DISSOCIATIONS AMONG PRIMING EFFECTS AFTER CEREBRAL LESIONS: EVIDENCE FOR NEURALLY DISTINCT MEMORY SYSTEMS

by

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Abstract

The aim of the studies presented in this thesis was to identify the neural circuits and characterize the cognitive mechanisms that support dissociable memory capacities. Previous studies have shown that patients with global amnesia due to lesions of medial temporal-lobe or diencephalic structures have impaired recall and recognition memory capacities, but show normal repetition priming effects. Priming is the facilitatory or biasing effect of recent exposure to stimuli upon subsequent processing of those stimuli. The present studies provided evidence for the existence of two dissociable priming mechanisms supported by distinct cortical circuits.

The subjects of study included patients with cerebral lesions due to Alzheimer's disease (AD) and trauma (Case 1), and their control subjects. The neuropathological changes in AD compromise areas in the medial temporal region and basal forebrain, selected subcortical nuclei, and frontal, temporal, and parietal cortices; primary sensory and motor cortices are relatively spared. Case 1 had a large, bilateral posterior cerebral lesion that included nearly the entire right temporal lobe as well as parieto-temporo-occipital areas bilaterally.

One series of experiments in AD demonstrated that perceptual priming processes (indexed by tasks requiring identification of briefly presented words and pseudowords) were intact, whereas conceptual priming processes (indexed by a word-completion task) were impaired. Further, (intact) perceptual and (impaired) conceptual priming processes were dissociable within a single group of AD patients. Consistent with prior studies, AD patients showed a recognition memory impairment. Another series of experiments in Case 1 demonstrated a complementary pattern of performance: Conceptual priming processes (indexed by a cross-modality word-completion task and a category exemplar production task) were intact, whereas perceptual priming processes (indexed by a within-modality word-completion task and a perceptual identification task) were impaired. Further, Case 1 provided the first demonstration of impaired priming coupled with intact recognition memory. Thus, the results of the present experiments constituted a double dissociation between perceptual and conceptual priming processes, and a double dissociation between perceptual priming and recognition memory.

On the basis of these results, we propose that priming is not mediated by a unitary mechanism, but reflects the operation of at least two learning mechanisms, one perceptual and the other conceptual, that contribute jointly

and variably to performance on different priming tasks. Perceptual priming appears to be supported by a memory system localized to posterior (occipital) circuits spared in AD and compromised in Case 1. Conceptual priming appears to be supported by a memory system localized to more anterior temporoparietal circuits spared in Case 1 and compromised in AD. Further, perceptual and conceptual priming are dissociable from recall and recognition capacities mediated by the limbic-diencephalic system.

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Preface

This dissertation comprises three articles. Each is intended to stand alone, but together they address a tightly related set of theoretical issues. For ease of access, the pertinent references and figures for each article are assembled at the end of that article.

Evidence For a Dissociation Between Perceptual and Conceptual Priming in Alzheimer's Disease

Introduction

The neural architecture of human memory is revealed by dissociations among memory capacities in patients with brain lesions. Some compelling dissociations come from the study of patients who are globally amnesic due to limbic-diencephalic lesions. Despite severe deficits in recall and recognition of recently encountered information, such patients can show normal repetition priming effects (Cermak, Talbot, Chandler, & Wolbarst, 1985; Graf, Squire, & Mandler, 1984; Jacoby & Witherspoon, 1982; Warrington & Weiskrantz, 1968, 1970). In priming tasks, the measure of memory is the facilitatory or biasing effect that exposure to a stimulus has upon subsequent processing of the same stimulus. The preservation of priming effects in amnesia suggests that priming does not depend upon limbic-diencephalic structures supporting recall and recognition. However, these findings do not elucidate the nature of the neural circuits upon which priming does depend. This issue has been addressed more recently in studies of patients with Alzheimer's disease (AD), whose neuropathology extends beyond limbic regions to include temporal, parietal, and frontal cortex (Brun & Englund, 1981; Pearson, Esiri, Hiorns, Wilcock, & Powell, 1985; Terry, Peck, DeTeresa, Schecter, & Horoupian, 1981; Wilcock & Esiri, 1982). Several investigators have reported that priming on a word-completion task is impaired in early-stage AD patients (Gabrieli, 1986; Heindel, Salmon, Shults, Walicke, & Butters, 1989; Salmon, Shimamura, Butters, & Smith, 1988; Shimamura, Salmon, Squire, & Butters, 1987). In contrast, Gabrieli et al. (submitted) found a near-normal magnitude of priming in AD on an incomplete-picture identification task. Word-completion and incomplete-picture identification tasks elicit normal (or near-normal) priming in amnesic

patients (Graf et al., 1984; Milner, Corkin, & Teuber, 1968; Warrington & Weiskrantz, 1968, 1970); their dissociability in AD patients suggests that each task invokes distinct cognitive processes mediated by separable neural circuits (not including limbic-diencephalic circuits). Priming in word completion may depend upon a neural circuit that is compromised in AD; priming in incomplete-picture identification may depend upon a neural circuit that is relatively spared in AD.

The goal of the current experiments was to clarify the conditions under which AD patients show a normal magnitude of priming and to test a hypothesis about the basis of such priming. Gabrieli et al. (Gabrieli, 1989, in press; Gabrieli et al., submitted) proposed that the status of priming in AD on a given task depends upon the relative contributions of perceptual and conceptual learning processes to the priming effect: Tasks in which priming is largely the product of enhanced perceptual processes (e.g., incomplete-picture identification) will elicit normal priming in AD. Tasks in which priming is largely the product of enhanced conceptual processes (e.g., word completion) will fail to elicit normal priming in AD. Further, Gabrieli et al. proposed that perceptual priming effects reflect the operation of a structural-perceptual memory system localized to occipital-lobe regions relatively spared in AD, and that conceptual priming effects reflect the operation of a lexical-semantic memory system localized to temporoparietal regions compromised in AD.[1]

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[1] In the present study, all references to priming refer specifically to repetition priming effects. We wish to distinguish repetition priming from semantic priming, which is manifested in a reduced time to process a word immediately preceded by a semantically related word rather than an unrelated word. Unlike the repetition priming effects that form the subject of the present study, semantic priming effects are short-lasting (i.e., not lasting beyond one or two items) in normal

However, word-completion and incomplete-picture identification tasks differ not only in terms of their conceptual or perceptual demands, but also in terms of their potential dependence upon the integrity of language processes. Because AD patients have a range of language deficits (Appell, Kertesz, & Fisman, 1982; Cummings, Benson, Hill, & Read, 1985; Huff, Corkin, & Growdon, 1986), one could postulate that impaired priming in word completion and intact priming in incomplete-picture identification is due to the fact that the stimuli are lexical in the former instance and pictorial in the latter. By this account, the status of priming in AD is tied to the nature of task stimuli, rather than to the perceptual or conceptual nature of the processes operating on those stimuli.

In the present study, we examined the performance of AD patients on a priming task requiring perceptual identification of briefly presented words. As in the word-completion task, the stimuli in the current task were lexical. Like the incomplete-picture identification task, this task posed a perceptual challenge. If the performance dissociation in AD were due to the lexical or pictorial nature of the priming stimuli, priming in perceptual identification of words would be impaired in AD. If the dissociation were due to the relative perceptual or conceptual demands of the task (as we postulate), priming in this task would be normal in AD. In a further experiment, we administered the perceptual priming task and a word-completion priming task to a single group of AD

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subjects (Dannenbring & Briand, 1982; Gough, Alford, & Holley-Wilcox, 1981). Further, there is evidence that repetition and semantic priming effects are additive, and so reflect the operation of separate processes (Den Heyer, Goring, & Dannenbring, 1985; Wilding, 1986). Our findings neither contradict nor support studies indicating that semantic priming effects may be normal in AD (Nebes, Boller, & Holland, 1986; Nebes, Brady, & Huff, 1989; Nebes, Martin, & Horn, 1984).

patients in order to demonstrate a within-subject dissociation between a perceptual and a conceptual priming task.

A large experimental literature examines priming in perceptual identification of briefly presented words in normal subjects (e. g., Jacoby, 1983A, 1983B; Jacoby & Dallas, 1981; Murrell & Morton, 1974; Postman & Solomon, 1949/50; Winnick & Daniel, 1970; Winnick & Nachbar, 1967). The results of those studies showed that perceptual priming effects are often small, and that the presence and size of such effects is influenced by a number of parameters, including word frequency, word length, and the number and spacing of stimulus presentations. Because the subject population in our patient study would be relatively small, it was important to demonstrate that our measure provided a reliable index of perceptual priming. To that end, in Experiments 1A and 1B, we administered the priming task to a large group of normal subjects. Secondarily, these experiments provided the opportunity to demonstrate that the priming effect elicited in the present task showed the same sensitivity to perceptual manipulations and the same relation to recognition memory as other perceptual priming tasks described in the literature.

EXPERIMENT 1

A number of studies have shown that prior exposure to a word facilitates perceptual identification of that word upon brief presentation. The size of this priming effect is enhanced following multiple prior exposures and is greater for low-frequency than high-frequency words (Jacoby & Dallas, 1981). Further, the priming effect is reduced or eliminated if the perceptual modality of presentation differs in the study and identification phases (Clarke & Morton, 1983; Jacoby & Dallas, 1981; Kirsner, Milech, & Standen, 1983; Winnick & Daniel,

1970). In Experiment 1A, we examined the effects of stimulus repetition and word frequency upon perceptual priming and recognition memory. In Experiment 1B, we examined the effect of a shift in presentation modality from study to test upon the same priming and recognition measures.

Experiment 1A

Method

Subjects

The subjects were 32 college students (15 men and 17 women) who were paid for their participation in the experiment.

Materials

We selected 280 four- and five-letter words, of which half were high-frequency (with at least 85 occurrences per million, mean = 237) and half were low-frequency (with no more than 10 occurrences per million, mean = 3.6), according to the Kucera and Francis (Kucera & Francis, 1967) word frequency count. Twenty-four of these words were used as filler items. The remaining 256 words were divided into four lists, which were used to create four distinct, balanced forms of the test. Each 64-word list included: 16 high-frequency 4-letter words; 16 low-frequency 4-letter words; 16 high-frequency 5-letter words; and 16 low-frequency 5-letter words. The mean frequency of high- and low-frequency words for each of the four lists was similar. In each of the test forms, half of the 64 words were presented in an initial study list and in the subsequent perceptual identification or recognition task (targets), and the other half appeared only in the perceptual identification or recognition task (foils). Of the words that appeared in the study list, half were presented once and half were presented three times. The target and foil word sets each included equal numbers of 4- and

5-letter and high- and low-frequency words, as did the word sets presented once or three times in the study list. Complete counterbalancing of words across conditions yielded 16 test forms: 4 different stimulus sets x 2 study conditions (presented vs. unpresented) x 2 exposure conditions (1 vs. 3 exposures).

Procedure

In brief, each subject studied one list of words, performed a perceptual identification task with studied and unstudied words, then studied a second, different list of words, and performed a yes/no recognition task with studied and unstudied words. All stimuli were presented on the screen of an IBM personal computer. Subjects were seated approximately 20 inches from the screen.

Study task. The procedure in the study phase was identical for the perceptual identification and the recognition tasks. Subjects were told that they would see a series of words presented one at a time on the computer screen and that they were to read each word aloud. Thirty-two different words were presented singly on the computer screen; half were presented one time and the other half were presented three times (once within each third of the list). In addition to these 64 trials, three filler words were presented at the beginning and end of the list (to blunt any primacy and recency effects upon later memory for the stimuli), yielding a total of 70 trials. At the initiation of the experimenter, each word was presented on the computer screen for 4 seconds. The study phase was followed immediately by a perceptual identification or recognition task.

Perceptual identification. Subjects were told that they would perform a second task that was unrelated to the study task. They were told that a series of words would be presented very briefly on the computer screen and that they were to identify each word. Each trial was preceded by the appearance of a fixation character ("+") in the middle of the screen. Subjects were instructed to

fixate this character in preparation for the brief appearance of a word. On each trial, a word was flashed on the computer screen and then replaced by a backward mask ("#####") of 250 msec duration. The initial presentation time was 16.7 msec. If the subject was unable to identify the word at this exposure time, it was presented in the following trial for 33.4 msec. The same word was presented in additional increments of 16.7 msec on successive trials until the subject correctly identified it. The computer recorded the number of presentations (i.e., the exposure time) required to identify each word. Sixty-four different words were presented in the perceptual identification task. Thirty-two of these words had appeared in the prior study list; 16 had appeared once and 16 had appeared three times. The other 32 words had not appeared in the prior study list.

Recognition. In the recognition test, subjects were told that a series of words would be presented on the computer screen, some of which had appeared in the preceding study list. Subjects were asked to respond "yes" if they had seen the word on the prior list and "no" if they had not. Sixty-four words were presented in the recognition test; half had appeared in the prior study list (once or three times) and half were new.

Each subject performed a perceptual identification task with one test form and a recognition test with a different test form composed of entirely different stimuli. The administration of the 16 test forms in the perceptual identification and recognition tasks was counterbalanced across the 32 subjects.

Results

Perceptual Identification

The dependent measure was the exposure time required for the correct identification of words. The experimental manipulations of interest were prior study condition (studied vs. unstudied), repetition (1 vs. 3 occurrences in the

study list), and word frequency (high vs. low). The first two manipulations were combined to yield a single design factor of prior exposure (0, 1, or 3), in which foils had zero prior exposures. For each subject, the mean exposure time (in msec) required to identify words was calculated for each of the 6 conditions defined by the combination of the prior exposure and word frequency factors (Figure 1). The magnitude of priming on this task was small, but the effect was robust: Every one of the 32 subjects showed a mean priming effect in the predicted direction.

Figure 1 about here

A 2-way repeated-measures analysis of variance (ANOVA) with factors of word frequency (high/low) and prior exposure (0, 1, 3) revealed a significant effect for prior exposure [$F(2, 62) = 36.49$, $p < .001$]. Planned comparisons indicated that this effect was due to a difference between studied and unstudied words [$F(1, 62) = 70.26$, $p < .001$]; the difference between items in the 1-exposure and 3-exposure conditions was only marginally significant [$F(1, 62) = 3.03$, $p < .10$]. High-frequency words were identified at a briefer exposure time than low-frequency words [$F(1, 31) = 4.07$, $p = .052$]. The magnitude of the priming effect, however, was greater for low-frequency words than for high-frequency words (5.68 msec and 2.63 msec, respectively). This difference was reflected in an interaction between prior exposure and word frequency [$F(2, 62) = 6.24$, $p < .005$].

Recognition

Because the study lists preceding the yes/no recognition test were identical to those preceding the perceptual identification task, the analysis of the effects of prior exposure and word frequency on recognition memory paralleled the

analysis of the perceptual identification data. For each subject, we calculated the proportion of words correctly recognized from the study list ("hits") in each of the four conditions defined by crossing repetition (1 vs. 3 exposures) with word frequency (high vs. low). We calculated the proportion of unstudied words incorrectly attributed to the study list ("false alarms") in each of the two word frequency conditions. These proportions were used to determine a d' score for studied words in each of the four study conditions defined by repetition and word frequency (Figure 2).

Figure 2 about here

A 2-way ANOVA with factors of repetition and word frequency showed that recognition was more accurate for words with three prior exposures than those with one [$F(1, 31) = 85.12$, $p < .001$] and that recognition was more accurate for low-frequency than high-frequency words [$F(1, 31) = 48.26$, $p < .001$]. There was no repetition x frequency interaction ($p > .5$).

Experiment 1B

Method

Subjects

The subjects were 32 college students (12 men and 19 women) who were paid for their participation in the experiment. None of these subjects had participated in Experiment 1A.

Materials and Procedure

The stimuli and procedure were identical to those used in Experiment 1A with one exception: In the study task, words were presented auditorily rather than visually. Subjects were asked to repeat each word after it was spoken by the

experimenter. In the perceptual identification or recognition task that followed the study task, words were presented visually as in Experiment 1A.

Results

Perceptual Identification

For each subject, we calculated the mean exposure time needed to identify high- and low-frequency words following 0, 1, or 3 exposures (Figure 3).

Figure 3 about here

A 2-way repeated-measures ANOVA revealed significant effects for prior exposure [$F(2, 62) = 6.42$, $p < .005$] and word frequency [$F(1, 31) = 13.37$, $p < .001$], but no interaction between prior exposure and word frequency ($p > .4$), in contrast to an interaction between these factors in Experiment 1A.

We combined the results of Experiments 1A and 1B and performed a 3-way ANOVA, adding one between-subjects variable (visual-visual presentation in Experiment 1A versus auditory-visual presentation in Experiment 1B) to the two within-subjects variables previously examined (prior exposure and word frequency). This analysis revealed main effects for prior exposure [$F(2, 124) = 35.18$, $p < .001$] and word frequency [$F(1, 62) = 16.74$, $p < .001$], an interaction between prior exposure and word frequency [$F(2, 124) = 5.97$, $p < .005$], and an interaction between prior exposure and modality of study task [$F(2,124) = 5.20$, $p < .01$]. The interaction between prior exposure and modality indicates that there was less priming in Experiment 1B, in which the modality of presentation was different in the study and perceptual identification tasks. None of the other main effects or interactions reached significance.

Recognition

We calculated the mean d' values for studied words in each of the four study conditions defined by repetition and word frequency (Figure 4).

Figure 4 about here

A 2-way repeated-measures ANOVA crossing repetition and word frequency revealed significant effects for repetition [$F(1, 31) = 49.89$, $p < .001$] and word frequency [$F(1, 31) = 34.57$, $p < .001$]. There was no repetition x frequency interaction. A second analysis combined the results of Experiments 1A and 1B in a 3-way ANOVA in order to examine the effect of a modality shift upon recognition memory for the words. This analysis revealed main effects for repetition [$F(1, 62) = 130.48$, $p < .001$], and word frequency [$F(1, 62) = 78.97$, $p < .001$]. None of the interactions reached significance. Notably, there was no main effect for modality of the study task ($p > .5$); that is, visual recognition memory following auditory study of words (Experiment 1B) was equivalent to that following visual study of words (Experiment 1A).

Discussion of Experiments 1A and 1B

In Experiments 1A and 1B, perceptual identification of a briefly presented word was facilitated by prior exposure to that word; the magnitude of this priming effect was greater with low-frequency than high-frequency words (but only when the modality of presentation was the same in the study and identification tasks); and a change in modality between study and test reduced the priming effect but did not influence recognition memory. These results are consistent with those obtained in prior perceptual priming studies and confirmed the validity of the present paradigm. The robustness of the priming effect in Experiment 1A made us confident that this measure would be reliable

in the smaller population of subjects who participated in Experiment 2.

In at least two prior studies, priming in perceptual identification of words was eliminated entirely under conditions in which the perceptual modality of stimuli differed in the study and identification tasks (e.g., Clarke & Morton, 1983, Exp. 2; Jacoby & Dallas, 1981). These results underscore the critical contribution of perceptual processes to the priming effect.

However, in Experiment 1B and in one other study (Kirsner et al., 1983), perceptual priming was significantly present (although reduced) under cross-modal study-test conditions: Auditory exposure to words had a significant facilitatory effect upon subsequent visual identification. Given that this facilitation occurred in the absence of overt perceptual overlap between stimuli at study and test, it raises the possibility that, in some instances, priming in perceptual identification of words may include a non-perceptual component. For example, modality-free lexical or semantic mechanisms might be responsible for residual cross-modal priming effects.

Alternatively, cross-modal perceptual priming effects might be the product of automatic visual processing that accompanies auditory exposure to a word (a possibility raised in the context of other priming tasks by Jacoby & Witherspoon, 1982; Roediger & Blaxton, 1987B; Schacter & Graf, 1989). For example, upon hearing a word at study, a subject may spontaneously imagine the appearance of that word; that mental image may exert the same influence as a real percept upon performance in the subsequent visual priming task. Support for this view comes from evidence that subjects instructed to image words presented auditorily at study can show priming effects equivalent to those shown by subjects who perceived words visually at study (Roediger & Blaxton, 1987A; Schacter & Graf, 1989). Although the priming tasks in these two studies were not the same as that in the present study, the findings suggest that cross-modal

study-test conditions do not necessarily eliminate the contribution of perceptual mechanisms: The significant (albeit reduced) cross-modal perceptual priming effects demonstrated in Experiment 1B (and in Kirsner et al., 1983) may reflect perceptual learning processes operating in the absence of a sensory stimulus.

Thus, there are two possible accounts of the cross-modal priming effect shown by subjects in Experiment 1B: It could reflect the contribution of non-perceptual (e.g., lexical-semantic) learning mechanisms, or it could reflect the contribution of perceptual learning mechanisms operating in the absence of a visual stimulus. By the former account, priming in perceptual identification of words does not constitute a pure index of perceptual learning processes, but by the latter account it does.

The hypothesis we wish to test in the present study is that the perceptual learning processes that contribute to priming effects are preserved in AD patients. Our prediction that AD patients will show normal priming in perceptual identification of words is based on the assumption that this task provides an accurate index of those processes. By one account of cross-modal perceptual priming effects, however, the task may include non-perceptual components; we would not expect the contribution of those non-perceptual components to be expressed in the performance of AD patients on this task.

EXPERIMENT 2

In Experiment 2, we examined priming during perceptual identification of briefly presented words in AD patients. We hypothesized that priming in this task relied on perceptual learning processes of the sort that mediate priming on an incomplete-picture identification task, and so would be normal in AD patients.

Method

Subjects

We tested 12 patients with a diagnosis of probable AD and 12 age-matched healthy control subjects.

AD patients. All AD patients had a diagnosis of probable AD based upon NINCDS (McKhann et al., 1984) and NIA (Khachaturian, 1985) criteria. The group included 5 women and 7 men. The mean age was 69.8 (range = 58 - 82) and the mean level of education was 14.3 years (range = 12 - 19). The mean Blessed Dementia Scale (BDS) score (Blessed, Tomlinson, & Roth, 1968) was 18.7 (range = 7 - 27.5), indicating mild to severe dementia. No patient was institutionalized.

Normal control subjects (NCS). The control group consisted of spouses or siblings of AD patients involved in research studies at the MIT Clinical Research Center and subjects recruited through newspaper advertisements. The group included 9 women and 3 men with a mean age of 64.6 years (range = 52 - 75), a mean educational level of 14.1 years (range = 12 - 20), and a mean BDS score of 0.5, indicating absence of dementia. (The BDS score was unavailable for one control subject; however, she was not demented upon neurological examination.) There was no significant difference between the mean ages or levels of education in the AD and NCS groups.

Materials

The stimuli and test forms used in this experiment were a subset of those described in Experiment 1 and formed a partially counterbalanced design. Specifically, 2 of the 16 test forms described above were used in the perceptual identification task; the two forms included identical stimulus items and counterbalanced those items across the two study conditions (studied vs. unstudied). Thus, the items that appeared as targets on one form appeared as

foils on the other. The administration of the two test forms was counterbalanced across subjects in each group. A single third form, composed of stimuli that did not overlap with the stimuli on the perceptual identification task, was used in the recognition test for all subjects.

Procedure

The procedure was identical to that described in Experiment 1A. Subjects studied a list of words; performed a perceptual identification task for studied and unstudied words; studied a second list of words; and performed a yes/no recognition test with studied and unstudied words. The stimuli were presented in the manner described in Experiment 1A.

Results

Perceptual identification

As in Experiment 1, the study condition factor (studied vs. unstudied) was combined with the repetition factor (1 vs. 3 occurrences in the study list) to yield a single factor of prior exposure (0 vs. 1 vs. 3), in which unstudied items had 0 prior exposures. The prior exposure factor was crossed with word frequency (high vs. low) to yield 6 experimental conditions. For each subject, the mean exposure time required to identify words was calculated for each of these conditions (Figure 5). Ten of 12 subjects in the NCS group and 10 of 12 subjects in the AD group showed a mean priming effect in the predicted direction.

Figure 5 about here

A 3-way repeated-measures ANOVA (with factors of subject group, prior exposure, and word frequency) showed that AD patients required significantly more exposure time than NCS to identify words [$F(1, 22) = 4.61$, $p < .05$], and that

high-frequency words were identified at briefer exposure times than low frequency words [$F(1, 22) = 4.57$, $p < .05$]. A main effect for prior exposure [$F(2, 44) = 9.87$, $p < .001$] indicated that subjects benefited from prior exposure to words in the study list when performing the perceptual identification task. Critically, there was no group x prior exposure interaction ($p > .5$), indicating that the priming effect did not differ in magnitude in the AD and NCS groups. The lack of interaction was supported by two further analyses. In the first, scores were collapsed across word frequency conditions and the two prior study repetition conditions (1 vs. 3 exposures) to yield a single score for studied and unstudied items. A 2-way ANOVA with factors of group and item type (studied or unstudied) revealed main effects for group [$F(1, 22) = 4.45$, $p < .05$] and item type [$F(1, 22) = 11.51$, $p < .005$], but no interaction between these two factors ($p = .4$). In the second analysis, a 3-way ANOVA of the studied items only (with factors of group, repetition, and frequency) revealed main effects for group [$F(1, 22) = 4.98$, $p < .05$] and repetition [$F(1, 22) = 5.24$, $p < .05$], and a marginally significant effect for frequency [$F(1, 22) = 3.83$, $p = .06$], but no interaction between group and repetition ($p > .5$), indicating that AD patients were influenced to the same degree as normal subjects by the number of prior stimulus exposures. In all of these analyses, there was no interaction between prior exposure and word frequency, i.e., the magnitude of the priming effect did not differ for high- and low-frequency words. Further, no group x prior exposure x frequency interaction occurred. However, inspection of the data clearly indicated the presence of an interaction between prior study and word frequency in the NCS group: The mean priming effect for low-frequency words was 12.36 msec and for high-frequency words was 5.02 msec. A 2-way ANOVA of the NCS data alone revealed a significant prior exposure x frequency interaction [$F(2, 22) = 5.06$, $p < .05$]. It appears then, that the NCS, like the college students in Experiment 1,

showed greater priming for low- than for high-frequency words. In contrast, in AD patients, the magnitude of the priming effect was similar for high- and low-frequency words (14.03 and 15.12, respectively).

Recognition

The mean d' scores in each of the four experimental conditions (defined by crossing repetition with word frequency) are shown in Figure 6.

Figure 6 about here

A 3-way repeated-measures ANOVA (with factors of group, repetition, and word frequency) revealed main effects for repetition [$F(1, 22) = 35.91$, $p < .001$] and word frequency [$F(1, 22) = 34.50$, $p < .001$], reflecting better recognition memory for words presented three times rather than once, and for low-frequency words than for high-frequency words. AD patients were significantly impaired overall relative to NCS [$F(1, 22) = 23.54$, $p < .001$] and did not show a normal effect of repetition [repetition x group $F(1, 22) = 12.06$, $p < .005$]. The word frequency x group interaction approached significance [$F(1, 22) = 3.76$, $p = .065$], reflecting the failure of the AD group to show a normal recognition advantage for low-frequency words. Neither of the remaining interactions reached significance. In two separate analyses, we examined the effect of word frequency and group on the hit and false alarm rates. A 2-way ANOVA of false alarm rates (with factors of group and word frequency) showed a higher rate of false alarms in the AD group [$F(1, 22) = 10.11$, $p < .005$] and a main effect for word frequency [$F(1, 22) = 16.2$, $p < .001$], indicating a higher incidence of false alarms for high- than low-frequency words. A group x frequency interaction that fell short of significance ($p < .10$) suggested a disproportionately higher rate of false

alarms to high- than low-frequency words in the AD group. The analysis of hit rates showed no effect for group ($p > .10$), but did show an effect for frequency [$F(1, 22) = 11.12$, $p < .005$], reflecting better performance with low- than high-frequency words, and a group x frequency interaction [$F(1, 22) = 9.99$, $p < .005$], reflecting the failure of the AD group to show a normal recognition advantage in hit rates for low-frequency words. Wilson et al. reported a similar pattern of hit-rate recognition performance in AD (Wilson, Bacon, Kramer, Fox, & Kaszniak, 1983).

Discussion

In Experiment 2, prior study of words reduced the exposure time necessary for subsequent identification of those words; the priming effect was of a normal magnitude in AD patients despite impaired recognition memory performance. These results have three implications. First, they constitute evidence that priming in a perceptual identification task is dissociable from recognition memory. Second, they suggest that this kind of priming does not depend upon limbic and cortical regions compromised in AD. Third, they suggest that impaired word-completion priming in AD is not due simply to the lexical nature of the priming stimuli. The results demonstrate, instead, that AD patients can show a normal magnitude of priming with words if the task invokes perceptual learning processes that are intact in AD.

The results of the present experiment must be interpreted with caution, however, because the performance of AD patients differs from that of NCS in two respects. First, baseline performance (i.e., the exposure time necessary to identify unstudied words) was significantly impaired in AD patients relative to NCS: On average, AD patients required 107 msec of exposure to identify unstudied words, whereas NCS required 38 msec. Such a discrepancy in the baseline performance of the two groups complicates an interpretation of the

priming effect in AD. AD patients have a variety of cognitive deficits (e.g., language, attention) that could contribute to inferior baseline performance on a perceptual identification task. Our interpretation of the current results assumes that the effect of these deficits on the priming measure is additive rather than multiplicative, i.e., that they add a constant amount to the exposure time necessary for AD patients to identify words, regardless of experimental condition. Under this assumption, the results of the present experiment suggest normal priming in AD.

However, a proportional measure of priming (i.e., priming calculated as a percentage of baseline performance) may be more appropriate than the absolute measure of priming used in the present study. For example, Snodgrass et al. (1988; Snodgrass, 1989) have demonstrated in normal subjects and in patients that priming effects in a fragmented-picture identification task are proportional to baseline performance. Further, within the present study, there is evidence in normal subjects that priming effects in perceptual identification of words depend upon baseline levels of performance: the NCS group in Experiment 2 required more exposure time to identify unstudied words than did the younger control subjects in Experiment 1A (37.5 msec vs. 24.4 msec), and showed a larger mean absolute priming effect than the younger subjects (8.7 msec vs. 4.1 msec). Although these data suggest that, across groups of normal subjects, the size of the perceptual priming effect varies directly with the level of baseline performance, they do not establish that such a relationship should be expected in a comparison across groups of normal and impaired subjects. It is possible that the mechanism underlying the higher baseline performance in the older relative to the younger control subjects is not the same as the mechanism underlying the higher baseline performance in the AD patients relative to age-matched NCS. It could be, for example, that the mechanism underlying age-

related decrements in baseline performance interacts with the priming effect, but that the mechanism underlying dementia-related decrements in baseline performance does not. (This circumstance would not preclude the possibility that priming within a patient group could vary directly with baseline performance: In addition to the effects of dementia, patients would also be subject to the same effects that produce various levels of baseline performance in normal populations.) For this reason, the data from the younger and older control subjects in Experiments 1A and 2 do not speak directly to the measurement issue involved in the comparison of normal and impaired populations.

It remains an open question whether the normal magnitude of priming shown by AD patients in the present study represents fully intact perceptual priming. But in light of the apparent dependence of priming upon baseline performance in normal subjects, we re-calculated the priming score for the AD and NCS groups as a percentage of baseline performance. By this measure, the AD group showed less priming (mean priming effect = 11.5%) than did the NCS group (mean priming effect = 18.5%). A 3-way ANOVA of these data, however, failed to show a significant effect of group upon the priming scores ($p > .2$). In other words, the priming effect shown by the AD group did not differ significantly from that shown by the NCS group, even when a proportional measure of priming was used. Nevertheless, the difference between the two groups in baseline performance diminishes the certainty with which we can argue that the priming effect is normal in AD. A more convincing demonstration of normal priming would come from an experiment in which there was no baseline difference between groups. In Experiment 3, we were able to address this issue more directly.

The second aspect of performance that distinguishes the AD from the NCS

group is the lack of an interaction between word frequency and prior exposure in the AD group. The NCS group, like the college students in Experiment 1, showed a greater priming effect for low-frequency than for high-frequency words. In contrast, AD patients showed a similar magnitude of priming for high- and low-frequency words. One explanation of the interaction in the NCS group may be that they reached a ceiling in performance with the high-frequency words. That is, because less exposure time was required to identify high-frequency than low-frequency words at baseline, there was less room for improvement (priming) in identifying high-frequency words. A performance ceiling might yield the observed larger priming effect for low-frequency than high-frequency words, as low frequency words would have more room to be primed. By this account, the reason that AD patients showed equivalent priming for high- and low-frequency words was because they never reached a performance ceiling.

A ceiling effect interpretation could cast doubt on the claim that the performance of the AD group is normal; one could argue that it appears normal only because improvement in the NCS group was artificially limited by a performance ceiling. However, examination of the data argues against this interpretation. It is clear that the NCS group was not at a performance ceiling for low-frequency words (as evidenced by a significant effect of frequency, reflecting better performance with high-frequency words). If the priming effect in AD were normal only due to a ceiling effect in the NCS group, then priming for low-frequency words should have been impaired in the AD group. A separate 2-way ANOVA for low-frequency words alone (with factors of group and prior exposure), indicated main effects for group [$\underline{F}(1, 22) = 4.42$, $\underline{p} < .05$] and prior exposure [$\underline{F}(2, 44) = 10.81$, $\underline{p} < .001$], but no interaction between these factors ($\underline{p} > .5$). Thus, the magnitude of the priming effect was normal in the AD group

in a condition in which there was no performance ceiling in the NCS group.

There is a second reason, however, to be concerned about the lack of an interaction between prior exposure and frequency in the AD group. Specifically, Experiment 1 demonstrated that the interaction may be modality-specific: It was evident in Experiment 1A (in which stimuli were studied and tested in the same perceptual modality), but not in Experiment 1B (in which stimuli were studied and tested in different perceptual modalities). In other words, the priming effect was greater for low- than high-frequency words only when stimuli were studied and tested in the same perceptual modality. [Jacoby and Dallas (1981) reported a similar result. However, in their study, subjects failed to show any significant cross-modal priming (for high- or low-frequency words). Thus, the absence of a priming advantage for low-frequency words under cross-modal conditions could have been due to a performance floor.] The results of Experiment 1 suggest that the locus of the low-frequency word priming advantage may be perceptual (rather than conceptual). The absence of this effect in the AD group weakens our claim that their performance represents intact perceptual priming.

However, studies that have examined in more detail the locus of the low-frequency word priming advantage have provided considerable evidence that the effect is not modality specific. For example, in four separate perceptual identification experiments, Kirsner et al. (1983) found a significant interaction between prior exposure and word frequency (reflecting greater priming for low- than high-frequency words) under cross-modal study-test conditions. In a further experiment, they demonstrated that there was no priming advantage for low-frequency words beyond that attributable to modality-free mechanisms (i.e., seeing a word did not add to the low-frequency word priming advantage effected by hearing the word). These experiments provide strong evidence that an

interaction between prior exposure and word frequency in perceptual identification reflects the contribution of non-perceptual (e.g., lexical or semantic) mechanisms. These results have two implications in the context of the present study: First, they suggest that the lack of a prior exposure x frequency interaction in the AD group was due to an impairment of non-perceptual mechanisms. Second, they suggest that the performance of the NCS group was mediated in part by non-perceptual mechanisms (because that group showed an interaction between prior exposure and frequency). These implications raise the possibility (discussed earlier) that normal priming in perceptual identification of words includes a non-perceptual component that is not expressed in the performance of AD patients. The contribution of this component, however, must be relatively small, as its absence in the AD group did not significantly reduce the magnitude of their priming effect relative to the NCS group.

In summary, despite a range of cognitive deficits spanning memory, language, attention, and visuospatial abilities, AD patients showed a priming effect in perceptual identification of words equivalent in magnitude to that shown by the NCS. Further, the priming effect in the two groups was similarly enhanced by stimulus repetition. Finally, when priming was expressed as a proportion of baseline performance (to correct for baseline differences between groups), priming in the AD and NCS groups was not significantly different. The one aspect of performance that distinguished the AD group from the NCS group was the failure of the AD group to show an interaction between prior exposure and word frequency. In light of the evidence from Kirsner et al. (1983) discussed above, it is plausible that this interaction reflects the contribution of lexical or semantic (rather than perceptual) mechanisms to the priming effect; thus, its absence in the AD group does not necessarily imply a deficit in perceptual learning mechanisms.

The results of Experiment 2 provide evidence that neural circuits relatively intact in AD support perceptual learning mechanisms that underlie priming in perceptual identification of words. Coupled with prior reports of impaired word-completion priming, these results establish a dissociation in AD between two components of verbal priming. However, because intact perceptual priming and impaired word-completion priming have not been demonstrated within a single group of AD patients, it is possible that the dissociation reflects variability among patient groups rather than differences among task processes. In Experiment 3, we sought stronger evidence for the separability of perceptual and conceptual priming processes by administering the perceptual priming task and a word-completion priming task to a single group of AD patients.

EXPERIMENT 3

Method

Subjects

We tested 10 patients with a diagnosis of probable AD and 10 age-matched healthy control subjects.

AD patients. All AD patients had a diagnosis of probable AD based upon NINCDS (McKhann et al., 1984) and NIA (Khachaturian, 1985) criteria. The group included 5 women and 5 men. The mean age was 70.5 years (range = 57 - 81) and the mean level of education was 13.6 years (range = 8 - 20). The mean Blessed Dementia Scale (BDS) score (Blessed et al., 1968) was 18.7 (range = 3 - 36.5), indicating mild to severe dementia. No patient was institutionalized.

Normal control subjects (NCS). The control group consisted of spouses or siblings of AD patients involved in research studies at the MIT Clinical Research Center and subjects recruited through newspaper advertisements. The group

included 5 men and 5 women with a mean age of 68.2 years (range = 55 - 80) and a mean educational level of 12.7 years (range = 8 - 20). None of the control subjects was demented upon neurological examination. There was no statistical difference between the AD and NCS groups in mean age or level of education.

Perceptual identification

Materials and procedure. The stimuli and procedure for the perceptual identification and recognition tasks were identical to those described in Experiment 2.

Word completion

Materials. We selected 92 words, 4 to 11 letters in length, of which half were high-frequency (with at least 85 occurrences per million, mean = 214) and half were low-frequency (with no more than 10 occurrences per million, mean = 2.9), according to the Kucera and Francis (1967) word frequency count. The stem (i.e., the first three letters) of each word was unique among the 92 words and constituted the beginning of at least 10 entries in the Merriam-Webster Dictionary (1974). Each of the 92 words was not the most common completion given for its stem in a pilot study of 60 normal subjects. Twelve of the words were used as filler items. The remaining 80 words were divided into two lists that were used to create two distinct, balanced forms of the test. Each 40-word list included 20 high-frequency and 20 low-frequency words. For each test form, half of the words were presented in an initial study phase and in a subsequent word-completion or recognition task (targets), and the other half were presented only in the word-completion or recognition task (foils). Of the words that appeared in the study phase, half were presented once and half were presented three times. The target and foil word-sets included equal numbers of high- and low-frequency words, as did the word-sets presented once or three times in the study list. Across subjects, the stimuli were counter-balanced so that each word

appeared equally often in the word-completion or recognition tasks, and as a target or foil item.

Procedure. The procedure in the study phase was the same as that described in Experiments 1A and 2. Twenty different words were presented singly on the computer screen; half were presented one time and the other half were presented three times. In addition to these 40 trials, three filler words were presented at the beginning and end of the list, in order to blunt any primacy and recency effects upon memory for the stimuli. The study phase was followed immediately by a word-completion or recognition task. Each subject performed a word-completion task with one test form and a recognition task with a second test form composed of different stimuli.

In the word-completion task, 40 three-letter word stems were presented one at a time on a computer screen; subjects were asked to complete each stem with the first word that came to mind. Twenty of the words had appeared in the prior study list; 10 had appeared once and 10 had appeared three times. The other 20 words had not appeared in the study list.

The procedure in the yes/no recognition task was the same as that described in Experiments 1 and 2. Subjects studied a list of 20 words, of which 10 appeared once and 10 appeared three times. Three filler words appeared at the beginning and end of the list. Immediately following this list, 40 words were presented for recognition, of which half had appeared on the prior study list (one or three times) and half had not. (We administered a recognition measure with the stem completion task rather than referring to the recognition measure administered with the perceptual identification task because the numbers of stimuli differed in the two priming tasks. By including a parallel recognition measure with each priming task, we could demonstrate that recognition memory in AD was impaired under both task conditions.)

Nine of the 10 AD patients in this experiment also received a test of category fluency as part of a separate cognitive screening battery. (They were given one minute per category to generate as many exemplars as they could from the categories "four-footed animals" and "vegetables".) The verbal fluency impairment in AD has been well-documented (Butters, Granholm, Salmon, Grant, & Wolfe, 1987; Ober, Dronkers, Koss, Delis, & Friedland, 1986), and is thought to reflect either the degradation of information in semantic memory or a deficit in lexical access. We hypothesized 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. On this basis, we predicted that performance in a category fluency task would be correlated with priming in a word-completion task, but uncorrelated with priming in a perceptual identification task.

Results

Perceptual identification

For each subject, we calculated the mean exposure time required to identify words in each of the experimental conditions defined by crossing number of prior exposures (0 vs. 1 vs. 3) with word frequency (Figure 7).

Figure 7 about here

All subjects in the NCS group and 9 of 10 subjects in the AD group showed a mean priming effect in the predicted direction.

A 3-way repeated-measures ANOVA (with factors of subject group, prior exposure, and word frequency) showed that AD patients required significantly more exposure time than NCS to identify words [group $\underline{F}(1, 18) = 5.76$, $\underline{p} < .05$],

and that high-frequency words were identified at briefer exposure times than low-frequency words [$F(1, 18) = 8.85$, $p < .01$]. The priming effect in perceptual identification was indicated by a main effect for prior exposure [$F(2, 36) = 14.51$, $p < .001$]. As in Experiment 2, there was no group x prior exposure interaction ($p > .4$), indicating that the priming effect did not differ in magnitude in the AD and NCS groups. The interaction between prior exposure and word frequency approached significance [$F(2, 36) = 2.90$, $p = .07$], reflecting greater priming for high- than low-frequency words in the 1-exposure condition, and greater priming for low- than high-frequency words in the 3-exposure condition. Neither of the other interactions reached significance. In contrast to the results of Experiment 2, analyses of the data from each subject group separately revealed no interaction between prior exposure and word frequency in the NCS group ($p > .2$) or in the AD group ($p > .1$).

The perceptual priming results in this experiment replicate those of Experiment 3 and indicate that AD patients showed a normal magnitude of priming in perceptual identification of words. However, an interpretation of this result is complicated by the fact that the AD group showed significantly worse performance at baseline than the NCS group (as was also the case in Experiment 2). In order to compare the priming performance of the two subject groups in the absence of baseline differences, we excluded the four AD patients who required the most exposure time to identify unstudied words. With the exclusion of these patients, the baseline performance of the two groups was similar (Figure 8). (We were unable to perform a similar analysis in Experiment 2 because there was not a subset of AD patients whose baseline performance approximated that of the NCS group.)

Figure 8 about here

A 3-way repeated-measures ANOVA (with factors of group, prior exposure, and word frequency) revealed no effect for group ($p > .2$), a main effect for prior exposure [$F(2, 28) = 35.41$, $p < .001$], and no group x prior exposure interaction ($p > .5$), indicating normal priming in the AD group. There was a main effect for word frequency [$F(1, 14) = 9.98$, $p < .01$] reflecting greater exposure time to identify low- than high-frequency words, and a prior exposure x frequency interaction [$F(2, 28) = 3.22$, $p = .055$], reflecting greater priming for high- than low-frequency words in the 1-exposure condition, and greater priming for low- than high-frequency words in the 3-exposure condition. Neither of the remaining interactions reached significance. These results indicate that when baseline performance was equated in the two groups, the priming effect in the AD group was normal.

Word completion

We calculated for each subject the proportion of word stems completed to target words in each of the six experimental conditions defined by crossing number of prior exposures (0,1,3) with word frequency. The proportion of stems completed to target words in the 0-exposure condition provided a baseline measure of word-completion performance. The baseline scores in the AD group were 17.2% for high-frequency and 5.0% for low-frequency words, and in the NCS group were 10.0% for high-frequency and 3.0% for low-frequency words. A 2-way repeated measures ANOVA of the baseline scores (with factors of group and word frequency) indicated that the baseline performance of the AD and NCS groups did not differ ($p > .10$), that there were more completions for high-

frequency than low-frequency words [$F(1, 18) = 14.03$, $p < .005$], and that this frequency effect did not interact with group ($p > .3$). We calculated four priming scores for each subject by subtracting the proportion of target completions in the baseline conditions from the proportion of target completions in the primed conditions (Figure 9).

Figure 9 about here

All subjects in the NCS group and 6 of 10 subjects in the AD group showed a mean priming effect in the predicted direction. A 3-way repeated-measures ANOVA of the priming scores [with factors of group, repetition (1 vs. 3), and word frequency] revealed impaired priming in the AD group [$F(1, 18) = 8.48$, $p < .01$]. The magnitude of the priming effect was not influenced by stimulus repetition ($p > .10$) or by word frequency ($p > .50$). However, an interaction between repetition and frequency [$F(1, 18) = 15.76$, $p < .001$] indicated a larger priming effect for high- than low-frequency words in the 1-exposure condition, and a larger priming effect for low- than high-frequency words in the 3-exposure condition. None of the three remaining interactions was significant. The lack of a repetition effect in this experiment differs from a report by Chen and Squire (1990) of a significant effect of repetition on word-completion priming. In the current experiment, the absence of a repetition effect could have been due to the performance of the AD group, who showed a mean priming effect of identical magnitude (12%) in the 1- and 3-exposure conditions. Although the NCS group did show a larger mean priming effect for words in the 3-exposure condition (36%) than for those in the 1-exposure condition (23%), this effect failed to reach

significance in an analysis of the NCS data alone ($p < .10$). The discrepancy between the results of the two studies may be due to the different repetition conditions used (1 or 3 exposures in the current study vs. 1, 2, or 4 exposures in the Chen and Squire study).

The analysis above revealed that word-completion priming in the AD group was significantly less than that in the NCS group. In order to determine whether priming in the AD group was greater than chance, we performed a t-test on the difference between completion rates for primed and unprimed word stems. This difference was significant [$t(9) = 2.76$, $p < .05$], indicating that priming was present (although reduced) in the AD group.

In the category fluency task, nine AD patients generated an average of 6.6 exemplars per category (range = 2 - 14.5). Performance in the category-fluency task was correlated with priming in the word-completion task ($r = .76$, $p < .05$), but uncorrelated with priming in the perceptual identification task ($r = -.11$).

Recognition

For both recognition memory measures, we calculated the mean d' scores in each of the four experimental conditions defined by crossing repetition with word frequency (Figures 10 and 11).

Figures 10 and 11 about here

For the 64-trial recognition measure, a 3-way repeated-measures ANOVA (with factors of group, repetition, and word frequency) revealed impaired performance by the AD group [$F(1, 18) = 11.77$, $p < .005$], and main effects for repetition [$F(1, 18) = 100.18$, $p < .001$] and word frequency [$F(1, 18) = 31.20$, $p < .001$], reflecting better memory for repeated words than for non-repeated words,

and for low-frequency words than for high-frequency words. AD patients failed to show a normal effect of repetition [repetition x group $F(1, 18) = 12.32$, $p < .005$]. None of the remaining interactions approached significance. In two separate analyses, we examined the hit and false alarm rates for high- and low-frequency words. A 2-way ANOVA of false alarm rates (with factors of group and word frequency) revealed impaired performance (i.e., a higher rate of false alarms) in the AD group [$F(1, 18) = 10.30$, $p < .005$], a higher rate of false alarms for high- than low-frequency words [$F(1, 18) = 13.23$, $p < .005$], and no group x frequency interaction ($p > .3$). A 2-way ANOVA of hit rates showed no effect for group ($p > .5$) and a main effect for word frequency [$F(1, 18) = 7.30$, $p < .05$] indicating more hits for low- than high-frequency words. Unlike the analysis of hit rates in Experiment 2, this analysis revealed no group x frequency interaction ($p > .5$), indicating that the advantage for low-frequency words was similar in the two groups.

In the 40-trial recognition memory measure, AD patients showed impaired performance. A 3-way ANOVA of d' scores showed main effects for group [$F(1, 18) = 6.77$, $p < .05$], repetition [$F(1, 18) = 31.64$, $p < .001$], and word frequency [$F(1, 18) = 33.77$, $p < .001$]. In this measure, unlike the 64-trial measure, there was no interaction between group and repetition, indicating that the advantage in recognition memory for repeated words was similar in the two groups. None of the remaining interactions was significant. A 2-way ANOVA of false alarm rates (with factors of group and word frequency) showed a higher rate of false alarms in the AD group [$F(1, 18) = 9.29$, $p < .01$] and a higher rate of false alarms for high- than low-frequency words [$F(1, 18) = 17.59$, $p < .001$]. An interaction between group and word frequency [$F(1, 18) = 5.43$, $p < .05$], indicated that the AD group showed a disproportionately higher rate of false alarms for high- than low-frequency words. A 2-way ANOVA of hit rates showed no effect for group

($p > .4$), and a main effect for word frequency [$F(1, 18) = 10.36$, $p < .005$], indicating a higher rate of hits for low- than high-frequency words. The interaction between group and word frequency failed to reach significance ($p > .10$).

Discussion

In Experiment 3, AD patients showed impaired recognition memory performance, a normal magnitude of priming in perceptual identification of words, and an impaired magnitude of priming in word completion. Further, in the AD group, word-completion priming was correlated with category fluency performance, but perceptual identification priming was not. The significance of these results is fourfold. First, they replicate the finding of an intact magnitude of perceptual priming in AD in Experiment 2; second, they replicate four prior reports of impaired word-completion priming in AD (Gabrieli, 1986; Heindel et al., 1989; Salmon et al., 1988; Shimamura et al., 1987); third, they demonstrate for the first time a within-subject dissociation in AD between priming in perceptual identification of words and priming in a word completion task; and fourth, they provide corroborative evidence (from the verbal fluency measure) of the dissociability of the mechanisms supporting priming in word completion and perceptual identification.

The results of Experiment 3 also gave us the opportunity to re-address two issues that complicated our interpretation of the performance of AD patients in Experiment 2. First, in Experiment 3, as in Experiment 2, the baseline performance of the AD group was worse than that of the NCS group (98 msec vs. 46 msec to identify unstudied words). Although the priming effect in the AD group was of a normal absolute magnitude, it was of a reduced magnitude if expressed as a percentage of baseline performance (18.3% priming in the AD group vs, 27.5% in the NCS group). Further (and in a contrast to Experiment 2), the difference between groups in the current experiment approached

significance (p = .07) when priming was measured proportionally rather than absolutely. Because it is unclear which measure (absolute or proportional) provides an appropriate index of priming across normal and impaired populations, an unambiguous comparison between groups requires that they exhibit similar levels of baseline performance. In Experiment 3, we were able to perform such a comparison between the NCS group and a subset of the AD group whose baseline performance was normal. As mentioned earlier, this analysis indicated normal perceptual priming in the AD group. This subsidiary analysis lends support to the claim that the normal magnitude of priming exhibited by the AD groups in Experiments 2 and 3 reflects intact perceptual priming.

The second issue that complicated an interpretation of the data in Experiment 2 was the presence of a prior exposure x frequency interaction (reflecting greater priming for low- than high-frequency words) in the NCS group and its absence in the AD group. In Experiment 3, this interaction was not evident in the global anaysis, nor was it evident in separate analyses of the NCS and AD data alone. Instead, in both groups, the mean priming effect for high- and low-frequency words was similar. Thus, the interaction between word frequency and priming is not reliable across healthy elderly control subjects (it was present in the NCS group in Experiment 2 but not in Experiment 3). Its absence in the AD groups in Experiments 2 and 3 may not reflect an impairment specific to AD.

GENERAL DISCUSSION

The aim of the current study was to determine whether priming in perceptual identification of briefly presented words was normal in AD patients,

and dissociable from priming in a word-completion task. In Experiment 1, in order to establish the reliability of our priming measure, we administered the task to a large group of normal subjects. Consistent with other studies, prior exposure to a word enhanced subsequent perceptual identification of that word; this priming effect was greater for low-frequency than high-frequency words (when words were studied and tested in the same modality), and the magnitude of the priming effect was reduced when the perceptual modality of presentation differed at study and identification. In Experiment 2, AD patients showed a normal magnitude of priming during perceptual identification of briefly presented words. In Experiment 3, we replicated this result and demonstrated a dissociation between perceptual priming and word-completion priming within a single group of AD patients. These results suggest the neural separability of two components of verbal priming: a perceptual component (intact in AD), and a conceptual component (impaired in AD).

Perceptual priming was dissociated from recognition memory in the present study in two ways. In Experiment 1B, a shift in perceptual modality between study and test reduced the magnitude of the priming effect but did not significantly affect recognition memory. In Experiments 2 and 3, AD patients showed a normal magnitude of perceptual priming, but impaired recognition memory. These results replicate similar dissociations between perceptual priming and recall/recognition memory in normal subjects (Jacoby & Dallas, 1981; Winnick & Daniel, 1970) and in patients with global amnesia (Cermak et al., 1985). More generally, the dissociation between recognition memory and priming is consistent with theories that posit a distinction between one form of memory that depends upon limbic-diencephalic function and another form that does not (Cohen & Squire, 1980; Graf & Schacter, 1985; Kinsbourne & Wood, 1975). The present study extends previous work, however, by demonstrating

that perceptual priming may not depend upon the cortical and subcortical structures outside the limbic-diencephalic region that are typically damaged in AD.

Three aspects of the current results provide evidence for the dissociability of perceptual priming and word-completion priming: First, AD patients showed normal perceptual priming by an absolute measure, but impaired word-completion priming by either an absolute or a proportional measure. Second, across Experiments 2 and 3, the percentage of AD patients who showed perceptual priming was 86% (vs. 91% in the NCS group) and the percentage who showed word-completion priming was 60% (vs. 100% in the NCS group.) Third, the performance of the AD patients on a category fluency task was correlated with word-completion priming, but uncorrelated with perceptual priming. These results provide strong evidence that perceptual priming and word-completion priming tasks index separate learning mechanisms that are differentially susceptible to the effects of AD.

Two prior studies reported intact repetition priming effects in AD on a lexical decision task (Moscovitch, 1982; Ober & Shenaut, 1988), in which the measure of priming was the reduction in response time from the first to the second presentation of a word. There is evidence that this priming effect may, under some conditions, include a substantial perceptual component: the effect can be attenuated or eliminated if the first occurrence of a word is presented in a different perceptual modality or in a different visual code (e.g., pictorial) than the second (Kirsner & Smith, 1974; Monsell, 1985; Scarborough, Gerard, & Cortese, 1979). The preservation of lexical decision repetition priming effects in AD may reflect the operation of those mechanisms that support normal perceptual priming in the present study.

Moscovitch et al. (Moscovitch, Winocur, & McLachlan, 1986) found that a

group of memory disordered patients (including AD patients) showed normal repetition effects upon speed of reading geometrically transformed script and upon speed of reading sentences and word pairs with and without contextual manipulation. Because the subject population in the Moscovitch et al. study included patients with etiologies other than AD, their results may not be directly comparable to our own. However, their results are consistent with the present study in that they suggest intact priming in AD on two priming tasks that may draw largely upon perceptual learning mechanisms.

Cognitive mechanisms underlying dissociable priming effects: Evidence from normal cognition

There is convergent evidence in normal cognition that priming is not the product of a unitary mechanism. For example, Witherspoon and Moscovitch (1989) reported stochastic independence between priming in perceptual identification of words and priming in word-fragment completion. Further, in a series of studies, Roediger and Blaxton (Blaxton, 1989; Roediger & Blaxton, 1987A; Roediger, Weldon, & Challis, 1989) demonstrated the dissociability of measures of memory that require an analysis of the physical features of stimuli (data-driven tasks) and measures that require an analysis of the meanings of stimuli (concept-driven tasks). The dissociation between data-driven and concept-driven processes in normal cognition parallels the dissociation between perceptual and conceptual priming in AD.

Evidence that priming in perceptual identification of words is primarily perceptual (rather than conceptual) comes from findings that this kind of priming in normal subjects depends critically upon a perceptual match between the study and test presentations of a word. Priming in perceptual identification of visually presented words is reduced or eliminated when the surface

characteristics (e.g., case, font) differ at study and test (Jacoby & Hayman, 1987); when the words are presented in pictorial form at study (Winnick & Daniel, 1970); when words are generated rather than read at study (Clarke & Morton, 1983, Exp. 1; Jacoby, 1983B; Winnick & Daniel, 1970); and when the words are presented auditorily at study (Experiment 1B; Clarke & Morton, 1983, Exps. 2, 3; Jacoby & Dallas, 1981, Exp. 6; Kirsner et al., 1983). Thus, priming in perceptual identification of words does not result merely from prior activation of the abstract representation of a word, but depends upon repeated processing of modality-specific perceptual features of the stimulus.

Modality specificity, however, is not restricted to priming tasks that involve perceptual identification. Indeed, priming effects in a variety of tasks, including word-stem completion (Bassili, Smith, & MacLeod, 1989; Graf, Shimamura, & Squire, 1985), context-dependent word-stem completion (Schacter & Graf, 1989), and word-fragment completion (Roediger & Blaxton, 1987A), are attenuated when the modality of exposure differs in the study and test phases. The ubiquitousness of modality effects across priming tasks suggests that all instances of priming depend to some extent upon perceptual learning processes.

There are three souces of evidence in normal cognition, however, that priming in a word-completion task includes a component beyond the perceptual one that it shares with priming in a perceptual identification task. First, priming in the two tasks is differentially sensitive to shifts in study-test modality. Priming in word completion has been reduced, but never eliminated, cross-modally (Bassili, Smith, & MacLeod, 1989; Graf, Shimamura, & Squire, 1985). In contrast, priming in perceptual identification of words has been statistically eliminated cross-modally in at least two studies (Clarke & Morton, 1983, Exp. 2, 3; Jacoby & Dallas, 1981). Second, priming in the two tasks is

dissimilarly influenced by depth-of-processing manipulations. Word-completion priming is sometimes enhanced by elaborative encoding: Two studies demonstrated significantly greater priming following semantic relative to non-semantic encoding of words (Chiarello & Hoyer, 1988; Graf et al., 1984), and one other study reported a similar (non-significant) trend (Graf & Mandler, 1984). On the other hand, priming in perceptual identification of words is not enhanced by elaborative encoding: In one study, the depth-of-processing manipulation had virtually no effect (Jacoby & Dallas, 1981) and in another, the manipulation produced a non-significant trend toward greater priming in the non-semantic encoding condition (Kirsner et al., 1983, Exp.1). Third, the duration of priming in the two tasks differs: Word-completion priming disappears after two hours (Graf et al., 1984) even with as many as 32 exposures to stimuli in a study list (Chen & Squire, 1990).[2] In contrast, priming in perceptual identification of words can persist for 24 hours (Jacoby & Dallas, 1981) or for several days (Jacoby, 1983A) following one or two exposures in a study list. These three lines of evidence demonstrate the dissociability of word-completion priming and perceptual priming in normal cognition, and suggest that the two tasks do not index a single cognitive mechanism.

In summary, we propose that all priming tasks depend upon perceptual

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[2] Note, however, that longer-lasting word-completion priming effects have been obtained in normal subjects when word-stems specified unique solutions (Squire, Shimamura, & Graf, 1987, Exp. 2). However, in that experiment, amnesic subjects failed to show normal priming; Squire et al. suggested that the long-lasting effect in normal subjects might have been mediated by conscious retrieval strategies.

learning processes, but differ in the degree to which they depend upon those processes and in the extent to which they draw additionally upon conceptual learning processes. On tasks in which subjects are provided with incomplete or degraded perceptual information (e.g., identification of briefly presented words or incomplete pictures), priming may reflect, in larger part, perceptual learning processes (and so might be eliminated under cross-modal conditions). On tasks requiring a search for a word satisfying a particular orthographic or semantic constraint (e.g., word completion, category exemplar production), priming may reflect a larger contribution of conceptual relative to perceptual learning processes (and so would not be eliminated under cross-modal conditions). The findings to date suggest that neural circuits spared in AD support perceptual learning processes but fail to support conceptual learning processes.

Neural basis of dissociable priming effects

Gabrieli et al. (Gabrieli, 1989, in press; Gabrieli et al., submitted) postulated that a structural-perceptual memory system, localized to the occipital lobe, supports perceptual priming effects, and that a lexical-semantic memory system, localized to temporoparietal cortex, supports conceptual priming effects. The dissociation in AD between perceptual priming and word-completion priming lends support to this hypothesis. The neuropathology in AD is not diffuse and complete, but exhibits regional variability, with pronounced involvement of neocortical association areas in the frontal, temporal, and parietal lobes (Brun & Englund, 1981; Pearson et al., 1985; Rogers & Morrison, 1985; Terry et al., 1981; Wilcock & Esiri, 1982), and relative sparing of primary sensory cortices (Brun & Englund, 1981; Esiri, Pearson, & Powell, 1986; Lewis, Campbell, Terry, & Morrison, 1987; Rogers & Morrison, 1985). Results of in vivo physiological studies reveal that metabolic activity is significantly reduced in temporoparietal

cortex but relatively normal in occipital cortex in AD patients (Johnson, Mueller, Walshe, English, & Holman, 1987). Further, a demonstration of an intact visual aftereffect in AD patients (Savoy & Gabrieli, 1990) provides evidence for normal plasticity in an occipital circuit. The reduction of temporoparietal-lobe function and the relative preservation of occipital-lobe function in AD, coupled with the results of the present study, suggest that perceptual priming may depend largely upon the integrity of occipital cortex, and word-completion priming may depend largely upon the integrity of more anterior cortical regions compromised in AD.

Convergent (albeit indirect) evidence about the neural localization of priming in perceptual identification of words comes from the work of Posner et al. (Posner, Petersen, Fox, & Raichle, 1988), who examined cerebral blood flow in normal subjects during word perception. They found that the brain activation attributable to coding of the visual word form was confined to the occipital lobe (in particular, to an area of extrastriate cortex). Thus, in normal cognition, an occipital circuit supports perceptual processes that enable one to identify word form. We propose that priming in perceptual identification of words reflects the enhancement of those processes and is similarly localizable to the occipital lobe.

Our account of the present results shares many features with a theory of priming put forward by Schacter and Tulving (Schacter, in press; Tulving & Schacter, 1990). They postulate that priming is mediated by a perceptual representation system that processes structural descriptions of objects and operates at a pre-semantic level. Thus, both their account and our own emphasize the critical role of perceptual learning processes in priming. Our account differs from Schacter and Tulving's in that it stresses, additionally, the interaction of conceptual (i.e., lexical-semantic) processes with those perceptual processes in a variety of priming tasks. The results of the present study

demonstrate a dissociation between perceptual and conceptual priming in AD and may elucidate the neural basis of dissociable priming effects in normal cognition.

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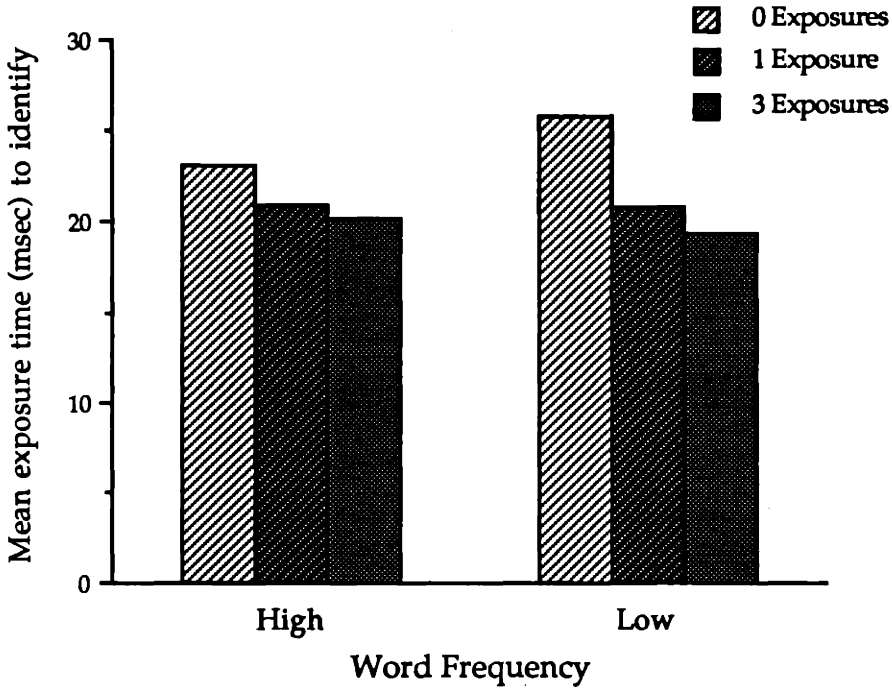

Figure 1. Experiment 1A: Priming during perceptual identification of briefly presented words in college students (N = 32). Bars show mean exposure time to identify unstudied (0 prior exposures) and studied (1 or 3 prior exposures) words of high and low frequency. The priming effect is the reduction in exposure time needed to identify studied words relative to unstudied words.

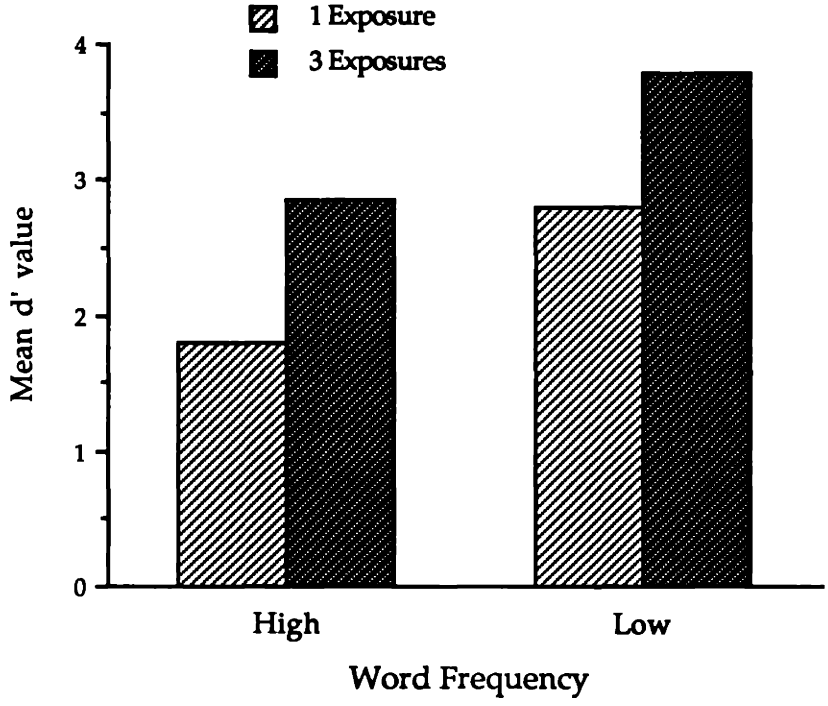

Figure 2. Experiment 1A: Visual recognition performance in college students (N = 32) for high-frequency and low-frequency words that were presented visually one or three times in a prior study list.

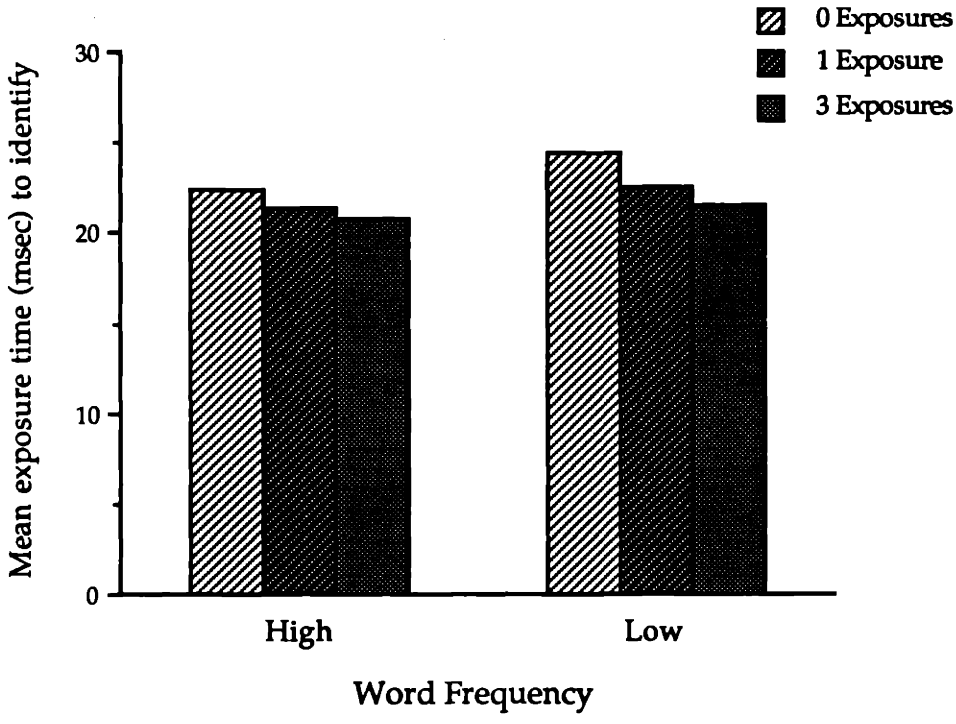

Figure 3. Experiment 1B: Priming during perceptual identification of briefly presented words following auditory study in college students (N = 32). Bars show mean exposure time to identify unstudied (0 prior exposures) and studied (1 or 3 prior exposures) words of high and low frequency. The priming effect is the reduction in exposure time needed to identify studied words relative to unstudied words.

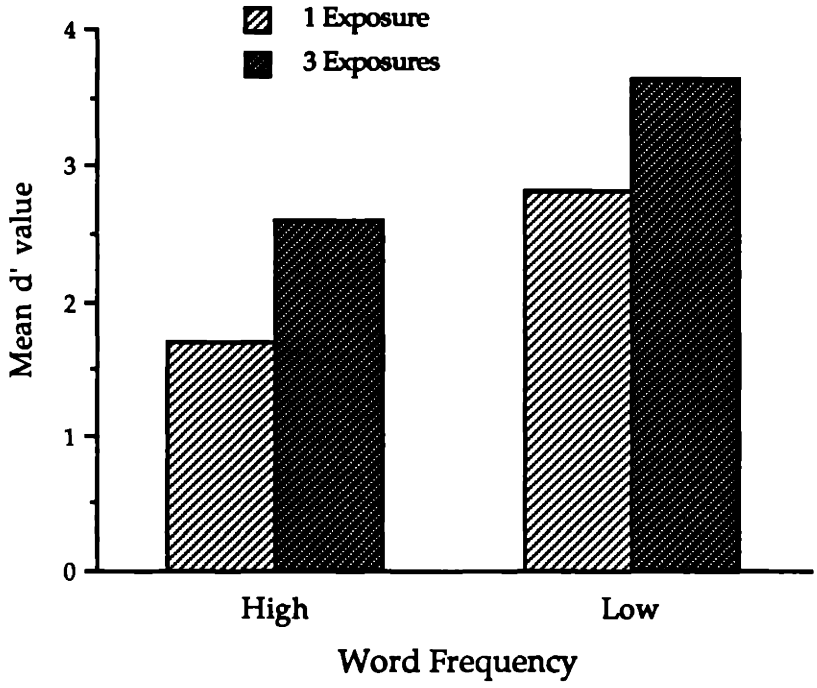

Figure 4. Experiment 1B: Visual recognition performance in college students (N = 32) for high- and low-frequency words that were presented auditorily one or three times in a prior study list.

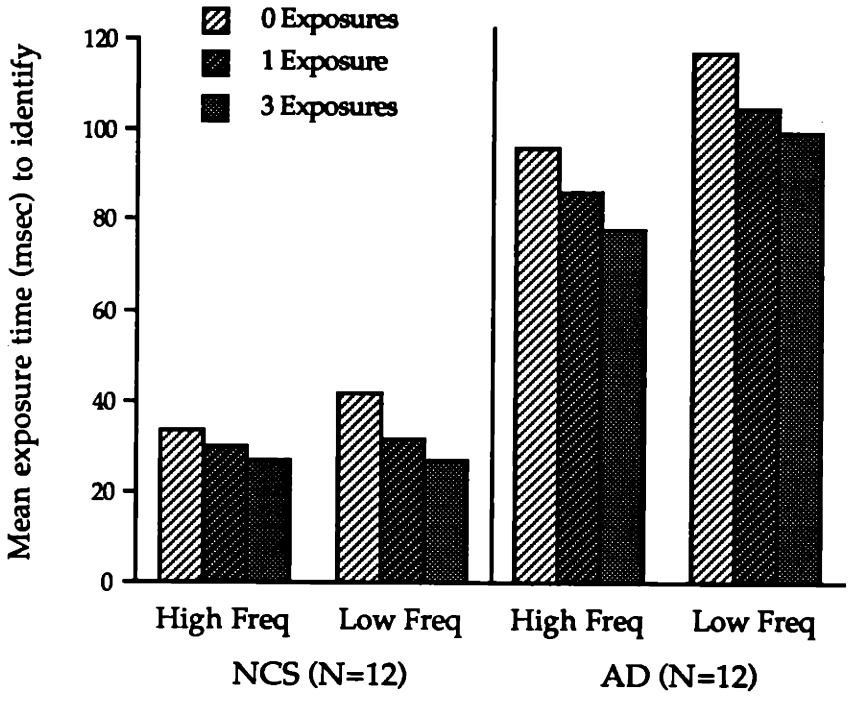

Figure 5. Experiment 2: Priming during perceptual identification of briefly presented words in AD and NCS groups. Bars show mean exposure time to identify unstudied (0 prior exposures) and studied (with 1 or 3 prior exposures) words of high and low frequency. The priming effect is the reduction in exposure time needed to identify studied words relative to unstudied words.

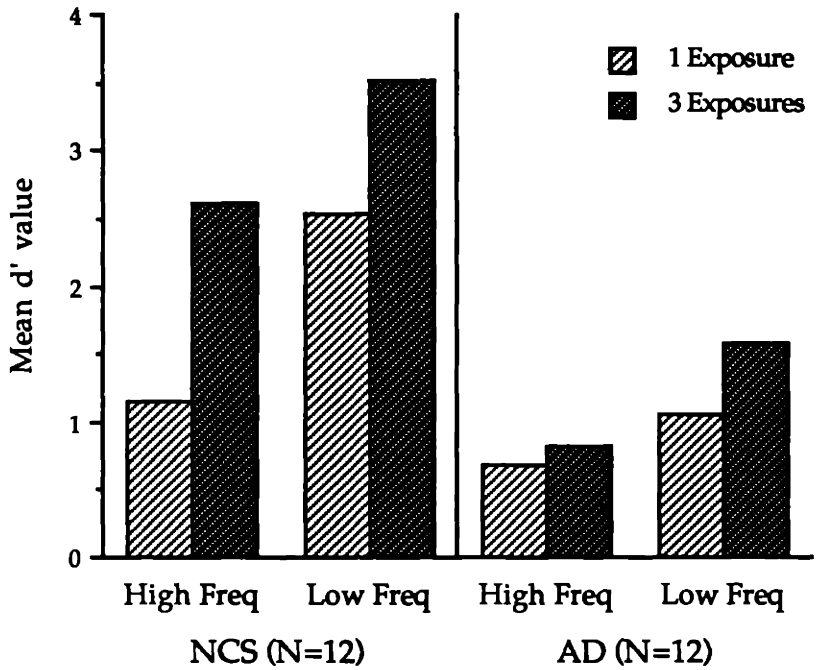

Figure 6. Experiment 2: Recognition performance in AD and NCS groups for high- and low-frequency words that appeared one or three times in a prior study list.

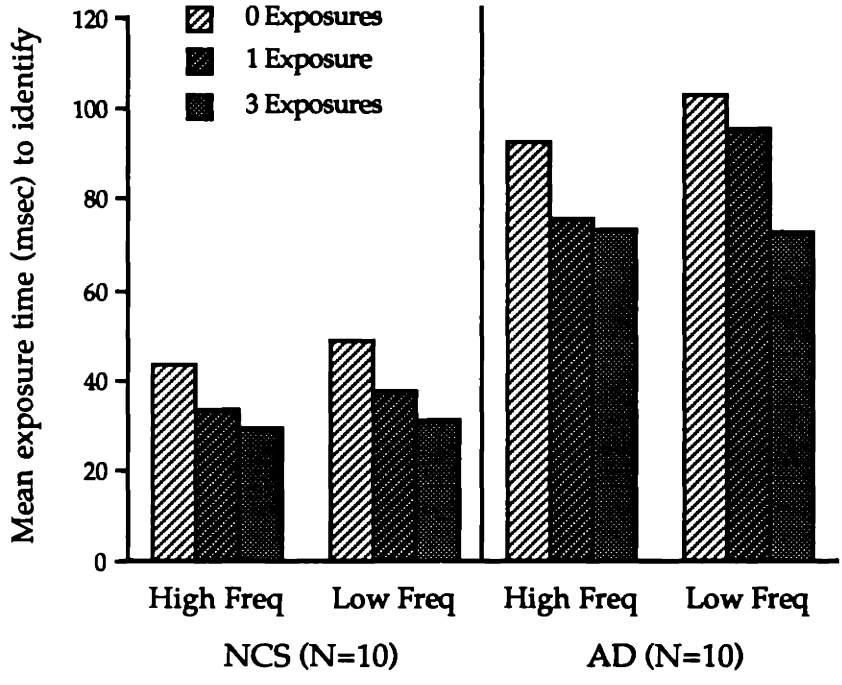

Figure 7. Experiment 3: Priming during perceptual identification of briefly presented words in AD and NCS groups. Bars show mean exposure time to identify unstudied (0 prior exposures) and studied (1 or 3 prior exposures) words of high and low frequency. The priming effect is the reduction in exposure time needed to identify studied words relative to unstudied words.

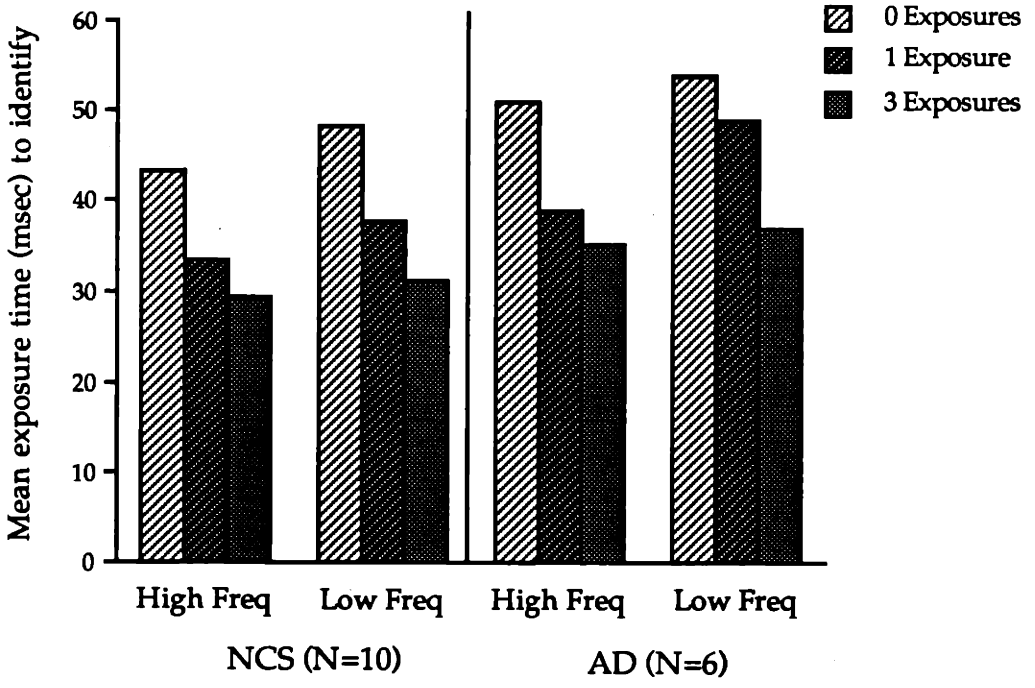

Figure 8. Experiment 3: Priming during perceptual identification of briefly presented words in AD and NCS groups, excluding the four AD patients with the highest (i.e., worst) baseline performance. Bars show mean exposure time to identify unstudied (0 prior exposures) and studied (1 or 3 prior exposures) words of high and low frequency. The priming effect is the reduction in exposure time needed to identify studied words relative to unstudied words.

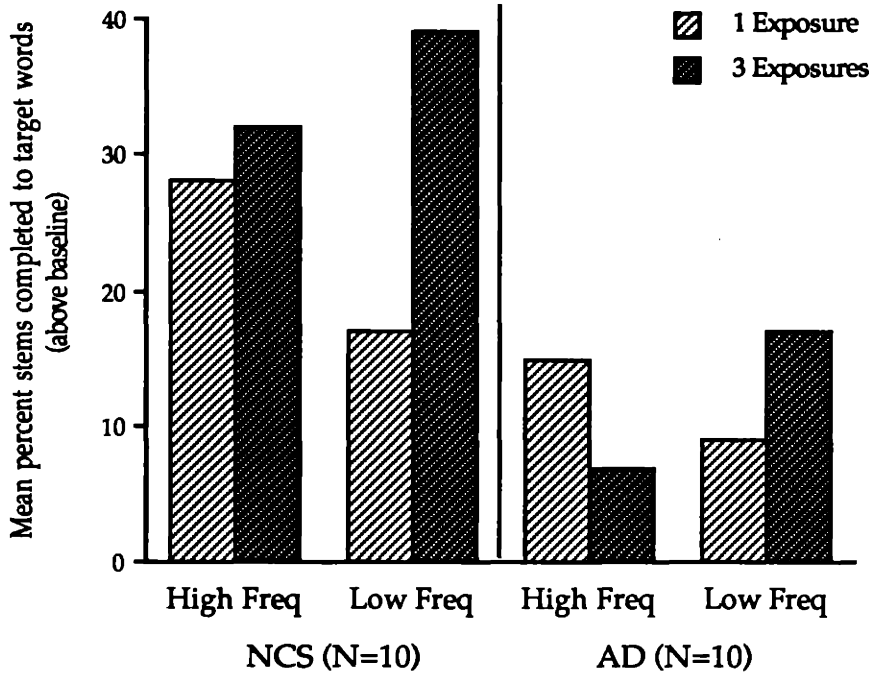

Figure 9. Experiment 3: Word-completion priming in the AD and NCS groups. Bars show mean priming scores for high- and low-frequency words following one or three prior exposures in a study list.

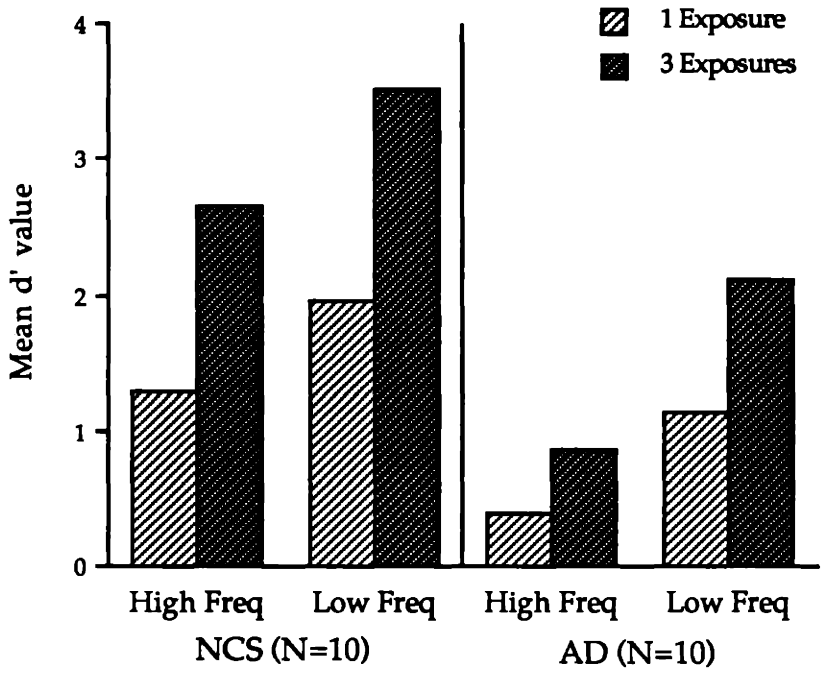

Figure 10. Experiment 3: Recognition performance (64-item test) in AD and NCS groups for high- and low-frequency words that appeared one or three times in a prior study list.

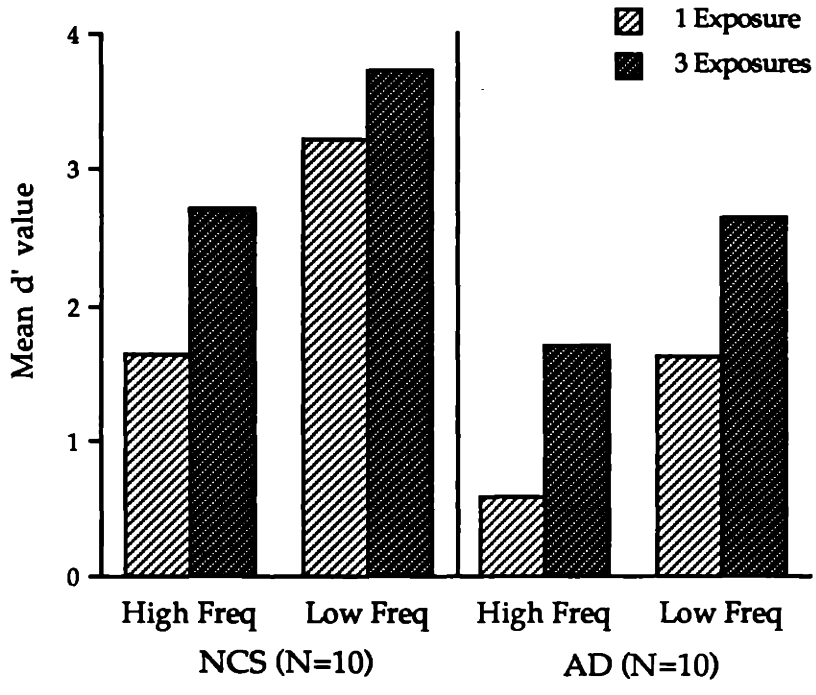

Figure 11. Experiment 3: Recognition performance (40-item test) in AD and NCS groups for high- and low-frequency words that appeared one or three times in a prior study list.

Normal Priming in Perceptual Identification of Pseudowords in Patients With Alzheimer's Disease

Introduction

Behavioral findings in patients with global amnesia have demonstrated that lesions to medial temporal-lobe and diencephalic structures impair performance on standard recall and recognition memory tests (often classified as explicit or direct measures), but do not affect performance on repetition priming tasks (often classified as implicit or indirect measures, (Graf & Schacter, 1985; Richardson-Klavehn & Bjork, 1988; Schacter, 1987). In a typical priming task, subjects study a list of words or pictures, and then perform a task that requires them to generate a word, given partial semantic or orthographic information, or to identify a word or picture, given incomplete or degraded perceptual information. The measure of memory is the facilitatory or biasing effect of prior exposure to words or pictures upon subsequent task performance with the same words or pictures. The dissociability of priming effects from recall/recognition memory in amnesia (for reviews see Richardson-Klavehn & Bjork, 1988; Shimamura, 1986) suggests that priming is mediated by memory processes that are independent of limbic-diencephalic structures.

Recently, studies of patients with Alzheimer's disease (AD) have revealed that priming effects may not reflect the operation of a unitary mechanism: AD patients show impaired priming on tasks in which they must retrieve a word satisfying a particular orthographic or semantic constraint (e.g., word completion, generation of semantic associates, Gabrieli et al., submitted; Heindel, Salmon, Shults, Walicke, & Butters, 1989; Huff, Mack, Mahlmann, & Greenberg, 1988; Keane, Gabrieli, Fennema, Growdon, & Corkin, in press; Salmon, Shimamura, Butters, & Smith, 1988; Shimamura, Salmon, Squire, & Butters, 1987), but normal priming on tasks in which they must identify a

stimulus from degraded perceptual information (e.g., identification of briefly presented words or fragmented drawings, Gabrieli et al., submitted; Keane et al., in press; but see Butters ref). This dissociation between (impaired) conceptual priming and (intact) perceptual priming in AD is evident within a single group of AD patients (Keane et al., in press), and so must not be due to variability among patient groups. Rather, it appears that normal priming must be the product of at least two separable learning processes, of which only the perceptual learning process is spared in AD.

Neuroimaging studies in normal subjects have provided evidence about a plausible neural locus of perceptual priming effects. In a series of positron emission tomography (PET) studies, Raichle and colleagues (Petersen, Fox, Posner, Mintun, & Raichle, 1988; Petersen, Fox, Posner, Mintun, & Raichle, 1989; Petersen, Fox, Snyder, & Raichle, 1990; Posner, Petersen, Fox, & Raichle, 1988) demonstrated that an area in the left, medial extrastriate visual cortex was selectively activated by visual presentation of words and orthographically regular pseudowords, but not by strings of consonants or strings of letter-like fonts. These findings suggest that information about the lexical status of a visual stimulus is available early in the visual system. Although these studies do not demonstrate directly that a posterior region is activated during lexical priming tasks, the results raise the possibility that perceptual priming of words (or word-like stimuli) reflects plasticity within an extrastriate area that is concerned with processing of the visual word form.

We reasoned that if this posterior visual word form area is the neural locus of perceptual priming of words and word-like stimuli in normal subjects, and more specifically, if this area forms the neural basis of intact perceptual priming of words in AD patients (Keane et al., in press), then AD patients should show intact perceptual priming effects with orthographically regular

pseudowords. We tested this hypothesis in the present study.

In normal subjects, prior exposure to pseudowords or nonsense syllables facilitates subsequent identification of those stimuli (relative to unstudied stimuli) upon brief visual presentation (Postman & Rosenzweig, 1956; Solomon & Postman, 1952; Sprague, 1959). In the present study, we examined perceptual priming for pseudowords in AD patients and normal control subjects (NCS). Subjects studied a list of three-letter pseudowords and were subsequently asked to identify studied and unstudied pseudowords presented briefly on a computer screen. In a second test session, subjects studied a different list of pseudowords and were then asked to perform a recognition task with studied and unstudied stimuli. This experiment served two purposes: First, it allowed us to examine whether perceptual priming of pseudowords was dissociable from recognition memory performance (which is typically impaired in AD patients). Second, it allowed us to determine whether intact perceptual priming in AD extended to pseudoword stimuli.

Method

Subjects

We tested 13 patients with a diagnosis of probable AD and 12 NCS.

AD patients. All AD patients had a diagnosis of probable AD based upon NINCDS (McKhann et al., 1984) and NIA (Khachaturian, 1985) criteria. The group included 8 women and 5 men. After testing, the data from one male patient were excluded from further analysis because his baseline performance was greater than 2 SD from the mean of the 13 AD patients, and he failed to identify 15.6% of the items in the perceptual identification task (compared to a mean failure rate of 0.4% for the other patients). For the remaining 12 patients, the mean age was 70.4 years (range = 57 - 83) and the mean level of education

was 12.9 years (range = 8 - 20). The mean Blessed Dementia Scale (BDS) score (Blessed, Tomlinson, & Roth, 1968) was 15.2 (range = 3 - 36.5), indicating mild to severe dementia. None of the patients was institutionalized.

NCS. The control group consisted of spouses of AD patients who were participating in research studies at the MIT Clinical Research Center, and subjects recruited through newspaper advertisements. All control subjects were found to be free of dementia upon neurological examination. The group included 7 women and 5 men, whose mean age was 62.6 years (range = 51 - 80) and whose mean level of education was 13.3 years (range = 8 - 20). The mean levels of education in the AD and NCS groups did not differ, but the mean age of the AD patients was greater than that of the NCS, $t = 2.26$, $p < .05$. With regard to the present study, however, this difference would likely work against our prediction of normal performance in the AD group.

Materials

The stimuli were 140 three-letter pronounceable pseudowords, formed by creating consonant-vowel-consonant strings that followed the rules of English orthography. Twelve of these pseudowords were used as filler items. Of the remaining 128 pseudowords, 64 were used in the perceptual identification task, and 64 were used in the recognition task.

Procedure

In brief, each subject studied one list of pseudowords, performed a perceptual identification task with studied and unstudied pseudowords, then studied a second, different list of pseudowords, and performed a yes/no recognition task with studied and unstudied pseudowords. All stimuli were presented on the screen of an IBM personal computer. Subjects were seated approximately 20 inches from the screen.

Study phase. The procedure in the study phase was identical for the

perceptual identification and the recognition tasks. Subjects were told that they would see a series of nonsense words presented one at a time on the computer screen and that they were to read each word aloud. Thirty-two different pseudowords were presented singly on the computer screen; half were presented one time and the other half were presented three times (once within each third of the list). In addition to these 64 trials, three filler pseudowords were presented at the beginning and end of the list (to blunt any primacy and recency effects upon later memory for the stimuli), yielding a total of 70 trials. Each pseudoword was presented on the computer screen for 4 seconds. The study phase was followed immediately by a perceptual identification or recognition task.

Perceptual identification. Subjects were told that they would perform a second task that was unrelated to the study task. They were told that a series of nonsense words would be presented very briefly on the computer screen and that they were to identify each word. Each trial was preceded by the appearance of a fixation character ("+") in the middle of the screen. Subjects were instructed to fixate this character in preparation for the brief appearance of a pseudoword. On each trial, a pseudoword was flashed on the computer screen and then replaced by a backward mask ("###") of 250 msec duration. The initial presentation time was 16.7 msec. If the subject was unable to identify the stimulus at this exposure time, it was presented in the following trial for 33.4 msec. The same pseudoword was presented in additional increments of 16.7 msec on successive trials until the subject correctly identified it (or until a maximum exposure time of 635 msec was reached). The computer recorded the number of presentations (i.e., the exposure time) required to identify each pseudoword. Sixty-four different pseudowords were presented in the perceptual identification task. Thirty-two of these stimuli had appeared in the prior study

list; 16 had appeared once and 16 had appeared three times. The other 32 had not appeared in the prior study list. Across subjects, the stimuli were counterbalanced so that each pseudoword appeared equally often as a studied or unstudied item in the perceptual identification task.

Recognition. In the recognition test, subjects were told that a series of nonsense words would be presented on the computer screen, of which some had appeared in the preceding study list. Subjects were asked to respond "YES" if they had seen the nonsense word on the prior list and "NO" if they had not. Sixty-four pseudowords were presented in the recognition test; half had appeared in the prior study list (once or three times) and half were new. The stimuli were counterbalanced across subjects so that each pseudoword appeared equally often as a studied or unstudied item in the recognition task.

Results

Perceptual Identification

The dependent measure was the exposure time needed to identify pseudowords. The experimental manipulations of interest were prior study condition (studied vs. unstudied) and repetition (one vs. three occurrences in the study list). These two manipulations were combined to yield a single design factor of prior exposure (none, one, or three) in which foils had no prior exposures. For each subject, we calculated the mean exposure time (in milliseconds) required to identify pseudowords in each of the three conditions (Figure 1). Ten of 12 subjects in the NCS group and 11 of 12 subjects in the AD group showed a mean priming effect in the predicted direction (i.e., required less exposure time to identify studied than unstudied pseudowords).

Figure 1 about here

We performed a two-way repeated-measures ANOVA with factors of subject group and prior exposure (none, one, or three). Although the AD patients required more exposure time overall than the NCS to identify pseudowords, the effect of subject group did not reach significance ($p = .102$). The priming effect in perceptual identification was indicated by a main effect for prior exposure, $F(2, 44) = 10.05$, $p < .001$. Critically, there was no interaction between group and prior exposure ($p > .5$), indicating that the magnitude of the priming effect was normal in the AD group. In view of the fact that the mean age of the AD group was greater than that of the NCS group, we examined the correlation between age and the mean priming effect for each subject across both groups: This analysis revealed no significant correlation between age and priming ($r = .11$).

The intactness of the priming effect in AD was supported by two further analyses. In the first, scores were collapsed across the two repetition conditions (one vs. three) to yield a single measure for studied items. The mean exposure times required to identify studied and unstudied items were 73.7 msec and 79.8 msec, respectively, in the AD group, and 47.6 msec and 53.1 msec, respectively, in the NCS group. A two-way ANOVA of these data with factors of group and study condition (studied vs. unstudied) revealed a non-significant effect for group ($p = .102$), a main effect for study condition, $F(1, 22) = 10.76$, $p < .005$, and no group x study condition interaction, $p > .5$.

In the second analysis, we examined only the scores for studied items, in order to determine whether AD patients and NCS were similarly affected by the number of prior exposures in the study list. The mean exposure times required to identify items with one or three exposures in the study list were 76.5 msec and 70.9 msec, respectively, in the AD group, and 49.1 msec and 46.1 msec,

respectively, in the NCS group. A two-way ANOVA of these data (with factors of group and repetition) revealed a non-significant effect for group ($p = .101$), and a main effect for repetition, $F(1, 22) = 8.70$, $p < .01$, reflecting enhanced performance with pseudowords studied three times relative to those studied once. Again, there was no interaction between group and repetition ($p > .3$), indicating that the effect of stimulus repetition was normal in the AD group.

Although the effect of group never reached significance in the analyses described above, it is clear that, on average, the AD patients required more exposure time than the NCS to identify pseudowords. This difference in baseline performance between the two groups complicates an evaluation of the intactness of priming in the AD group. In particular, although the AD group showed a normal absolute magnitude of priming, it is unclear from the analyses described whether priming in the AD group would appear normal if it were expressed as a proportion of baseline performance. To address this issue, we calculated proportional priming scores for each subject by subtracting the mean exposure time to identify studied pseudowords from the mean exposure time to identify unstudied pseudowords, and dividing this difference by the mean exposure time to identify unstudied pseudowords. By this measure, the priming scores for pseudowords with one or three prior exposures were 3.8% and 13.5%, respectively, in the AD group, and 7.4% and 11.5%, respectively, in the NCS group. A two-way ANOVA of these data showed a main effect for repetition, $F(1, 22) = 10.22$, $p < .005$, reflecting more priming for stimuli with three prior exposures than for those with one prior exposure. The amount of priming in the two groups did not differ ($p > .5$), and there was no interaction between group and repetition ($p > .2$). Thus, priming appears to be normal in the AD group, whether the effect is measured in absolute or proportional terms.

In order to document the status of priming in a group of AD patients

whose baseline performance was clearly normal, we re-analyzed the present results after eliminating the 4 AD patients who required the most exposure time to identify unstudied words (Figure 2).

Figure 2 here

The baseline performance of the remaining 8 AD patients was comparable to that of the NCS. A two-way ANOVA of these data with factors of group and prior exposure indicated a main effect for prior exposure, $F(2, 36) = 7.90$, $p < .005$, but no effect for group ($p > .5$) and no interaction between group and prior exposure ($p > .5$). Thus, the priming effect was normal in a subset of AD patients whose baseline performance was normal.

Recognition

For each subject, we calculated the proportion of pseudowords correctly recognized from the study list (hits) in each of the two repetition conditions (one and three), and the proportion of unstudied pseudowords incorrectly assigned to the study list (false alarms). We used these proportions to determine d' scores for studied pseudowords (Figure 3).

Figure 3 here

A two-way ANOVA of these scores with factors of group and repetition showed that recognition performance was impaired in the AD group, $F(1, 22) = 4.84$, $p < .05$, recognition was better for stimuli with three prior exposures than for those

with one prior exposure, $F(1, 22) = 22.8$, $p < .001$, and the AD and NCS groups were similarly affected by stimulus repetition (group x repetition, $p > .5$).

Discussion

We hypothesized that perceptual priming with real words and orthographically regular pseudowords depends upon a unitary mechanism dissociable from explicit memory. In light of evidence that AD patients show intact perceptual priming with words (Keane et al., in press), we predicted that they would show intact perceptual priming with pseudowords in the present study. Consistent with this prediction, AD patients showed normal priming in perceptual identification of pseudowords coupled with impaired recognition memory for pseudowords. These results have two implications: First, they demonstrate that priming in perceptual identification of pseudowords does not depend upon the processes that support recognition memory. This finding is consistent with a large body of evidence demonstrating the dissociability of priming from explicit memory in amnesic patients and in normal subjects (reviewed by Richardson-Klavehn & Bjork, 1988; Schacter, 1987; Shimamura, 1986). Second, the present results extend the boundaries of intact perceptual priming in AD to include pseudoword stimuli, and suggest that such priming does not depend upon the integrity of the particular cortical and subcortical structures that are compromised in AD.

The AD patients' impaired recognition memory performance in the present study is likely due to the bilateral hippocampal pathology that characterizes AD (Hyman, Van Hoesen, & Damasio, 1990; Hyman, Van Hoesen, Damasio, & Barnes, 1984; Hyman, Van Hoesen, Kromer, & Damasio, 1986; Wilcock & Esiri, 1982). Numerous studies have documented the critical role of the hippocampus and surrounding medial temporal-lobe structures in

recognition memory processes in humans and subhuman primates (Gaffan, 1974; Mahut, Moss, & Zola-Morgan, 1981; Mahut, Zola-Morgan, & Moss, 1982; Mishkin, 1978; Penfield & Milner, 1958; Scoville & Milner, 1957; Zola-Morgan & Squire, 1985; Zola-Morgan, Squire, & Amaral, 1986). In AD, the effective isolation of the hippocampus from cortical projection sites (Hyman et al., 1990; Hyman et al., 1984; Hyman et al., 1986) mimics the effect of hippocampal ablation and forms the neural basis of the recognition memory impairment evident in this and many other behavioral studies in AD patients (e.g., Corkin, 1982).

AD patients' intact pseudoword priming in the present study, coupled with prior reports of normal priming in AD in perceptual identification of words (Keane et al., in press), suggests that perceptual priming of words and pseudowords may reflect the operation of a unitary mechanism. Further, the neuropsychological findings converge with PET studies in normal subjects demonstrating that processing of the visual form of words and pseudowords (but not strings of consonants or letter-like fonts) selectively activates an area in the left, medial extrastriate cortex (Petersen et al., 1988; Petersen et al., 1989; Petersen et al., 1990; Posner et al., 1988). The neuroimaging evidence points to an extrastriate area as a plausible locus of intact perceptual priming of words and pseudowords in AD patients.

It is clear that primary sensory and motor areas are relatively preserved in AD (Brun & Englund, 1981; Esiri, Pearson, & Powell, 1986; Pearson, Esiri, Hiorns, Wilcock, & Powell, 1985; Rogers & Morrison, 1985); the neocortical regions most compromised by the disease process are association areas in frontal, temporal, and parietal cortex (Brun & Englund, 1981; Pearson et al., 1985; Rogers & Morrison, 1985; Terry, Peck, DeTeresa, Schecter, & Horoupian, 1981; Wilcock & Esiri, 1982). Thus, for example, striate cortex (area 17) is relatively free of

pathology. In contrast, however, extrastriate cortex (area 18) is clearly not free of pathology (though it is somewhat less affected than higher visual areas e.g., Lewis, Campbell, Terry, & Morrison, 1987). This evidence appears to be inconsistent with the hypothesis that an extrastriate circuit forms the neural basis of perceptual priming in AD.

However, in addition to being regionally specific, the neuropathology in AD is remarkably lamina-specific: There is some evidence that the pathology is most severe in layers 3 and 5, less in layer 4, and least in layers 1 and 6 (Lewis et al., 1987; Pearson et al., 1985; Rogers & Morrison, 1985). Evidence about the laminar organization of cortical projections in subhuman primates (Maunsell & Van Essen, 1983; Rockland & Pandya, 1979) suggests that layers 3 and 4 largely constitute the origin and termination sites of <u>feedforward</u> projections and layers 1, 5, and 6 largely constitute the origin and termination sites of <u>feedback</u> projections. Coupled with the neuropathological findings in AD, these results suggest that feedforward projections may be compromised to a greater degree than feedback projections, which may be relatively preserved in AD. Hence, if perceptual priming in normal cognition and in AD has an extrastriate locus, such priming effects may depend largely upon the integrity of feedback (rather than feedforward) projections to and from that area.

Evidence of intact perceptual priming in AD in the present study and in prior studies (Gabrieli et al., submitted; Keane et al., in press; Moscovitch, Winocur, & McLachlan, 1986) stands in contrast to evidence of impaired priming in AD on tasks of word completion (Gabrieli et al., submitted; Heindel et al., 1989; Keane et al., in press; Salmon et al., 1988; Shimamura et al., 1987) and word association (Huff et al., 1988; Salmon et al., 1988). Priming tasks that elicit normal performance in AD may draw more heavily upon perceptual processes and those that elicit impaired performance may draw more heavily upon

conceptual processes. The performance dissociation suggests that normal priming is the product of at least two dissociable components (that contribute variably to performance on different tasks) and that these components are differentially vulnerable to the effects of AD.

Theoretical accounts of repetition priming

Current theoretical accounts of repetition priming share an emphasis on the perceptual nature of priming effects. For example, Schacter and colleagues (Schacter, in press; Tulving & Schacter, 1990) have proposed the existence of pre-semantic perceptual representation systems, devoted to processing the visual form of words and objects. By these authors' account, priming reflects the activation of pre-existing, stored representations of the visual features of words and objects, or the de novo creation of structural representations of novel stimuli. The activation or creation of these stimulus representations within a visual word form system (first described by Warrington & Shallice, 1980) or a structural description system (in the case of objects) underlies the bias or facilitation (i.e., priming) that occurs when those stimuli are encountered in a subsequent episode. This theoretical approach grew largely out of two sources of evidence: first, evidence in normal cognition that priming, unlike explicit memory performance, is sensitive to variations in the perceptual characteristics of stimuli at initial exposure and subsequent test (Bassili, Smith, & MacLeod, 1989; Clarke & Morton, 1983; Graf, Shimamura, & Squire, 1985; Kirsner & Smith, 1974; Roediger & Blaxton, 1987; Schacter & Graf, 1989; Winnick & Daniel, 1970); and second, evidence from patients with acquired dyslexias or visual agnosias that access to stored representations of the visual features of words or objects can be dissociated from access to stored representations of the meanings associated with those words or objects (e.g., Lissauer, 1890; Rubens & Benson, 1971;

Schwartz, Marin, & Saffran, 1979; Warrington & Shallice, 1979; Warrington & Shallice, 1980; Warrington & Taylor, 1978).

Gabrieli and colleagues (Gabrieli, 1989; Gabrieli, in press; Gabrieli et al., submitted) similarly stress the critical role of perceptual learning processes in priming effects. However, these investigators focus on the dissociability of those processes from conceptual learning processes that form another important component of priming effects. This theoretical approach grew largely out of an attempt to account for the dissociability of performance on different priming tasks in AD (Gabrieli, in press; Gabrieli & Keane, 1988; Gabrieli et al., submitted; Keane, Gabrieli, & Corkin, 1989; Keane et al., in press; Keane, Gabrieli, Kjelgaard, Growdon, & Corkin, 1988), in light of evidence from normal cognition that the perceptual specificity of priming effects varies among different priming tasks. Gabrieli and colleagues (Gabrieli, 1989; Gabrieli, in press; Gabrieli et al., submitted) postulated that a structural-perceptual memory system, localized to occipital circuits relatively preserved in AD, mediates perceptual priming effects, and that a lexical-semantic memory system, localized to temporoparietal circuits compromised in AD, mediates conceptual priming effects.

A different theoretical viewpoint is expressed by Roediger and colleagues (Roediger & Blaxton, 1987; Roediger, Weldon, & Challis, 1989), who have drawn a distinction between data-driven processes (involved in the processing of stimulus features) and conceptually driven processes (involved in the processing of stimulus meaning). They postulate that priming tasks typically draw upon data-driven processes, whereas recall and recognition tasks typically draw upon conceptually driven processes, but that there is no necessary correspondence between the two kinds of processes and two classes of memory tasks (i.e., implicit and explicit memory tasks). That is to say, the dissociability of implicit and explicit memory performance in normal cognition is not due to the

inherently perceptual nature of implicit memory (i.e., priming) relative to explicit memory, but to the historically coincidental use of priming tasks that have a perceptual basis and explicit memory tasks that have a conceptual basis. Support for this view comes from evidence that dissociations within implicit memory (and within explicit memory) can be observed among tasks that are designed to vary in the degree to which they draw upon data-driven and conceptually driven processes (Blaxton, 1989). The theoretical viewpoint expressed by Roediger and colleagues represents an effort to refute the notion that performance on implicit and explicit memory tasks reflects the operation of separable, neurally distinct memory systems. In fact, as discussed below, the account offered by Roediger and colleagues may be compatible with the memory systems approaches that it is intended to counter.

The results of the present study, in conjunction with prior behavioral findings in AD, speak to all of the theoretical accounts outlined above. Evidence that AD patients show normal perceptual priming with words and pseudowords (present study; Keane et al., in press), coupled with evidence from PET studies that an extrastriate circuit is devoted to processing visual word form (Petersen et al., 1988; Petersen et al., 1989; Petersen et al., 1990), supports the view that there exists a memory system, localizable to a posterior visual area, that supports priming in perceptually based tasks (a view expressed by Gabrieli and colleagues and Schacter and colleagues). The dissociation of (normal) perceptual priming in AD (Gabrieli et al., submitted; Keane et al., in press) from (impaired) word-completion priming in AD (Gabrieli et al., submitted; Heindel et al., 1989; Keane et al., in press; Salmon et al., 1988; Shimamura et al., 1987) is consistent with the dissociation of different priming effects in normal cognition (Blaxton, 1989; Witherspoon & Moscovitch, 1989), and lends support to the claim that implicit memory tasks can vary in the degree to which they depend upon perceptual

(data-driven) processes (a view expressed by Gabrieli and colleagues and Roediger and colleagues). Finally, the dissociability of performance on two classes of priming tasks in AD suggests that the processes supporting perceptual (data-driven) and conceptual (conceptually driven) priming effects are mediated by separate neural circuits.

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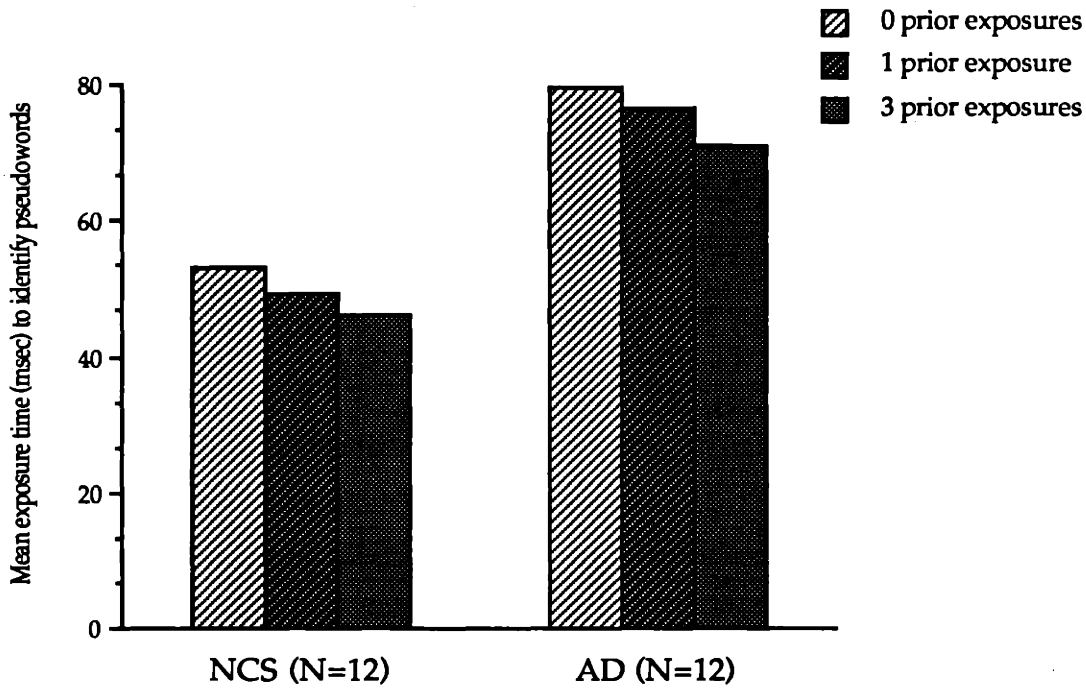

Figure 1. Priming during perceptual identification of briefly presented pseudowords in patients with Alzheimer's disease (AD) and normal control subjects (NCS). Bars show mean exposure time to identify unstudied (0 prior exposures) and studied (1 or 3 prior exposures) pseudowords. The priming effect is the reduction in exposure time needed to identify studied pseudowords relative to unstudied pseudowords.

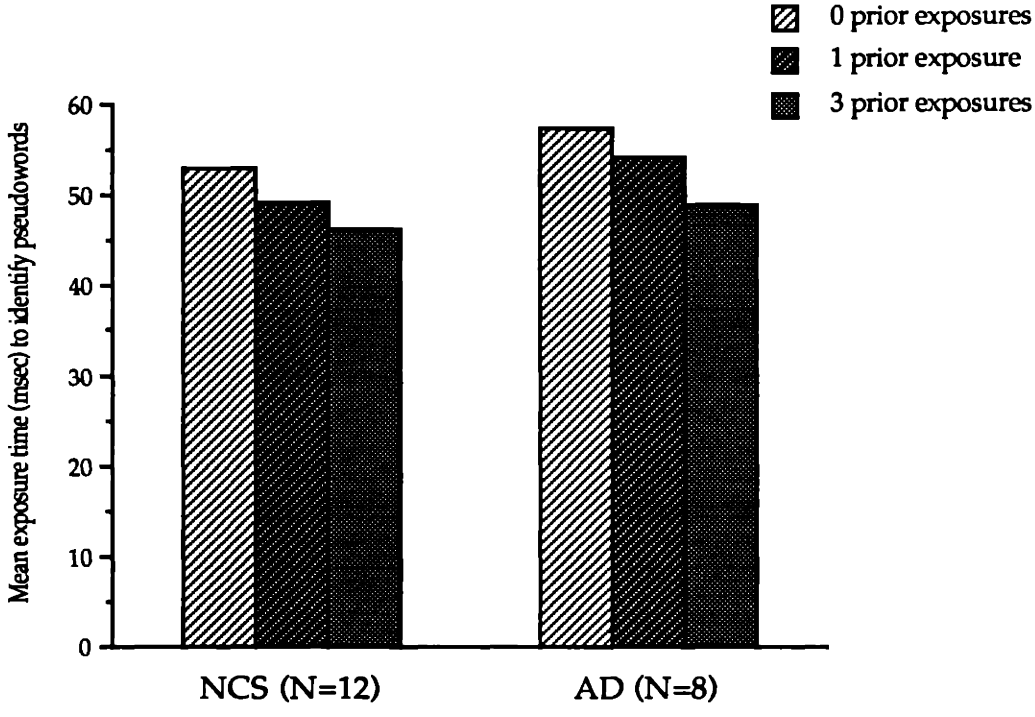

Figure 2. Priming during perceptual identification of briefly presented pseudowords in patients with Alzheimer's disease (AD) and normal control subjects (NCS), excluding the four AD patients with the highest (i.e., worst) baseline performance. Bars show mean exposure time to identify unstudied (0 prior exposures) and studied (1 or 3 prior exposures) pseudowords. The priming effect is the reduction in exposure time needed to identify studied pseudowords relative to unstudied pseudowords.

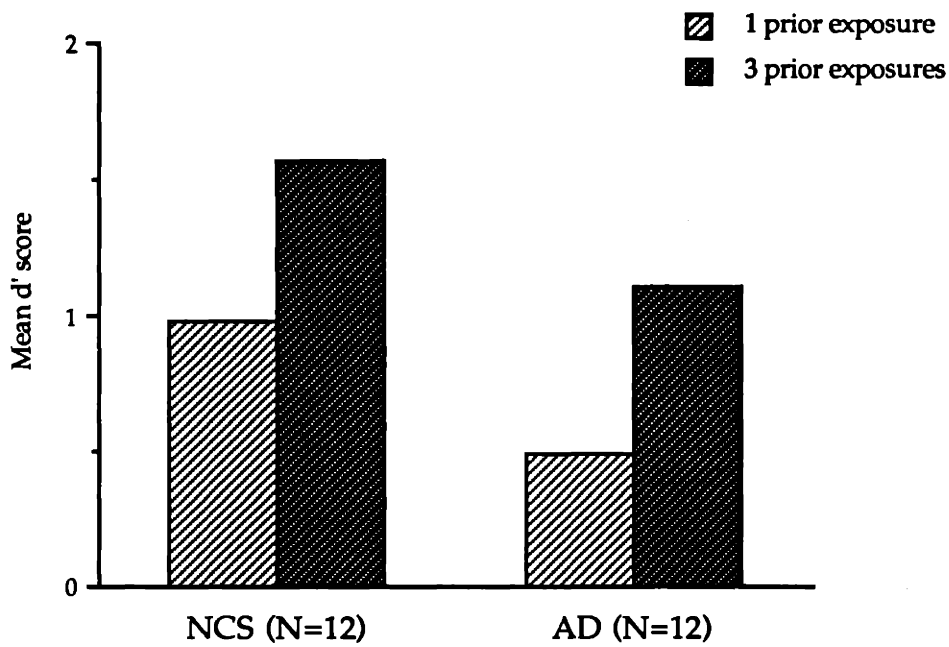

Figure 3. Recognition performance in patients with Alzheimer's disease (AD) and normal control subjects (NCS) for pseudowords that appeared one or three times in a prior study list.

Impaired Perceptual Priming and Intact Conceptual Priming in a Patient with Posterior Cerebral Lesions

Introduction

Experience can leave its mark in a number of ways: It can give one a conscious sense of the past (e.g., I can consciously recall that I went to the movies last weekend); it can enhance one's skilled performance of a task (e.g., I can play a piano piece more adroitly because I practiced it last week); or it can influence one's interpretation of an incomplete, degraded, or ambiguous percept (e.g., When I see the cue "ELE..." in a crossword puzzle, I think of "ELEPHANT" because I encountered that word in my reading a few minutes ago). All of these instances are manifestations of memory. The first is an expression of explicit memory (Graf & Schacter, 1985; Schacter, 1987); explicit memory processes are tapped in direct memory tasks (Richardson-Klavehn & Bjork, 1988) that require a conscious, deliberate effort to bring to mind details of a prior experience. The second and third are expressions of implicit memory (Graf & Schacter, 1985; Schacter, 1987), the second being an illustration of skill learning (the improvement in performance of a perceptual, cognitive, or motor task following practice), and the third being an illustration of repetition priming (the facilitatory or biasing effect of prior exposure to a stimulus upon subsequent processing of the same, or part of the same, stimulus). Implicit memory processes are tapped in indirect memory tasks (Richardson-Klavehn & Bjork, 1988) that do not require deliberate reference to (or awareness of) a prior episode.

Separate neural circuits are believed to mediate implicit and explicit memory processes. Patients who are amnesic following lesions of medial-temporal or diencephalic structures show impaired performance on direct memory tasks, and normal performance on indirect memory tasks (Brooks & Baddeley, 1976; Cermak, Talbot, Chandler, & Wolbarst, 1985; Cohen & Squire,

1980; Corkin, 1968; Graf, Squire, & Mandler, 1984; Milner, Corkin, & Teuber, 1968; Warrington & Weiskrantz, 1968; Warrington & Weiskrantz, 1970). Further, the neural dissociability of skill learning and priming (Heindel, Butters, & Salmon, 1988; Heindel, Salmon, Shults, Walicke, & Butters, 1989) suggests that indirect memory tasks tap at least two distinct implicit memory processes. Recently, a number of experiments in patients with Alzheimer's disease (AD) have revealed that priming may not be a unitary phenomenon, but may be the product of at least two dissociable memory processes: one that enhances perceptual operations, and another that enhances conceptual operations (Gabrieli, 1989; Gabrieli et al., 1991; Keane, Gabrieli, Fennema, Growdon, & Corkin, 1991). The purpose of the present study was to garner stronger evidence for the dissociability of perceptual and conceptual priming processes, and for the dissociability of priming and explicit memory processes.

Priming tasks typically comprise two phases: In the first phase, subjects are exposed to a list of words or pictures under specified processing conditions (e.g., they are asked to read or answer a question about each word). In the second phase, subjects are asked to perform a task in which they must generate a word (given incomplete orthographic or semantic information) or identify a word or picture (given partial or degraded perceptual information). The test stimuli in the second phase include items from the prior study list, as well as new items. The measure of priming is the facilitation or bias evident for studied items relative to unstudied items.

The status of priming in AD depends upon the nature of the task: AD patients show impaired priming on a word-completion task (in which subjects must generate completions for three-letter word stems) (Gabrieli et al., 1991; Heindel et al., 1989; Keane et al., 1991; Salmon, Shimamura, Butters, & Smith, 1988; Shimamura, Salmon, Squire, & Butters, 1987), and on a word association

task (in which subjects must generate semantic associates to words) (Huff, Mack, Mahlmann, & Greenberg, 1988). In contrast, AD patients show a normal magnitude of priming on tasks requiring identification of briefly presented words or pseudowords (Keane et al., 1991; Keane, Gabrieli, Growdon, & Corkin, 1991) and on a task requiring identification of fragmented drawings (Gabrieli et al., 1991). The dissociation between (impaired) word-completion priming and (intact) perceptual priming of words is evident not only between groups of AD patients, but also within a single group of AD patients (Keane et al., 1991). On the basis of these results, we (Gabrieli, 1989; Gabrieli, in press; Gabrieli et al., 1991; Keane et al., 1991) hypothesized that one class of priming tasks (including word completion and word association) depends to a large extent upon conceptual learning processes localized to neural circuits that are impaired in AD, and another class (including identification of briefly presented words and fragmented drawings) depends to a large extent upon perceptual learning processes localized to neural circuits that are spared in AD.

One could argue, however, that perceptual priming tasks are simply easier than conceptual priming tasks, and therefore, more sensitive to any residual capacity in a damaged process or circuit. By this account, perceptual and conceptual priming tasks reflect the operation of a unitary mechanism, but are differentially sensitive to damage to that mechanism. If this account were correct, then it should not be possible to observe the reverse dissociation, namely, impaired perceptual priming and intact conceptual priming (because impairment on the easier task would necessitate impairment on the more difficult task). Alternatively, the presence of such a reverse dissociation, in conjunction with the original dissociation in AD, would constitute a double dissociation between perceptual and conceptual priming processes and would require, by way of explanation, the postulation of two distinct priming processes.

In the present study, we examined the status of perceptual and conceptual priming in a patient whose primary cognitive deficit was in the perceptual domain: He was unable to recognize familiar faces, although he could recognize individuals through the use of other (visual and nonvisual) cues, and he could recognize other complex visual stimuli. His deficit (termed "prosopagnosia") was known to result from bilateral, posterior cortical lesions (Damasio, Damasio, & Van Hoesen, 1982; Meadows, 1974). We hypothesized that this pattern of lesions should compromise the neural substrate of perceptual priming processes (presumed to be localized to posterior brain areas), and may spare the neural substrate of conceptual learning processes (presumed to be localized to more anterior brain areas). The results of the study confirmed our hypothesis.

The present study allowed us to examine a second issue related to dissociable memory processes, specifically, the dissociation between performance on direct memory tasks (recall and recognition) and performance on priming tasks. Until now, this dissociation has been demonstrated only in patients who were impaired on the former tasks and normal on the latter (for reviews, see Richardson-Klavehn & Bjork, 1988; Schacter, 1987; Shimamura, 1986). We now report the first demonstration of intact recognition performance and impaired priming. Interestingly, it has been questioned whether such a reverse dissociation could be observed (Squire, 1987), given the possibility that explicit memory processes would depend upon the integrity of the representations that support priming.

We addressed the two major issues just outlined in three experiments. In Experiment 1, we examined priming in perceptual identification of words. There is evidence (reviewed below) that priming in this task is mediated largely by perceptual learning processes. In Experiment 2, we examined priming in a

word-stem completion task. Priming in this task may reflect the contribution of perceptual and conceptual learning processes. In order to tease apart the contribution from each of these sources, we administered the task under two conditions: In the first, words were studied and tested in the same perceptual modality, and in the second, words were studied and tested in different perceptual modalities. In Experiment 3, we examined priming in a category exemplar production task. Because there is no overlap in stimulus identity in the study and test phases, priming in this task must reflect the operation of conceptual learning processes. In all three experiments, we administered parallel recognition memory measures in order to document the status of explicit memory performance.

Experiment 1

A host of experiments spanning the last 40 years have demonstrated that prior exposure to words enhances subsequent identification of those words (relative to unstudied words) upon brief visual presentation (Clarke & Morton, 1983; Jacoby, 1983; Jacoby & Dallas, 1981; Kirsner, Milech, & Standen, 1983; Murrell & Morton, 1974; Neisser, 1954; Postman & Solomon, 1949/50; Ross, Yarczower, & Williams, 1956; Winnick & Nachbar, 1967). Evidence that this priming effect is based largely upon a perceptual (rather than an abstract conceptual) representation of the word comes from evidence that the effect is attenuated or abolished when the perceptual modality of stimuli differs at study and test (Clarke & Morton, 1983; Jacoby & Dallas, 1981; Keane et al., 1991; Kirsner et al., 1983), when stimuli are studied and tested in different lexical/pictorial formats (Winnick & Daniel, 1970), when the typefont of stimuli differs at study and test (Jacoby & Hayman, 1987), and when stimuli are generated rather than read at study (Clarke & Morton, 1983; Jacoby, 1983; Schwartz, 1989; Winnick &

Daniel, 1970).

Evidence that priming in this kind of task is dissociable from recognition memory comes from two sources. First, in normal subjects, Winnick and Daniel (1970) and Jacoby and Dallas (1981) demonstrated that a number of experimental manipulations have dissimilar effects upon perceptual priming and recognition memory performance. Second, Cermak et al. (1985) showed that perceptual priming was normal in a group of amnesic patients who showed impaired recognition memory performance.

Evidence that priming in perceptual identification of words is dissociable from other kinds of priming comes from two sources. First, priming in this task is stochastically independent of priming in a word-fragment completion task (Witherspoon & Moscovitch, 1989), and dissociable from priming in a category exemplar production task (Rappold & Hashtroudi, 1991). Second, Keane et al. (Keane et al., 1991) found that patients with AD showed normal priming in perceptual identification of words and impaired priming in a word-completion task (the latter finding having been reported previously in a number of studies, e.g., Gabrieli et al., 1991; Heindel et al., 1989; Salmon et al., 1988; Shimamura et al., 1987).

In Experiment 1, we contrasted priming in perceptual identification of words with recognition memory in a patient with a severe deficit in visual perception. We hypothesized that he would show impaired priming (due to lesions of neural structures supporting the perceptual learning processes that mediate priming in this task), and normal recognition memory (due to the preservation of limbic-diencephalic structures supporting recognition memory processes).

Method

We tested one patient (described below) and four age- and education-

matched normal control subjects (NCS) on a perceptual priming task and a recognition memory task.

Subjects

The same subjects participated in all three experiments; they will be described only here.

Case 1. Case 1 (who was Case 10 in Koerner & Teuber, 1973) is a 41-year-old, right-handed man, who suffered a severe closed-head injury in an automobile accident at the age of 18. The injuries sustained in that accident required him to undergo a right anterior temporal lobectomy, and to have a ventriculovenous shunt inserted for hydrocephalus. His most recent MRI scan (performed in 1989) revealed bilateral damage to visual association cortices and the underlying white matter, including the right temporal lobe, the left subcortical occipitotemporal white matter, and bilateral parietooccipital regions.

Although he initially exhibited a variety of cognitive impairments and appeared nearly blind during the weeks following his accident, his condition improved dramatically over the subsequent months and years. At the time of the present studies, his performance on a range of vision tests indicated normal central acuity (20/30) with correction; normal contrast sensitivity; impaired color vision; and slightly impaired stereoacuity (on the Randot Stereoacuity test, he required a disparity of 100 seconds of arc to perceive depth). He reads slowly and can write normally. He achieved a WAIS-R Verbal IQ of 123, a Performance IQ of 95, and a memory quotient of 101 on the Wechsler Memory Scale (revised version). His most prominent deficit is an inability to recognize faces: he cannot recognize his parents', wife's, children's, or acquaintances' faces, although he can recognize individuals from the sounds of their voices or by means of other characteristic features.

NCS. Three women and one man participated as normal control subjects

in these experiments. The group had a mean age of 43.0 years (range = 39-46), a mean educational level of 17 years (range = 16-18 years), and a mean WAIS-R age-scaled vocabulary score of 11.8 (The vocabulary subscale score for Case 1 was 12).

Materials

We selected 140 four- and five-letter words, of which half were high-frequency (with at least 96 occurrences per million, mean = 280) and half were low-frequency (with no more than 10 occurrences per million, mean = 3.5) (Kucera & Francis, 1967). Twelve of these words were used as filler items. The remaining 128 words were divided into two lists that were balanced for word frequency and word length. Each 64-word list included: 16 high-frequency 4-letter words; 16 low-frequency 4-letter words; 16 high-frequency 5-letter words; and 16 low-frequency 5-letter words. One list was used in the perceptual priming task and the other was used in a parallel recognition memory task.

Procedure

In brief, each subject studied one list of words, performed a perceptual identification task with studied and unstudied words, then studied a second, different list of words, and performed a yes/no recognition task with studied and unstudied words. All stimuli were presented on the screen of an IBM personal computer. Subjects sat approximately 20 in. from the screen.

Study task. The procedure in the study phase was identical for the perceptual identification and the recognition tasks. Subjects were told that they would see a series of words presented one at a time, and that they were to read each word aloud. Thirty-two different words were presented singly; half were presented one time and the other half were presented three times (once within each third of the list). In addition to these 64 trials, three filler words were presented at the beginning and end of the list (to blunt any primacy and recency

effects upon later memory for the stimuli), yielding a total of 70 trials. At the initiation of the experimenter, each word was presented for 7 seconds. The study phase was followed immediately by a perceptual identification or recognition task.

Perceptual identification. Subjects were told that they would perform a second task that was unrelated to the study task. They were told that a series of words would be presented very briefly, and that they were to identify each word. Each trial was preceded by the appearance of a fixation character (+) at the location where the word was to appear. Subjects were instructed to fixate this character in preparation for the brief appearance of a word. On each trial, a word was flashed and then replaced by a backward mask (#####) of 250 msec duration. The initial presentation time was 16.7 msec. If subjects were unable to identify the word at this exposure time, it was presented in the following trial for 33.4 msec. The same word was presented in additional increments of 16.7 msec on successive trials (to a maximum presentation time of 635 msec) until subjects correctly identified it. The computer recorded the number of presentations (i.e., the exposure time) required to identify each word. Sixty-four different words were presented in the perceptual identification task. Thirty-two of these words had appeared in the prior study list; 16 had appeared once and 16 had appeared three times. The other 32 words had not appeared in the prior study list. Across NCS, and within Case 1 across 2 visits, stimuli were counterbalanced so that each word appeared equally often as a studied or unstudied item in the perceptual identification task.

Recognition. In the recognition test, subjects were told that they would see a series of words, some of which had appeared in the preceding study list. Subjects were asked to respond "yes" if they had seen the word on the prior list and "no" if they had not. Sixty-four words were presented in the recognition

test; half had appeared in the prior study list (once or three times) and half were new. Across NCS (but not within Case 1), the stimuli were counterbalanced so that each word appeared equally often as a studied or unstudied item in the recognition task.

Results

We used analysis of variance (ANOVA) procedures to evaluate priming in the NCS group, and compared their results descriptively to those of Case 1.

Priming in perceptual identication of words

Case 1 performed two versions of the priming task on two separate occasions, separated by four weeks, so that we could obtain a measure of his performance with items counterbalanced across studied and unstudied conditions. In both testing sessions, he had very little difficulty identifying and reading aloud words in the study task; on two trials in which he initially misread a word, the experimenter asked him to read it again, and he corrected the mistake. However, in both testing sessions, he became fatigued during the perceptual identification task and was able to complete only the trials for the first half (i.e., 32) of the words. (Subjects often find this task to be a strain because the stimuli are sub-threshold; the task was particularly stressful to Case 1 due to his impairment in visual perception.) The perceptual identification task was designed so that the first 32 and the second 32 trials were balanced with respect to numbers of studied and unstudied words, and numbers of words studied once or three times. Therefore, with data from the first 32 items in two different testing sessions (for a total of 64 data points), we were able to examine performance with equal numbers of words in the studied and unstudied conditions, and equal numbers of words studied once or three times, with one exception: Case 1 failed to identify one stimulus item (a low-frequency, unstudied word) in the perceptual identification task; that item was excluded

from the analysis. We calculated the mean exposure time (in milliseconds) needed to identify unstudied (no prior exposures) and studied (one or three prior exposures) words of high and low frequency (Table 1).

Table 1 about here

The priming effect is indicated by a reduction in the exposure time required to identify studied words compared to unstudied words. On average, Case 1 required 253.7 msec (range = 116.9 - 484.3) to identify unstudied words, 273.5 msec (range = 100.2 - 501.0) to identify words with one prior exposure in a study list, and 263.0 (range = 133.6 - 417.5) msec to identify words with three prior exposures in a study list. These results indicate an absence of priming: In Case 1, perceptual identification performance was not enhanced by prior exposure to words.

In contrast, the NCS did benefit from prior exposure to words in the study list: They needed a mean exposure time of 29.14 msec (range for most variable NCS = 16.7 - 167.0) to identify unstudied words, 23.80 msec (range for most variable NCS = 16.7 - 66.8) to identify words studied once, and 20.63 msec (range for most variable NCS = 16.7 - 50.1) to identify words studied three times. Further, the priming effect was not merely a result of averaging across subjects: Each of the four individual NCS required, on average, less exposure time to identify studied than unstudied words. In a repeated-measures ANOVA with factors of prior exposure (0, 1, or 3 prior exposures) and word frequency (high or low), the priming effect was indicated by a main effect for prior exposure, $\underline{F}(2, 6) = 8.12$, $\underline{p} < .05$. This analysis also revealed a main effect for word frequency

(high-frequency words were identified with less exposure time than low-frequency words), $F(1,3) = 12.75$, $p < .05$, and no interaction between prior exposure and word frequency ($p > .4$). In order to evaluate the performance of the NCS on just those items to which Case 1 had responded (i.e., the first 32 items in each of two counterbalanced versions of the task), we recalculated the mean scores in each of the six experimental conditions for just the first 32 items in the perceptual identification task (Table 1). For these items, the NCS required 29.30 msec to identify unstudied words, 25.05 msec to identify words studied one time, and 19.90 msec to identify words studied three times. Again, the benefit in identification of studied relative to unstudied words was present for each individual subject. In a repeated-measures ANOVA, the priming effect was indicated by a main effect for prior exposure, $F(2,6) = 11.25$, $p < .01$.

Recognition

For each subject, we calculated the proportion of words correctly recognized from the study list (hits) in each of the four conditions defined by crossing repetition (one vs. three exposures) with word frequency (high vs. low). We calculated the proportion of unstudied words incorrectly attributed to the study list (false alarms) in each of the two word frequency conditions. These proportions were used to determine a d' score for studied words in each of the four study conditions defined by repetition and word frequency (Table 2).

Table 2 about here

Although the d' scores for Case 1 were lower than the mean d' scores for the NCS group in three conditions, they were well within the range of the NCS group. In a two-way repeated-measures ANOVA of the NCS means with factors of repetition (one vs. three) and word frequency (high vs. low), the two main

effects missed significance (repetition, $p > .10$ and frequency, $p > .10$), as did the interaction ($p > .20$). However, the mean scores across subjects indicated a recognition advantage for words with three prior exposures relative to words with one prior exposure. This repetition effect is consistent with a prior study in which the same effect (with the same test materials) reached significance with a larger group of subjects (Keane et al., 1991).

Discussion

Case 1 failed to show any evidence of perceptual priming in identification of briefly presented words, in contrast to the striking priming effect for each of the four NCS. These results support our prediction that Case 1 should fail to show normal perceptual priming, due to disruption of posterior cortical circuits supporting perceptual priming processes. One could object to this conclusion on two bases, however. First, the performance of Case 1 differed from the NCS in that he required far more (on the order of eight times more) exposure time than did the NCS to identify briefly presented words. Perhaps such impaired performance precludes the possibility of observing priming effects. Second, one could question any conclusion based on the performance of a single patient on a single test. Both of these objections may be addressed by referring to a series of experiments (reported in Keane et al., 1991) in which this perceptual priming task was administered to 32 college students (Experiment 1A), 22 patients with AD (Experiments 2 and 3), and 22 elderly control subjects (Experiments 2 and 3). The data from those experiments, as well as the present results, are summarized in Figure 1.

Figure 1 about here

Two points illustrated in this figure merit attention with regard to the present results. First, within the AD group, 3 patients showed baseline levels of performance similar to that of Case 1, but all three of these patients showed substantial perceptual priming. These results argue against the notion that impaired baseline performance precluded the possibility of normal priming. Second, at the level of individual subjects, 32 of 32 college students, 20 of 22 elderly control subjects (mean age 66.2 years), 19 of 22 AD patients (mean age 70.1 years), and 4 of the 4 NCS in the present study, showed a priming effect. These data suggest that there may be a slight age-associated attenuation in perceptual priming. However, among the 37 subjects aged 46 years or younger in the present and prior studies (i.e., all of the subjects in the present experiment and 32 college students in Keane et al., 1991, Experiment 1A), Case 1 was the only subject who failed to show priming in this task. These data suggest that priming in perceptual identification of words is robust at the level of individual subjects, and argue against the notion that the absence of priming in Case 1 is the result of an unreliable measure.

In contrast to his failure to show perceptual priming, recognition performance in Case 1 was similar to that of the NCS, in accordance with our prediction. In Experiment 2, we extended our examination of priming in Case 1 with a task that invokes conceptual as well as perceptual priming processes.

Experiment 2

Word-completion priming was the first example of verbal priming shown to be normal in amnesic patients (Graf et al., 1984; Warrington & Weiskrantz, 1970) and, therefore, independent of recall and recognition memory processes. A number of recent studies provided evidence about the relative contributions of perceptual and conceptual processes to priming in word completion.

Evidence that priming in word completion includes a perceptual contribution comes from experiments demonstrating that the priming effect is reduced when words are studied and tested in different perceptual modalities (Bassili, Smith, & MacLeod, 1989; Graf, Shimamura, & Squire, 1985; McClelland & Pring, 1991). That the priming effect is not mediated solely by perceptual learning processes is suggested by the fact that priming in word completion has never been eliminated cross-modally. Rather, it is reliably present even when target words are inferred (but not actually read) at study (Bassili et al., 1989). Further, there is some evidence that word-completion priming (unlike perceptual-identification priming) can be influenced by the level of semantic processing required in the study task (Chiarello & Hoyer, 1988; Graf et al., 1984).

Several studies demonstrated that word-completion priming is impaired in patients with AD (Gabrieli et al., 1991; Heindel et al., 1989; Keane et al., 1991; Salmon et al., 1988; Shimamura et al., 1987). Gabrieli and colleagues (Gabrieli, 1989; Gabrieli, in press; Gabrieli et al., 1991; Keane et al., 1991) postulated that this impairment reflected the disruption of neural circuits mediating conceptual priming processes (circuits that lie anterior to those mediating intact perceptual priming effects in AD).

In Experiment 2, we examined word-completion priming in Case 1 under two different experimental conditions: one in which the perceptual modality of stimuli were the same in the study and test phases, and a second in which the perceptual modality of stimuli differed in the study and test phases. In the first (within-modality) condition, normal priming reflects the contribution of perceptual and conceptual priming processes (because the stimulus percept, as well as the stimulus concept, is identical in the two phases). In the second (cross-modality) condition, normal priming reflects only the contribution of conceptual learning processes (because there is no perceptual overlap between

stimuli at study and test).[1] We hypothesized that the pattern of cortical damage in Case 1 would disrupt perceptual priming processes, but would spare conceptual priming processes. Based on this hypothesis, we made the following predictions about his performance in these tasks: first, that he would show impaired (but significant) priming in the within-modality condition; second, that he would show normal priming in the cross-modality condition; and third, that he would show similar levels of priming in the two conditions (whereas normal subjects would show greater priming in the within-modality than the cross-modality condition, as prior studies have demonstrated). Finally, we administered parallel measures of within-modality and cross-modality recognition. Because recognition in normal subjects is relatively insensitive to the surface format (e.g., perceptual modality) of stimuli, and because the neural

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[1] There is, however, an alternative account of the mechanisms mediating cross-modal priming. A number of investigators have suggested that cross-modal priming may reflect learning processes operating on a mental image formed at the time a word is heard at study (Jacoby & Witherspoon, 1982; Roediger & Blaxton, 1987; Schacter & Graf, 1989). By this account, cross-modal priming, like within-modality priming, is perceptually based. Evidence for this view comes from studies demonstrating that subjects who are instructed to form mental images of auditory stimuli at study show as much priming as subjects who are presented with visual stimuli at study (Roediger & Blaxton, 1987; Schacter & Graf, 1989). (Reductions of word-completion priming under cross-modal conditions could be explained by positing that subjects do not reliably generate mental images at study unless instructed to do so.) This account makes different predictions than our own about the outcome of Experiment 2. Specifically, if word-completion priming within and across modalities reflects a single (perceptual) mechanism (similar to the mechanism mediating perceptual priming in Experiment 1), then Case 1 should show impaired priming in both conditions. We predicted normal word-completion priming in Case 1 in the cross-modal condition.

substrate of recognition memory is spared in Case 1, we predicted that he would show normal and equivalent levels of performance in the two recognition tasks.

Method

We tested Case 1 and the same 4 NCS as in Experiment 1 on two word-completion priming measures (across-modality and within-modality) and two recognition memory measures (across-modality and within-modality).

Materials

We selected 120 four- to seven-letter words, of medium frequency (mean = 97 per million) (Kucera & Francis, 1967). The stem (i.e., the first three letters) of each word was unique among the 120 words and constituted the beginnings of at least 10 dictionary entries . Each of the 120 words was not the most common completion given for its stem in a pilot study of 60 normal subjects. We selected 24 additional words to be used as filler items in the study task; none of these words began with the same stem as any of the test words. Of the 120 test words, 80 were used in the word-completion tasks, and 40 were used in the recognition memory tasks. For each of the 40 words to be used in the recognition memory tasks, we selected 2 other words that began with the same three-letter stem. These words were used as distractor items in a three-choice recognition test.

Procedure

The experiment was conducted in four phases: In Phase 1, subjects studied a list of words presented visually (or auditorily), and then performed a word-stem completion task with visually presented word stems. In Phase 2, this procedure was repeated with a second list of words presented for study in the other perceptual modality. In Phase 3, subjects studied a list of words presented visually (or auditorily), and then performed a three-choice recognition task with visually presented words. In Phase 4, this procedure was repeated with words presented for study in the other perceptual modality. The priming tasks (Phases

1 and 2) always preceded the recognition tasks (Phases 3 and 4) in order to minimize the likelihood that subjects would treat the word-stem completion task as a cued recall task. However, within the priming and recognition tasks, the order of administration of the within-modality (visual-visual) and cross-modality (auditory-visual) tasks was counterbalanced across subjects. Further, within each of the two priming tasks (visual-visual and auditory-visual), the stimuli were counterbalanced across subjects so that each word appeared equally often in the studied or unstudied condition. Finally, in the recognition tasks, the stimuli were counterbalanced across subjects so that each word appeared equally often in the visual-visual or auditory-visual task.

Study task. In the visual study condition, target words were presented one at a time on the screen of an IBM personal computer. In the auditory study condition, words were spoken aloud by the experimenter. For each word, subjects were instructed to answer the question, "Is this word the name of an object that you could touch?" The study list contained 20 target words, in addition to 3 filler words at the beginning and end of the list (to blunt primacy and recency effects upon memory for the stimuli).

Word-completion. In the word-completion task, 40 three-letter word stems were presented one at a time on a computer screen; subjects were asked to complete each stem with the first word that came to mind. Twenty of the words had appeared in the prior study list, and the other 20 words had not appeared in the study list. Across subjects, word stems were counterbalanced across the studied and unstudied conditions.

Recognition. In the recognition task, on each of 20 trials, three words appeared on a computer screen. One of these words had appeared in the study list; the other two words began with the same three-letter stem as the studied word. Subjects were instructed to read the words aloud and to select the word

that had appeared in the prior study list.

Results and Discussion

For Case 1 and within the NCS group, we evaluated priming statistically. We compared the performance of Case 1 with the NCS group descriptively.

Word-completion priming

Case 1 performed two versions of the priming task on two separate occasions, separated by four weeks, so that we could obtain a measure of his performance with the same items counterbalanced across studied and unstudied conditions within each of the priming tasks (visual-visual and auditory-visual). The results presented below reflect mean scores across the two testing occasions. In the study tasks, with the exception of two items, Case 1 responded correctly to each word. For the two exceptions (which occurred in the visual study tasks), Case 1 misread the word on the screen. Those two items were excluded from the analysis of his priming performance. For Case 1 and NCS, we calculated the proportion of word stems completed with target words in the studied and unstudied conditions following auditory or visual study. The number of unstudied stems completed to target words provides a baseline measure of priming in the absence of prior exposure to target completions. The baseline scores for Case 1 were 15.0% in the visual-visual task and 7.5% in the auditory-visual task. The mean baseline scores for NCS were 7.5% (s.d. = 6.5) in the visual-visual condition and 15.0% (s.d. = 10.8) in the auditory-visual condition (the two baseline scores for the NCS did not differ significantly by t-test). To calculate priming scores, we subtracted the baseline proportions from the proportion of target completions following auditory or visual study (Figure 2).

Figure 2 about here

Consistent with our predictions, priming scores for Case 1 were similar in the visual-visual and auditory-visual conditions (17% vs. 20%); he showed less priming than the NCS in the visual-visual condition (17% vs. 28.8%); and he showed normal priming in the auditory-visual condition (20% for Case 1 vs. 12.5% for the NCS).

In order to determine whether priming in Case 1 was significantly above chance, we collapsed his scores across the visual-visual and auditory-visual conditions. (We needed to combine his results in this way in order to have a sufficient number of observations upon which to perform a statistical test. Further, it seemed reasonable to do so in light of the fact that his performance was similar in the two experimental conditions). We compared the mean proportion of target completions for primed items with the mean proportion of target completions for baseline items, across four testing sessions (two sessions each in the visual-visual and auditory-visual conditions). Overall, Case 1 generated target completions for 29.8% of the items in the primed conditions and 11.3% of the items in the baseline condition. A paired t-test indicated that the mean priming effect (18.5%) was significantly above chance, $t(3) = 3.98$, $p < .05$.

For the NCS group, the difference in the mean proportion of target completions for primed items versus baseline items (i.e., the priming effect) was significant in the visual-visual condition, $t(6) = 5.81$, $p < .001$, but fell short of significance in the auditory-visual condition, $t(6) = 1.56$, $p = .085$. Further, the difference in the magnitude of priming in the visual-visual condition (28.8%) relative to the auditory-visual condition (12.5%) also fell short of significance, $t(6) = 1.51$, $p = .091$. The fact that the latter two effects failed to reach significance is likely due to the few number of subjects in the present experiment. Prior

studies conducted with larger groups of subjects have demonstrated that cross-modal word-completion priming is significantly greater than chance, and significantly reduced relative to within-modality priming (Bassili et al., 1989; Graf et al., 1985; McClelland & Pring, 1991).

For the purposes of the present hypothesis, the critical results are that word-completion priming in Case 1 was as great as that in NCS in the auditory-visual condition, reduced relative to NCS in the visual-visual condition, and of a similar magnitude in the visual-visual and auditory-visual conditions. This pattern of results supports the hypothesis that conceptual priming processes are spared in Case 1, that those processes (in addition to perceptual priming processes) contribute to within-modality word-completion priming, and that those processes are indexed relatively purely in cross-modality word-completion priming.

Recognition

For each subject, we calculated the proportion of correct responses in the three-choice visual recognition tests following visual or auditory study of words. Again, scores for Case 1 represent means across two testing sessions (separated by four weeks), in which test stimuli were counterbalanced across studied and unstudied conditions. The mean scores in the NCS group were 96.25% in the visual-visual condition and 92.50% in the auditory-visual condition; the mean scores for Case 1 across the two testing sessions were 92.50% in the visual-visual condition and 87.50% in the auditory-visual condition. Although mean scores for Case 1 were slightly lower than the means in the NCS group, they were within the normal range, and did not indicate a recognition memory impairment.

Experiment 3

In Experiment 3, we examined priming on a task in which there was no overlap between stimuli at study and test. In category-exemplar-production priming tasks, subjects initially study a word list that includes low-typicality exemplars from a variety of categories (e.g., "MANGO"). Subsequently, subjects are asked to generate exemplars for a number of categories (e.g., "FRUIT") as quickly as they can in a given amount of time. Priming is reflected in the tendency to generate exemplars from the prior study list more often than would be expected by chance. Patients with global amnesia show normal priming on such tasks (Gardner, Boller, Moreines, & Butters, 1973; Graf et al., 1985); thus, like all the other instances of priming described in the present experiments, priming in category exemplar production is dissociable from the recall and recognition memory processes that are impaired in global amnesia.

We reasoned that this kind of task would not invoke perceptual priming processes that contribute to identification of briefly presented words or to word completion: The to-be-primed stimulus (e.g., "MANGO") shares no perceptual features with the priming cue (e.g., "FRUIT"); the two stimuli are related only in meaning. This line of reasoning is supported by experimental evidence that priming in category exemplar production is dissociable from priming in perceptual identification of words: Categorical organization of words in a study list enhances priming in the former (but not the latter) task (Rappold & Hashtroudi, 1991), and the level of semantic processing at study influences priming in the former (Hamann, 1990) (but not the latter) task (Jacoby & Dallas, 1981; Kirsner et al., 1983). Because a category-exemplar-production task provides a pure measure of conceptual priming processes, we predicted that it would elicit normal priming in Case 1.

Method

To the same patient and 4 NCS, we adminsistered a category exemplar production priming task and a recognition memory task.

Materials

The target stimuli were low-typicality exemplars of 16 categories (Battig & Montague, 1969). For 8 of the 16 categories, we selected 5 exemplars and for the other 8 categories we selected 10 exemplars. Each of these exemplars was listed by at least 10 of 442 subjects asked to generate members of that category, but none of the exemplars was among the 10 most frequent responses for that category (Battig & Montague, 1969). In terms of response frequency, the mean rank of the target exemplars was 26.4 (range 11-48) (Battig & Montague, 1969). We selected 3 exemplars from each of 8 additional categories to be used as filler items.

Procedure

The experiment proceeded in four phases:

Phase 1. In Phase 1, we obtained a baseline measure of category exemplar production for each subject: The experimenter spoke aloud the names of each of the 16 target categories, and subjects were asked to generate (aloud) as many exemplars of each category as possible in one minute. The experimenter recorded their responses.

Phase 2. In Phase 2 (separated from Phase 1 by at least 24 hours), subjects were told that they would hear a series of words, and that they were to decide whether each word was the name of something natural or manmade. The experimenter read a list of 28 words aloud; the list included 5 exemplars from each of 4 target categories (presented in a random order) as well as 4 filler exemplars at the beginning and 4 filler exemplars at the end of the list to blunt any primacy and recency effects upon memory for the stimuli. After this study task, subjects performed a category exemplar production task like the one they

performed in Phase 1: The experimenter spoke aloud the names of 4 target categories (whose exemplars constituted the prior study list), and subjects were asked to generate (aloud) as many exemplars of that category as possible in one minute. The experimenter recorded their responses.

Phase 3. Phase 3 was identical to Phase 2, except that the target stimuli were 5 exemplars from each of 4 new categories (and 8 new filler items were included in the study list).

Phase 4. In Phase 4, as in Phases 2 and 3, subjects performed the study task with 5 exemplars from each of 4 new categories (and 8 new filler items). However, in Phase 4 (unlike Phases 2 and 3), this study task was followed by a four-choice recognition task: On each of 20 trials, the experimenter spoke aloud four words, and subjects had to indicate which of these four words had appeared in the prior study list. On each trial, the four words comprised one exemplar from the prior study list, another (unstudied) exemplar from the same category, and two exemplars from a different (unstudied) category. The exemplars from unstudied categories comprised 5 exemplars from each of 8 categories. Thus, the stimuli in the recognition task included 5 (studied) exemplars from each of 4 categories, 5 (unstudied) exemplars from each of 4 (studied) categories, and 5 (unstudied) exemplars from each of 8 (unstudied) categories. This task served as a recognition memory measure and also as a priming episode for the category exemplar production task that followed. In that task (as in Phases 1, 2, and 3), the experimenter spoke aloud the names of 8 categories (whose exemplars had appeared in the prior study list and/or in the prior recognition task); subjects were asked to list as many exemplars of that category as possible in one minute. The experimenter recorded their responses.

Results

We evaluated priming within Case 1 and the NCS group statistically, and

compared the two sets of results descriptively.

Category exemplar production priming

Case 1 performed this task in its entirety twice, in two separate testing sessions separated by four weeks. His results represent the mean of his performance across the two testing sessions. For each subject, we calculated the proportion of target exemplars produced in the category exemplar production task in Phase 1. This score provided a measure of baseline performance in the absence of prior exposure to exemplars. The baseline score for Case 1 was 11.3% and for NCS was 24.6% (s.d. = 5.5). Across Phases 2, 3, and 4, we calculated the proportion of target exemplars generated following exposure to those exemplars in the study list or in the recognition task. Priming is reflected in an increase in the mean proportion of target exemplars generated in the primed condition relative to the baseline condition (Figure 3).

Figure 3 here

The mean priming score for Case 1 across two sessions was 17.5%; the mean priming score for the NCS group was 13.8% (s.d. = 9.8). Priming in the NCS group was significantly above chance: The mean proportion of target exemplars generated in the primed condition was significantly greater than the mean proportion produced in the baseline condition, $t(3) = 2.81$, $p < .05$. To determine whether priming in Case 1 was above chance, we compared the number of target items generated for each of the 16 categories in the baseline condition to the number of target items generated for each of those categories in the primed condition. A paired t-test revealed that the mean number was significantly

greater in the primed condition, $t(15) = 5.74$, $p < .001$.

Recognition

The recognition score for each subject was the proportion of studied exemplars correctly identified in the four-choice recognition test. The mean score for Case 1 across the two testing sessions was 92.5%; the mean score for the NCS group was 98.75%.

Discussion

Consistent with our prediction, Case 1 showed normal priming in category exemplar production and normal recognition memory. However, one aspect of the present results is neither predicted nor explained by our original hypothesis. Specifically, in Case 1, baseline performance (i.e., the proportion of target exemplars generated in the absence of prior exposure) was well below that of the NCS. Further, examination of the total number of exemplars generated for each category at baseline (a measure of verbal fluency) revealed that the mean number of exemplars produced per category was lower for Case 1 (8.9) than for the NCS group (17.5). In a prior study, we reported that verbal fluency impairments were correlated with word-completion priming impairments (but were unrelated to perceptual priming performance) in patients with AD (Keane et al., 1991). Contrary to that finding, Case 1 showed intact (auditory-visual) word-completion priming (Experiment 2) in the face of impaired category fluency performance (Experiment 3). Thus, contrary to the implications of the prior study (Keane et al., 1991), the results of the present study suggest that an impairment in a verbal fluency task does not predict an impairment in conceptual priming tasks. It is possible, however, that the mechanism underlying the verbal fluency impairment in Case 1 is idiosyncratic (i.e., is not the same as the mechanism that produces such an impairment in other patient populations). That is to say, the verbal fluency impairments in Case 1 and in

AD patients may reflect two fundamentally different mechanisms, of which one is associated with conceptual priming processes, and the other is not. We are currently re-addressing this issue in a study that includes a larger group of patients with focal lesions in various cortical loci.

General Discussion

We hypothesized that normal priming reflects the operation of two distinct learning processes, one perceptual and the other conceptual, that contribute to variable degrees to performance on different priming tasks, and that are localizable to distinct neural circuits. In prior studies, we demonstrated the dissociability of (intact) perceptual priming and (impaired) conceptual priming in patients with AD. In the present study, we sought evidence for the opposite dissociation in a patient who has a severe perceptual impairment consequent to bilateral posterior brain lesions. Consistent with our predictions, this patient showed impaired perceptual priming (i.e., impaired priming in perceptual identification of words and in within-modality word completion) and normal conceptual priming (i.e., normal priming in cross-modality word completion and in category exemplar production). Further, he showed normal recognition memory performance.

Together with prior behavioral findings in AD (Keane et al., 1991), these results constitute a double dissociation between perceptual and conceptual priming, and provide strong evidence for the existence of two priming processes that reflect the operation of distinct cognitive mechanisms and depend upon the integrity of separate neural circuits.

The intact recognition-memory performance shown by Case 1, coupled with impaired perceptual priming, provides evidence that priming can be impaired in the face of fully normal recognition memory. Taken together with

a reports of intact perceptual priming and impaired recogniton memory in AD (Keane et al., 1991) and amnesia (Cermak et al., 1985), these results demonstrate, for the first time, a double dissociation between priming and recognition memory. These findings bolster the (widely accepted) claim that priming and recognition memory depend upon distinct cognitive and neural mechanisms.

Neural basis of perceptual and conceptual priming

All of the priming effects discussed thusfar (perceptual and conceptual) are intact in patients with global amnesia consequent to lesions of medial-temporal or diencephalic structures (Cermak et al., 1985; Gardner, Boller, Moreines, & Butters, 1973; Graf et al., 1985; Graf et al., 1984; Warrington & Weiskrantz, 1970). Therefore, perceptual and conceptual priming effects must be independent of those neural structures.

Recent positron emission tomographic (PET) studies in normal subjects have provided evidence for the existence of a posterior cortical visual word-form area that may constitute the locus of perceptual priming effects. Raichle and colleagues (Petersen, Fox, Posner, Mintun, & Raichle, 1988; Petersen, Fox, Posner, Mintun, & Raichle, 1989; Petersen, Fox, Snyder, & Raichle, 1990; Posner, Petersen, Fox, & Raichle, 1988) have demonstrated in normal subjects that passive viewing of visually presented words or orthographically regular pseudowords (but not strings of consonants or false fonts) selectively activates an area in the left, medial extrastriate cortex. A number of investigators (Gabrieli et al., 1991; Keane et al., 1991; Keane et al., 1991; Petersen et al., 1990; Schacter, in press; Schacter, Rapscak, Rubens, Tharan, & Laguna, 1990; Tulving & Schacter, 1990) have proposed that plasticity within this area may form the neural basis of perceptual priming. The results of the present study are consistent with this proposal: The perceptual priming deficit in Case 1 is

consequent to a lesion that included regions at the occipitotemporal and parietooccipital junctions bilaterally, a lesion that likely disrupted projections to, from, or within the word-form area identified in PET studies. Further, prior studies have demonstrated that patients with AD show normal perceptual priming with words and orthographically regular pseudowords (Keane et al., 1991; Keane et al., 1991). There is evidence to suggest that the neuropathological changes in AD may (relatively) spare posterior cortical circuits (see Gabrieli, in press; Gabrieli et al., 1991; Keane et al., 1991; Keane et al., 1991 for discussion of this issue). Thus, the behavioral evidence in patients with cortical lesions and the neuroimaging evidence in normal subjects points to an extrastriate area as a plausible substrate for perceptual priming effects.

Evidence about the neural locus of conceptual priming effects comes exclusively from behavioral studies in neurologically impaired patients. Patients with AD have shown impaired priming in word completion (Gabrieli et al., 1991; Heindel et al., 1989; Keane et al., 1991; Salmon et al., 1988; Shimamura et al., 1987) and in word association (Huff et al., 1988). The cortical pathology in AD is widespread and includes loci in temporal, parietal, and frontal cortices (Brun & Englund, 1981; Terry, Peck, DeTeresa, Schecter, & Horoupian, 1981; Wilcock & Esiri, 1982). By themselves, the behavioral findings in AD provide no clues concerning which of these pathological loci is responsible for the conceptual priming deficit. However, the normal conceptual priming effects shown by Case 1 in the present study eliminate some of these areas as candidate substrates. Specifically, conceptual priming probably does not depend upon circuits localized to occipitotemporal cortex, parietooccipital cortex, or right temporal cortex, all of which are compromised in Case 1. Further, priming in category exemplar production is normal in patients with Korsakoff's syndrome (KS) (Graf et al., 1985), and priming in word completion is normal in

patients with KS (Graf et al., 1984; Warrington & Weiskrantz, 1970), Huntington's disease (HD) (Heindel et al., 1989; Salmon et al., 1988; Shimamura et al., 1987) and Parkinson's disease without dementia (PD) (Heindel et al., 1989). There is neuropsychological evidence for frontal-lobe dysfunction in all three of these patient groups (Brandt, in press; Janowsky, Shimamura, Kritchevsky, & Squire, 1989; Shimamura, Janowsky, & Squire, 1990; Taylor, Saint-Cyr, & Lang, 1986), presumably reflecting disruption of reciprocal thalamocortical (in the case of KS) or corticostriatal (in the case of HD and PD) circuits (Adams & Victor, 1985). These findings demonstrate that conceptual priming effects can remain intact despite frontal-lobe pathology. The sum of the neuropsychological evidence therefore provides reason to think that conceptual priming effects may be mediated by anterior parietal or left anterior temporal cortex (areas that are compromised in AD, but relatively preserved in Case 1 and in patients with KS, PD and HD).

Dissociations between perceptual and conceptual priming in normal cognition

The results of the present study suggest that verbal priming reflects the operation of at least two learning processes (one perceptual and the other conceptual) that depend upon the integrity of distinct cortical circuits. Convergent evidence in normal cognition for the existence of separable priming mechnisms comes from demonstrations that performance on different priming tasks is experimentally dissociable: Manipulations affecting the perceptual processing of stimuli have greater effects on perceptual than conceptual priming, and manipulations affecting the semantic processing of stimuli have greater effects on conceptual than perceptual priming. Specifically, variations in the level of semantic processing or categorical organization of stimuli at study have greater effects on priming in word-completion and category exemplar

production (Chiarello & Hoyer, 1988; Graf et al., 1984; Hamann, 1990; Rappold & Hashtroudi, 1991) than on priming in perceptual identification of words (Jacoby & Dallas, 1981; Kirsner et al., 1983; Rappold & Hashtroudi, 1991). Conversely, manipulations in the perceptual modality or surface format of stimuli at study have more dramatic effects on priming in perceptual identification of words (Clarke & Morton, 1983; Jacoby & Dallas, 1981; Kirsner et al., 1983; Schwartz, 1989; Winnick & Daniel, 1970) than on priming in word completion (which is reduced, but never eliminated under these conditions, (Bassili et al., 1989; Graf et al., 1985; McClelland & Pring, 1991).

Roediger and colleagues (Roediger & Blaxton, 1987; Roediger, Weldon, & Challis, 1989) have suggested that such dissociations in normal cognition may be understood within the theoretical framework of transfer-appropriate processing. (Although their approach was originally intended to account for dissociations between implicit and explicit memory processes, it also accounts well for dissociations among implicit memory processes, e.g., Blaxton, 1989.) By this view, priming reflects the enhancement of cognitive processes that are repeated at study and test. Perceptual or data-driven processes are invoked in tasks that require processing of the physical features of stimuli; conceptual or conceptually driven processes are invoked in tasks that require processing of the semantic features of stimuli. An experimental manipulation will affect priming on a given task to the extent that the manipulation reduces the overlap between the processes that are required at study and test. For example, priming in perceptual identification of words (a data-driven task) is relatively unaffected by depth-of-processing at study, because the amount of perceptual processing of a word at study is relatively constant regardless of the degree to which one processes the meaning of the word; and the perceptual identification task that follows the study task requires the re-engagement of those perceptual processes. This

account has tremendous explanatory power with respect to the dissociability of different instances of priming (described above) and the independence of different priming effects (Witherspoon & Moscovitch, 1989) in normal cognition.

Further, the transfer-appropriate processing view provides an elegant account of the cognitive mechanisms underlying dissociable priming effects in patients with brain lesions in the present and prior studies (Gabrieli et al., 1991; Keane et al., 1991). In turn, the neuropsychological findings elucidate the neural fractionation of the learning mechanisms associated with these cognitive processes: learning mechanisms that enhance data-driven processes rely on the integrity of posterior (occipital) circuits; learning mechanisms that enhance conceptually driven processes rely upon the integrity of more anterior (temporoparietal) circuits.

Relation to neuropsychological models of word perception

Recently, Schacter and colleagues (Schacter, in press; Schacter, in press; Tulving & Schacter, 1990) have suggested that perceptual priming phenomena can be understood in the context of neuropsychological findings in word and object perception. The first such finding was described a hundred years ago by Lissauer (1890), who drew a distinction between apperceptive agnosia, in which patients are unable to distinguish the perceptual form of objects, and associative agnosia, in which patients are unable to access the meanings associated with objects; his distinction has been elaborated extensively since its publication (De Renzi, Scotti, & Spinnler, 1969; De Renzi & Spinnler, 1966; Hécaen, Goldblum, Masure, & Ramier, 1974; Rubens & Benson, 1971; Taylor & Warrington, 1973; Warrington & James, 1967; Warrington & Taylor, 1973; Warrington & Taylor, 1978). More recently, a similar distinction has been drawn in the domain of

word perception: peripheral dyslexia (or "word-form" dyslexia) is characterized by an inability to attain the visual form of a word (Shallice, 1988; Shallice & Warrington, 1980; Warrington & Shallice, 1980), whereas semantic access dyslexia is characterized by an inability to access the semantic attributes of a word (Schwartz, Marin, & Saffran, 1979; Shallice, 1988; Shallice & Warrington, 1980; Shallice, Warrington, & McCarthy, 1983; Warrington & Shallice, 1979). Schacter and colleagues (Schacter, in press; Schacter, in press; Tulving & Schacter, 1990) suggested that perceptual priming may reflect learning processes associated with the first stage of word and object perception: the attainment of the visual form (or structural description) of a word or object. They proposed that these learning effects are mediated by perceptual representation systems (PRS) localized to posterior cortical circuits.

The demonstration in the present study of impaired perceptual priming in a patient with a large posterior lesion, coupled with prior demonstrations of intact perceptual priming in AD patients whose lesions may spare posterior occipital circuits, provides strong support for the PRS proposal. Schacter and Tulving (1990) acknowledge, however, that their theoretical framework does not account for conceptual priming effects (e.g., priming in category exemplar production). They suggest that such effects may reflect learning processes (distinct from those mediating perceptual priming) that add to or modify information in semantic memory.

The results of the present study offer two new insights with regard to conceptual priming. First, they provide new evidence about the neural basis of such priming effects: Coupled with reports of impaired conceptual priming in patients with AD (Heindel et al., 1989; Huff et al., 1988; Keane et al., 1991; Salmon et al., 1988; Shimamura et al., 1987), and intact conceptual priming effects in KS, PD, and HD patients (Graf et al., 1985; Graf et al., 1984; Heindel et

al., 1989; Salmon et al., 1988; Shimamura et al., 1987; Warrington & Weiskrantz, 1970), the preservation of conceptual priming in Case 1 in the present study suggests that these effects may be mediated by anterior parietal or temporal circuits (see earlier discussion).

Second, the present results provide neuropsychological evidence that conceptual priming processes make a substantial contribution to priming in word completion: Case 1 showed impaired priming in identification of brief words, impaired priming in within-modality word completion, intact priming in cross-modality word completion, and intact priming in category exemplar production. On the assumption that the first and last tasks provide relatively pure measures of perceptual and conceptual priming processes, respectively, the pattern of performance in Case 1 suggests the preservation of conceptual, but not perceptual, processes. Consequently, intact cross-modality word-completion priming in Case 1 likely reflects the operation of those intact conceptual processes (while impaired within-modality word-completion priming reflects the impairment of perceptual processes). The idea that word-completion priming includes a conceptual component (in addition to a perceptual component) is further supported by evidence that word-completion priming and perceptual-identification priming are dissociable in normal subjects (see earlier discussions) and in patients with AD (Keane et al., 1991). These lines of evidence suggest that conceptual processes play a ubiquitous role in priming, and are not limited to performance on tasks in which there is no perceptual overlap between stimuli at study and test.

In summary, the results of the present study provide strong evidence that verbal priming is the product of at least two mechanisms: a perceptual learning mechanism localized to posterior (occipital) circuits and a conceptual learning mechanism localized to more anterior temporoparietal circuits. Further, in

conjunction with prior behavioral studies in AD, the present study demonstrates that those mechanisms are doubly dissociable in patients with cerebral lesions. These results suggest that priming is not mediated by a unitary mechanism, but likely reflects the contribution of perceptual and conceptual processes that operate interactively in a wide range of tasks in normal cognition.

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Table 1. Mean Exposure Time (msec) to Identify Brief Words

	High Frequency Words # of prior exposures			Low Frequency Words # of prior exposures		
Subject Group	0	1	3	0	1	3
L.H.	243.3	244.3	288.1	283.9	302.8	238.0
NCS (N=4)	27.2	23.6	20.9	31.1	24.1	20.4
NCS (N=4) (1st 32 items only)	25.7	25.1	18.9	32.9	25.1	20.9

Table 2. Recognition Performance (d' scores)

	High Frequency Words # of prior exposures		Low Frequency Words # of prior exposures	
Subject Group	1	3	1	3
Case 1	1.55	3.87	2.02	3.50
NCS (mean, N=4)	1.64	3.05	3.17	3.67
(standard deviation)	(.55)	(.54)	(1.39)	(.23)

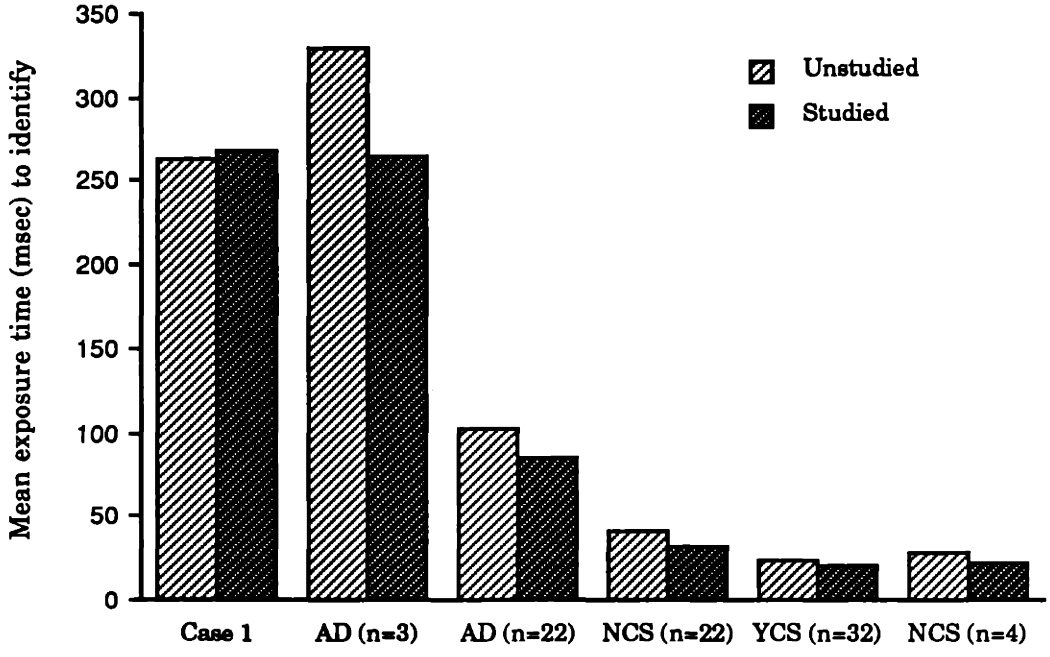

Figure 1. Priming in perceptual identification of briefly presented words in Case 1 (present study), three patients with Alzheimer's disease (AD) whose baseline performance was worse than that of Case 1 (Keane et al., 1991, Experiments 2 and 3), 22 AD patients (Keane et al., 1991, Experiments 2 and 3), 22 normal control subjects (NCS) (Keane et al., 1991, Experiments 2 and 3), 32 young (college student) control subjects (YCS) (Keane et al., 1991, Experiment 1A), and four NCS (present study). Bars show mean exposure time (msec) to identify studied and unstudied words. The priming effect is the reduction in exposure time needed to identify studied words relative to unstudied words. Priming is absent in Case 1, but is present in all other groups.

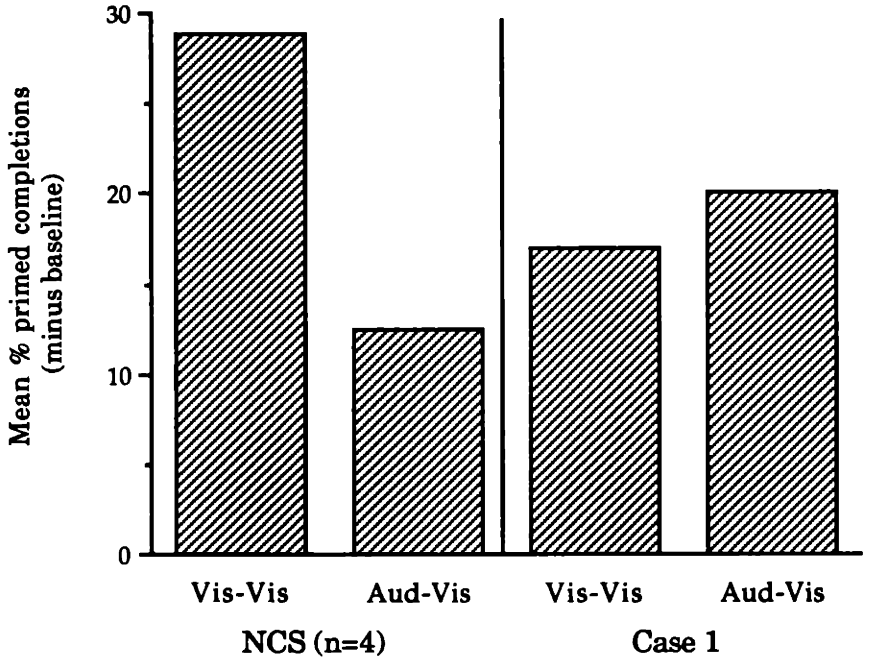

Figure 2. Word completion priming in normal control subjects (NCS) and in Case 1. Bars indicate mean percent of primed stems completed to target words minus the mean percent of unprimed (baseline) stems completed to target words, in the within-modality (Vis-Vis, words studied and tested visually) and cross-modality (Aud-Vis, words studied auditorily and tested visually) conditions.

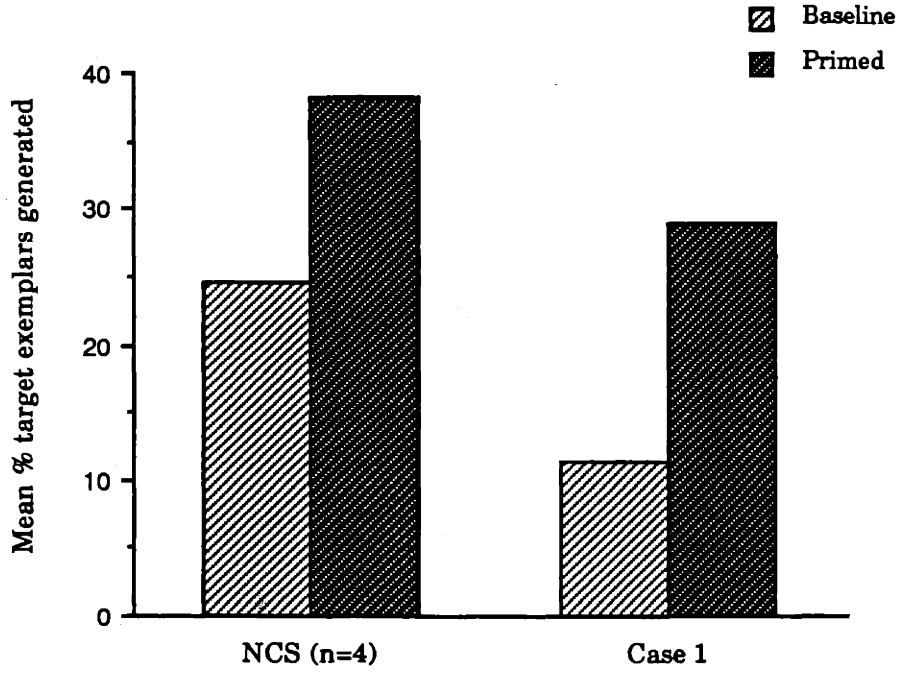

Figure 3. Category exemplar production priming in four normal control subjects (NCS) and Case 1. Bars indicate mean percent target exemplars generated in the baseline and primed conditions. Priming is indicated by an increase in the percent of target exemplars generated in the primed condition relative to baseline.