deficits in Alzheimer-Type Dementia, Swartz, M.F. (Editor), MIT Press, Cambridge, MA, 143-175.

McDermott, K.B. and Roediger, H.L., III (1996). Exact and conceptual repetition dissociate conceptual memory tests: problems for transfer appropriate processing theory. Canadian Journal of Experimental Psychology, **50**, 57-71.

McKhann, G., Drachman, D., Folstein, M., Katzman, R., Price, D., and Stadlan, E.M. (1984). Clinical diagnosis of Alzheimer's disease: Report of the NINCDS-ADRDA work group under the auspices of the Department of Health and Human Services task force on Alzheimer's disease. Neurology, **34**, 939-944.

Mendez, M.F., Tomsak, R.L., and Remler, B. (1990). Disorders of the visual system in Alzheimer's disease. Journal of Clinical and Neurological Ophthalmology, **10**, 62-69.

Mendola, J.D., Cronin-Golomb, A., Corkin, S., and Growdon, J.H. (1995). Prevalence of visual deficits in Alzheimer's disease. Optomological and Vision Sciences, **72**, 155-167.

Mesulam, M.-M. (1985). Patterns in behavioral neuroanatomy: Association areas, the limbic system, and hemispheric specialization. In: Principles of Behavioral Neurology, M.-M. Mesulam (Editor), F. A. Davis, Philadelphia, 1-71.

Miller, E.K. and Desimone, R. (1994). Parallel neuronal mechanisms for short-term memory. Science, **263**, 520-522.

Milner, B., Corkin, S., and 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. (1992). Cerebral Memory Circuits. In: Exploring Brain Functions: Models in Neuroscience, T.A. Poggio and D.A. Glaser (Editors), John Wiley and Sons, Chichester, 113-125.

Monti, S.L., Gabrieli, J.D.E., Reminger, S.L., Rinaldi, J.A., Wilson, R.S., and Fleischman, D.A. (1996). Differential effects of aging and Alzheimer's disease on conceptual implicit and explicit memory. Neuropsychology, **10**, 101-112.

Morton, J. (1970). A functional model for memory. In: Models of Human Memory, D. A. Norman (Editor), Academic Press, New York, 203-254.

Moscovitch, M. (1994). Memory and working with memory: evaluation of a component process model and comparisons with other models. In: Memory Systems 1994, D.L. Schacter and E. Tulving (Editors), MIT Press, Cambridge, MA., 269-310.

Murray, E. A., Gaffan, D., and Mishkin, M. (1993). Neural substrates of visual stimulus-stimulus association in Rhesus monkeys. Journal of Neuroscience, **13**, 4549-4561.

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

Musen, G. (1991). Effects of verbal labeling and exposure duration on implicit memory for visual patterns. Journal of Experimental Psychology: Learning, Memory, and Cognition, **17**, 954-962.

Musen, G. and Squire, L.R. (1992). Nonverbal priming in amnesia. Memory and Cognition, **20**, 441-448.

Nyberg, L., Winocur, G., and Moscovitch, M. (1997). Correlation between frontal lobe functions and explicit and implicit stem completion in healthy elderly. Neuropsychology, **11**, 70-76.

Perrett, D.I., Rolls, E.T., Caan, W. (1982). Visual neurons responsive to faces in the monkey temporal cortex. Experimental Brain Research, **47**, 329-342.

Petersen, S. E. and Fiez, J. A. (1993). The processing of single words studied with positron emission tomography. Annual Review of Neuroscience, **16**, 509-530.

Plaut, D.C. and Farah, M.J. (1992). Visual object representation: interpreting neurophysiological data within a computational framework. Journal of Cognitive Neuroscience, **2**, 320-343.

Postman, L. and Soloman, R.L. (1949/50). Perceptual sensitivity to completed and incompleted tasks. Journal of Personality, **18**, 347-357.

Postle, B.R. and Corkin, S. (1994). H.M. shows impaired word-stem completion priming with novel words. Society for Neuroscience Abstracts, **20**, 1289.

Postle, B.R., Corkin, S., and Growdon, J.H. (1996). Intact implicit memory for novel patterns in Alzheimer's disease. Learning and Memory, **3**, 305-312.

Postle, B.R. and Corkin, S. (in revision). Manipulation of familiarity dissociates word-stem completion priming from perceptual identification priming. Memory & Cognition.

Postle, B.R., Growdon, J.H., and Corkin, S. (submitted). Impaired word-stem completion priming with novel words: Evidence from the amnesic patient H.M. Neuropsychologia.

Rajaram, S. and Roediger, H.L., III (1993). Direct comparison of four implicit memory tests. Journal of Experimental Psychology: Learning, Memory, and Cognition, **19**, 765-776.

Recanzone, G.H., Jenkins, W.M., Hradek, G.H., and Merzenich, M.M. (1992a). Progressive improvement in discriminative abilities in adult owl monkeys performing a tactile frequency discrimination task. Journal of Neuropsyiology, **67**, 1015-1030.

Recanzone, G.H., Merzenich, M.M., and Schreiner, C.E. (1992b). Changes in the distributed temporal response properties of SI cortical neurons reflect improvements in performance on a temporally based tactile discrimination task. Journal of Neuropsyiology, **67**, 1071-1091.

Recanzone, G.H., Schreiner, C.E., and Merzenich, M.M. (1993). Plasticity in the frequency representation of primary auditory cortex following discrimination training in adult owl monkeys. Journal of Neuroscience, **13**, 87-103.

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

Roediger, H.L., III (1990). Implicit memory. American Psychologist, **45**, 1043-1056.

Roediger, H.L., III, Weldon, M.S., Stadler, M.L., and Rigler, G.L. (1992). Direct comparison of two implicit memory tests: Word fragment and word stem completion. Journal of Experimental Psychology: Learning, Memory, and Cognition, **18**, 1251-1269.

Roediger, H.L., III, and McDermott, K.B. (1993). Implicit memory in normal human subjects. In: Handbook of Neuropsychology, **8**, F. Boller and J. Grafman (Editors), Elsevier Science Publishers, 63-131.

Rozin, P. (1976). The psychobiological approach to human memory. In: Neural Mechanisms of Learning and Memory, M. R. Rosenzweif and E. L. Bennett (Editors), MIT Press, Cambridge, MA, 1-48.

Rueckl, J. G. (1990). Similarity effects in word and pseudoword repetition priming. Journal of Experimental Psychology: Learning, Memory, and Cognition, **16**, 374-391.

Salasoo, A., Shiffrin, R.M., and Feustel, T.C. (1985). Journal of Experimental Psychology: General, **114**, 50-77.

Salmon, D. P., Shimamura, A. P., Butters, N. and Smith, S. (1988). Lexical and semantic priming deficits in patients with Alzheimer's disease. Journal of Clinical and Experimental Neuropsychology, **10**, 477-494.

Sato, T., Kawamura, T., and Iwai, E. (1980). Responsiveness of inferotemporal single units to visual pattern stimuli in monkeys performing discriminations. Experimental Brain Research, **38**, 313-319.

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

Schacter, D.L. (1990). Perceptual representation systems and implicit memory: Toward a resolution of the multiple memory systems debate. In: Neural Bases of Higher Cognitive Fuctions, Annals of the New York Academy of Sciences, A. Diamond (Ed.), **no. 608**, 543-571.

Schacter, D.L., Cooper, L.A., Tharan, M. and Rubens, A.B. (1991). Preserved priming of normal objects in patients with memory disorders. Journal of Cognitive Neuroscience, **3**, 117-130.

Schacter, D. L. (1992). Priming and multiple memory systems: perceptual mechanisms of implicit memory. Journal of Cognitive Neuroscience, **4**, 244-256.

Schacter, D. L., Chiu, C.-Y. P., and Ochsner, K. N. (1993). Implicit memory: a selective review. Annual Review of Neuroscience, **16**, 159-182.

Schacter, D. L. (1994). Priming and multiple memory systems: Perceptual mechanisms of implicit memory. In: Memory Systems 1994, D.L. Schacter and E. Tulving (Editors), MIT Press, Cambridge, MA., 233-268.

Schacter, D. L. and Tulving, E. (1994). Memory Systems 1994, MIT Press, Cambridge, MA.

Schacter, D.L., Reiman, E., Uecker, A., Polster, M.R., Yun, L.S., and Cooper, L.A. (1995). Brain regions associated with retrieval of structurally coherent visual information. Nature, **376**, 587-590.

Schacter, D. L., Alpert, N. M., Savage, C. R., Rauch, S. L. and Albert, M. S. (1996). Conscious recollection and the human hippocampal formation: Evidence from positron emission tomography. Proceedings of the National Academy of Sciences, **93**, 321-325.

Schwartz, B.L. (1989). Effects of generation on indirect measures of memory. Journal of Experimental Psychology: Learning, Memory, and Cognition ,**15**, 1119-1128.

Schwartz, B.L., Hashtroudi, S., Herting, R.L., Schwartz, P., and Deutsch, S.I. (1996). d-Cycloserine enhances implicit memory in Alzheimer patients. Neurology, **46**, 420-424.

Schwartz, E.I., Desimone, R., Albright, T.D., and Gross, C.G. (1983). Shape recognition and inferior temporal neurons. Proceedings of the National Academy of Sciences (USA), **80**, 5776-5778.

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

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

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

Shimamura, A. P., Salmon, D. P., Squire, L. R., and Butters, N. (1987). Memory dysfunction and word priming in dementia and amnesia. Behavioral Neuroscience, **101**, 347-351.

Shimamura, A. P. (1993). Neuropsychological analyses of implicit memory: History, methodology, and theoretical interpretations. In: Implicit Memory: New Directions in Cognition, Development, and Neuropsychology, P. Graf and M. E. J. Masson (Editors), Erlbaum, Hillsdale, N.J., 265-285.

Simpson, W. A. (1989). The step method: A new adaptive psychophysical procedure. Perception and Psychophysics, **45**, 572-576.

Smith, M. E. and Oscar-Berman, M. (1990). Repetition priming of words and pseudowords in divided attention and in amnesia. Journal of Experimental Psychology: Learning, Memory, and Cognition, **16**, 1033-1042.

Soloman, R.L. and Postman, L. (1952). Frequency of usage as a determinant of recognition threshold for words. Journal of Experimental Psychology, **43**, 195-201.

Squire, L.R. (1986). Memory and Brain. Oxford University Press, New York.

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., Ojemann, J.G., Miezin, F.M., Petersen, S.E., Videen, T.O. and Raichle, M.E. (1992). Activation of the hippocampus in normal humans: a functional anatomical study of memory. Proceedings of the National Academy of Sciences (USA), **89**, 1837-1841.

Tenpenny, P. and Shoben, E.J. (1991). Component processes and the utility of the conceptually-driven/data-driven distinction. Journal of Experimental Psychology: Learning, Memory, & Cognition, **18**, 25-42.

The American Heritage Dictionary (1991). Second College Edition, Houghton Mifflin Company, Boston, MA.

Ungerleider, L. (1995). Functional brain imaging studies of cortical mechanisms for memory. Science, **270**, 769-775.

Verfaellie, M., Milberg, W.P., Cermak, L.S. and Letourneau, L.L. (1992). Priming of spatial configurations in alcoholic Korsakoff's amnesia. Brain and Cognition, **18**, 34-45.

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

Warrington, E. K. and Weiskrantz, L. (1970). The amnesic syndrome: Consolidation or retrieval? Nature, **228**, 628-630.

Witherspoon, D. and Moscovitch, M. (1989). Stochastic independence between two implicit memory tasks. Journal of Experimental Psychology: Learning, Memory, and Cognition, **15**, 22-30.

Whitlow, J.W., Jr. and Cebollero, A. (1989). The nature of word frequency effects on perceptual identification. Journal of Experimental Psychology: Learning, Memory, and Cognition, **15**, 643-656.

Whitlow, J.W., Jr. (1990). Differential sensitivity of perceptual identification for words and pseudowords to test expectations: implications for the locus of word frequency effects. Journal of Experimental Psychology: Learning, Memory, and Cognition, **16**, 837-851.

Winocur, G., Moscovitch, M., and Stuss, D.T. (1996). Explicit and implicit memory in the elderly: evidence for double dissociation involving medial temporal- and frontal-lobe functions. Neuropsychology, **10**, 1-9.

Zola-Morgan, S. and Squire, L.R. (1990). Neuropsychological investigations of memory and amnesia: findings from human and nonhuman primates. In: The Development and Neural Bases of Higher Cognitive Functions, A. Diamond (Editor), New York Academy of Sciences, New York., 434-456.

Appendix A: Post-1965 Words
(Experiments 1a., and 2)

AEROBICS
AFRO
AMARETTO
AMNIOCENTESIS
APARTHEID
AQUARIAN
ARUGULA
ASTROTURF
AWACS
BEANIE
BIATHLON
BIKINI
BIONICS
BIRIANI
BISCOTTI
BLEEP
BLOCKBUSTER
BONG
CASTROISM
CELLULITE
CHARBROILER
CHICANO
CHUGALUG
CILANTRO
COBOL
CODON
CORTISONE
COUTH
CROCKPOT
CRUDITES
CYBORG
DECATHLETE
DEFOGGER
DELI
DEPROGRAM
DERAILLEUR
DISKETTE
DOMINATRIX
DORK
DREADLOCKS
DUMPSTER
EUROCRAT
FALAFEL
FICHE
FLACKERY
FLOOZY
FRACTAL
FREEBEE
FRISBEE
FUTON
GIMMICK
GLASPHALT
GLITZ
GLOP
GONZO
GRANOLA
GRIDLOCK
GRUNGE
GULAG
HACKER
HAVARTI
HOLOGRAM
HOMOPHOBIA
HUCKSTER
JACUZZI
HONCHO
HYPE
INTERFERON
KAYAK
KLICK
KUDO
LAMAZE
LIBBER
LUMPECTOMY
MACHO
MAMMOGRAM
MARGARITA
MAVEN
MEDICARE
MELATONIN
MOTOCROSS
NAUGAHYDE
NERD
NEUROSCIENCE
NOSH
PAPARAZZI
PARAMEDIC
PHEROMONE
PICOGRAM

PIZZAZZ
PLASMID
PREPPY
PSYCHEDELIA
PULSAR
QUASAR
RASTAFARIAN
REGGAE
REPO
REVERB
SALSA
SANDINISTA
SASQUATCH
SCAM
SCHLOCK
SLEAZE
SONOGRAM
SPRITZ
STAGFLATION
SUSHI
TAHINI
TELETHON
TERIYAKI
TRIATHLON
TOKE
VALIUM
VELCRO
WIMP
YUPPIE
ZINGER

Appendix B: Pre-1953 Words (Experiments 1b. and 2)

ABOLITIONIST
ACCREDITATION
AFFIRMATION
AQUEDUCT
ARBOR
ASTERISK
BALM
BENT
BLIZZARD
BLUSTER
BOTANY
BRIAR
CHECKMATE
CLAPPER
CRABAPPLE
CRUMB
DAREDEVIL
DECANTER
DEODORANT
DESPERADO
DOMICILE
DRAM
ESCAPADE
FILLET
FLAMINGO
FOSSIL
GLITTER
GLOSSARY
GROUCH
HARPOON
HUSK
INFINITY
LAIR
MEAD
MERIDIAN
MILDEW
MIME
MONOGRAM
MORASS
MUSTARD
OCTAVE
ORIOLE
PECK
PEDESTRIAN
PHARMACY
PILING
PISTACHIO
PRETZEL
QUICKSILVER
RECIPROCAL
REGALIA
ROULETTE
SALUTATION
SAUSAGE
SCALLION
SCONCE
SHAD

SIMILE
SLOP
SMUDGE
SNEEZE
SPIDERWEB
SQUAWK
STEW
STUPIDITY
SUFFIX
TASSEL
THIMBLE
THUMB
TIDBIT
TRAMPOLINE
TREBLE
TRIAGE
TROT
TRUANT
VASE
VELOUR
WEAKLING
WRANGLER
YARN

Appendix C: Unfamiliar Words (Experiments 3-6)

ABOMASUM
ACCIDIE
ADVOWSON
AFFLATUS
AFFRIATE
BALMACAAN
BASTNAESITE
BELEMNITE
BLATHERSKITE
BOUSTROPHEDON
BREDE
BRIMBORION
BROMIDROSIS
BRUCCINE
BURGONET
CASTROPHRENIA
CALOTTE
CAVETTO
CLIVIA
COMPLORATION
CONTRECTATION
CORYZA
COURGETTE
COUVADE
CREODONT
CRICOID
CURASSOW
DECANE
DELAINE
DESMID
DETUMESCENCE
ENCOPRESIS
EQUISETUM
EXPERGEFACTION
FILARIA
FLANCH
FOUMART
FRIPPET
GARGANEY
GLOSSOLALIA
GRAPHOLAGNIA
GRIFFONAGE
GROBIANISM
HALIEUTICS
HALZOUN
INTESTACY
INVULTUATION
MACRENCEPHALY
MINIFIDIANISM
MISONEISM
MONOPSONY
MOROLOGY
NATROLITE
OLIBANUM
PARADIASTOLE
PORIOMANIA
PREPUCE
QUAGGA
RADZIMIR
RECTRIX
REFOCILLATION
REGUR
REMONTADO

RENIN
REPTATION
RESH
RETENE
ROUP
SALLET
SANDARAC
SCANDIUM
SCOLEX
SELENDOESY
SENE
SERIEMA
SHILL
SILOXANE
SOLANUM
SPERRYLITE
SPIEGELEISEN
SPODUMENE
SQUALENE
STEARATE
STICHOMYTHIA
TORULA
TRACHEID
TRUNNION
VENIREMAN
VERATRINE
VESICANT
WHIMBREL
ZINKENITE

Appendix D: Familiar Words (Experiments 3-6)

AEROBICS
AIKIDO
AMARETTO
AMNIOCENTESIS
APARTHEID
AQUARIAN
ATTITUDE
BEANIE
BIATHLON
BIONICS
BISCOTTI
BLOCKBUSTER
CASTLE
CELLULITE
CHARBROILER
CHICANO
CHUGALUG
CILANTRO
CORTISONE
CROCKPOT
CRYONICS
DECATHLETE
DEFOGGER
DELI
DEPRESSION
DERAILLEUR
DETERGENT
DISKETTE
DEPRESSION
DERAILLEUR
DOMINATRIX
DORK
DREADLOCKS
DUMPSTER
FIDO
FLACKERY
FLOOZY
FRACTAL
FREEBEE
FRISBEE
FUTON
GIRO
GLASPHALT
GLITZ
GRANOLA
GRIDLOCK
GRUNGE
GULAG
HACKER
HOLOGRAM
HOMOPHOBIA
HONCHO
HUMUS
INTERFERON
JACUZZI
JUGGERNAUT
LIBBER

LUMPECTOMY
MAMMOGRAM
MAOISM
MARGARITA
MEDICARE
MENSCH
MELATONIN
MIDI
MOONIE
MOTOCROSS
MYLAR
NAUGAHYDE
NERD
NEUROSCIENCE
PALIMONY
PAPARAZZI
PARAMEDIC
PHEROMONE
PICOGRAM
PIXEL
PLASMID
POTHEAD
PROTOTYPE
PSYCHEDELIC
PULSAR
QUASAR
RASTAFARIAN
REGGAE
REVERB
RORSCHACH
SALSA
SCAM
SCHLOCK
SCHTICK
SKIFFLE
SLEAZE
SONOGRAM
SPRING
STAGFLATION
TELETHON
TERIYAKI
TRIATHLON
VALLEY
VELCRO
ZINGER

Appendix E: Familiar Words (Experiment 7)

(* indicates foil words)
BIOLOGY*
BIONICS
BLOCKBUSTER
BLOCKHOUSE*
CHEMICAL*
CHEMISTRY
DREADLOCKS
DREADNOUGHT*
FLOOZY
FLOWER*
FRACTAL
FRACTION*
GLINT*
GLITZ
GYMNASIUM
GYMNASTICS*
HOLOCAUST*
HOLOGRAM
HOMOPHOBIA
HOMOPHONE*
HONCHO
HONEY*
MAMMOGRAM
MAMMOUTH*
MELANCHOLY*
MELATONIN
MOTOCROSS
MOTORCADE*
NERD
NERVE*
PESTICIDE*
PESTILENCE
PLASMID
PLASTIC*
REVERB
REVERSAL*
SLEAVE*
SLEAZE
TELETEXT*
TELETHON

Appendix F: Unfamiliar Words and Foil Stimuli (Experiment 7)

(* indicates foil stimuli)
BOUSTROPHEDON
BOUSTROTEALIC*
CALOTHUM*
CALOTTE
DELAINE
DELATTIE*
EQUISETUM
EQUISTIN*
FILARIA
FILASHOT*
GLOSSOLALIA
GLOSSOLENE*
GROBIALTO*
GROBIANISM
HALIESCENCE*
HALIEUTICS
NATROGLIMP*
NATROLITE
RENIN
RENOTILE*
REPTALOG*
REPTATION
RESH
RESOR*
RETALLE*
RETENE
SALLET
SALLOOP*
SERIEMA
SERIOTE*
SHILL
SHINK*
SILOXANE
SILOXATE*
SOLANT*
SOLANUM
SPODULATE*
SPODUMENE
WHIMBOOR*
WHIMBREL