*Journal of the International Neuropsychological Society* (2001), **7**, 785–794.


# Impaired production priming and intact identification priming in Alzheimer's disease

DEBRA A. FLEISCHMAN,[1,2] LAURA A. MONTI,[1] LISA M. DWORNIK,[1] TERESA T. MORO,[1] DAVID A. BENNETT,[1,2] AND JOHN D.E. GABRIELI[1,3]

[1]Rush-Presbyterian-St. Luke's Medical Center, Department of Neurological Sciences, Chicago, Illinois
[2]Rush Alzheimer's Disease Center, Chicago, Illinois
[3]Stanford University, Department of Psychology, Palo Alto, California

(RECEIVED May 9, 2000; REVISED October 16, 2000; ACCEPTED October 18, 2000)

**Abstract**

This study examined the distinction between identification and production processes in repetition priming for 16 patients with Alzheimer's disease (AD) and 16 healthy old control participants (NC). Words were read in three study phases. In three test phases, participants (1) reread studied words, along with unstudied words, in a word-naming task (identification priming); (2) completed 3-letter stems of studied and unstudied words into words in a word-stem completion task (production priming); and (3) answered *yes* or *no* to having read studied and unstudied words in a recognition task (explicit memory). Explicit memory and word-stem completion priming were impaired in the AD group compared to the NC group. After correcting for baseline slowing, word-naming priming magnitude did not differ between the groups. The results suggest that the distinction between production and identification processes has promise for explaining the pattern of preservation and failure of repetition priming in AD. (*JINS*, 2001, *7*, 785–794.)

**Keywords:** Alzheimer's disease, Implicit memory, Repetition priming, Identification priming, Production priming

## INTRODUCTION

Studies of patients with brain damage are an essential element in elucidating the neurological and psychological bases of dissociable forms of long-term human memory. One such dissociation that has been well-established in neuropsychological studies is between *explicit* and *implicit* memory (Graf & Schacter, 1985). Retrieval tasks that require conscious and deliberate reconstruction of the study-phase experience, such as recall and recognition, are referred to as explicit (Schacter & Graf, 1986), direct (Richardson-Klavehn & Bjork, 1988), or declarative (Cohen & Squire, 1980). Retrieval tasks that require no reference to the study-phase experience, but measure memory as a change in speed, accuracy, or response bias in the processing of study-phase stimuli, are referred to as implicit, indirect, or procedural.

One class of implicit retrieval tasks is repetition priming. Repetition priming is calculated as the difference in performance between repeated (studied) *versus* new (unstudied, baseline) stimuli. For example, after being exposed to a word, a participant is more likely to complete a three-letter word-stem (e.g., gra) with the studied word (e.g., grain) than with an unstudied alternative word (e.g., grape), or a participant is more likely to read the studied word faster the second time it is encountered and/or faster than an unstudied word. This indirect effect of experience on subsequent performance reflects memory acquired in the study phase and retrieved in the test phase.

Amnesic patients with focal bilateral damage to mesial–temporal and/or diencephalic structures have a profound impairment in explicit retrieval, but can show fully intact repetition priming for the identical materials they can neither recall or recognize (e.g., Cermak et al., 1988; Gabrieli et al., 1994; Graf et al., 1984; Warrington & Weiskrantz, 1968, 1970). These findings suggest that the mesial-temporal and diencephalic regions of the brain that support explicit retrieval are not necessary for normal repetition priming.

Studies of patients with Alzheimer's disease (AD) have suggested what neural substrates may underlie repetition priming (reviewed in Fleischman & Gabrieli, 1998). AD is characterized by degeneration of mesial–temporal structures, which, as in focal amnesia, results in profoundly

Reprint requests to: Debra Fleischman, Department of Neurological Sciences, Rush Alzheimer's Disease Center, 1645 W. Jackson, Suite 450, Chicago, IL 60612. E-mail: dfleisch@rush.edu

impaired recall and recognition. Unlike focal amnesia, AD is additionally characterized by progressive and selective damage to association neocortices, which causes deficits in multiple cognitive domains (reviewed in Nebes, 1989), as well as a reduction or a failure of some kinds of priming. These findings suggest that association neocortex may be the critical neural substrate underlying priming.

Priming is not a unitary phenomenon (e.g., Blaxton, 1989), however, and some forms of priming appear to be preserved in AD. A question of theoretical interest is what distinguishes those forms of priming that are intact in AD from those forms of priming that are impaired. One distinction that has proven useful for understanding the pattern of results occurs between *perceptual* and *conceptual* processes in priming (Blaxton, 1989). Many studies (see Fleischman & Gabrieli, 1998) have shown that AD priming is intact on tasks that emphasize visual perceptual processing, such as word-identification, picture and word naming, and lexical and object decision. In contrast, priming is impaired on tasks that emphasize conceptual (meaning-based) processing such as word-association and category exemplar generation. The distinction does not provide a fully satisfactory explanation, however, because it cannot explain the numerous reports of impaired word-stem completion priming, a task that is considered predominantly perceptually driven (Roediger & McDermott, 1993).

Another distinction that has promise for explaining the pattern of priming results in AD occurs between *identification* and *production* processes. Identification tasks draw upon test-phase processes concerned with identification or verification of single items. This form of priming occurs on tasks that require threshold identification of target stimuli from within visual (e.g., Jacoby & Dallas, 1981) or auditory (e.g., Schacter & Church, 1992) noise, repeated identification of single words or pictures (e.g., Carr et al., 1982), identification of single words from word fragments (e.g., Tulving et al., 1982), lexical classification of words (e.g., Scarborough et al., 1979), and semantic category classification of single word exemplars (e.g., Vaidya et al., 1997). Production priming tasks draw upon test-phase processes concerned with the selection and production of a response(s) from an array of potential responses. This form of priming occurs on tasks such as word-stem completion (e.g., Graf & Mandler, 1984), in which one word must be selected in response to a cue, although many potentially accurate responses are available, or on category exemplar generation (e.g., Srinivas & Roediger, 1990), in which one or more exemplars must be produced in response to a category cue.

Some studies suggest that identification priming remains preserved in AD, even after explicit retrieval and production priming have failed. For example, priming has been shown to be preserved in AD on tasks such as word identification (e.g., Abbenhuis et al., 1990; Fleischman et al., 1995; Keane et al., 1991,1994; Koivisto et al., 1996; Russo & Spinnler, 1994), lexical decision (e.g., Balota & Ferraro, 1996; Ober et al., 1991; Ober & Shenaut, 1988), object decision (Fleischman et al., 1998); picture naming (e.g., Gabrieli et al., 1999; Park et al., 1998; Sullivan et al., 1995), and category exemplar verification (Gabrieli et al., 1999). Production priming has been shown to be impaired in AD on tasks such as word association (e.g., Brandt et al., 1988; Carlesimo et al., 1995; Salmon et al., 1988; but see Vaidya et al.,1999 for an exception) and category exemplar generation (e.g., Gabrieli et al., 1999; Monti et al., 1996).

The purpose of this study is to test the usefulness of the identification/production framework for explaining the pattern of preservation and loss in AD priming. Because priming tasks may differ along a variety of dimensions, including task difficulty, an optimal test of the proposed distinction requires that four critical constraints be met in the experimental design. First, the priming tasks must be similar in processing characteristics. The tasks chosen for this study were word naming and word-stem completion. Both tasks are considered perceptual priming tasks (Roediger & McDermott, 1993) that require the processing of a single word at both encoding and retrieval. Second, the encoding task must be identical. In this study, words were encoded in both tasks by reading aloud. Third, all materials must be fully counterbalanced across all tasks. Fourth, the distinction must be tested on the same groups of AD patients and control subjects (within-subjects design). In this way, task- and participant-based factors are controlled, leaving only the distinction between identifying *versus* producing a word at retrieval to be tested. These constraints were met in this study, and it was predicted that in the same group of AD patients, production priming on word-stem completion would be impaired, whereas identification priming on word-naming would be intact.

## METHODS

### Research Participants

The sample consisted of 16 patients with a clinical diagnosis of AD and 16 old healthy control participants. Each AD patient received a standard diagnostic evaluation at the Rush Alzheimer's Disease Center that included a medical history, neurological examination, neuropsychological testing, magnetic resonance (MRI) scan if not scanned within the past 12 months, and routine blood tests including glucose, cholesterol, thyroid function, vitamin B-12, and syphilis serology as recommended by the Quality Standards Subcommittee, American Academy of Neurology (1994). All patients met clinical criteria for probable AD as outlined by the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA) work group (McKhann et al., 1984). The NINCDS-ADRDA inclusion criteria for probable AD are a history of progressive cognitive decline with onset between the ages of 40 and 90, impaired episodic memory [operationalized in this study as a score of 5 or less on the Delayed Word List Recall measure from the Consortium to Establish a Registry for Alzhei-

https://doi.org/10.1017/S1355617701777016 Published online by Cambridge University Press

mer's Disease (CERAD); Morris et al., 1989], and impairment in at least one other cognitive domain. The NINCDS-ADRDA exclusion criteria are disturbed consciousness, history of major psychiatric disorder, and concurrent systemic or neurological illness believed to contribute to cognitive impairment. Dementia severity, as measured by the Mini-Mental Status Examination (MMSE; Folstein et al., 1975), was mild.

The control participants were recruited through church organizations, independent living retirement communities, and from spouses of neurologic patients. All were in good physical and mental health by self-report, had no history of major psychiatric disorder, or systemic or neurological illness. In addition, inclusion in the sample required a MMSE score of 27 or greater. The AD and the NC groups were equivalent in age ($p$ = .70) and years of education ($p$ = .78). Table 1 provides demographic and psychometric information.

## Materials and Procedures

The target stimuli were 216 words that had three-letter word-stems which could be completed with at least ten words according to *Merriam-Webster's Collegiate Dictionary* (10th ed.; Mish et al., 1996), and were not the most common completions for the stems as determined by an independent sample of ten young normal volunteers. The words were randomly assigned to six lists of 36 words each, and subsequently reassigned to equate lists for the average number of syllables in each word ($M$ = 1.9; range = 1–5) and word frequency ($M$ = 21/1,000,000, range = 0–182; Kucera & Francis, 1967).

Each 40-item study list comprised 36 target words, two filler words at the beginning of the list to provide practice and reduce any primacy effect, and two filler words at the end of the list to reduce any recency effect. Three, 80-item test lists were created by combining one studied list (36 words), one unstudied list (36 words), and eight filler words (six at the beginning of the list to provide practice and two at the end of the list). Word order within the lists was pseudo-randomized and fixed such that no more than three studied or unstudied words occurred consecutively. Across participants, each word appeared equally often as a studied and an unstudied target, and in all implicit and explicit tasks. Administration order of the implicit tasks was randomized across participants, and the explicit task always followed the completion of both implicit tasks.

The stimuli were delivered individually via Superlab software and a MacIntosh PowerBook 5300c computer. For the study phase of each task, participants were told that the purpose of the task was to measure how quickly and accurately they could read single words. A card with the phrase "Read Word Aloud" was placed on the keyboard to remind the participant of the task instruction. Once the experimenter was confident that the participant understood the instructions, the first trial was initiated. A fixation cross appeared in the center of the computer monitor for 500 milliseconds (ms). Following a pause of 500 ms, the target word appeared centrally on the computer monitor for 1000 ms or until the word was read. The experimenter then pressed a key to advance to the next trial, which began after a 500 ms interval. Response latencies were registered via voice-activated software. The experimenter recorded accuracy.

The test phase of the word-naming task was identical to the study phase. For the test phase of the word-stem completion task, participants were told that they would be performing a test of their knowledge of words. They were told that three letters would appear on the computer monitor and that they were to complete those letters into the first word that came to mind. Participants were cautioned not to complete stems with proper nouns. A card with the phrase, "Complete The Word Stem" was placed on the keyboard to remind participants of the task instruction. Once the experimenter was confident that the participant understood the instructions, the first trial was initiated. A three-letter word-stem appeared centrally on the computer monitor. If the participant completed the stem with a proper noun or an incorrect word for the word stem (e.g., *delight* for *det*), the error was pointed out and the participant was given another

**Table 1.** Demographic and psychometric characteristics

| Group | *N* | Age (years) | Educ (years) | MMSE | Episodic Memory | |
|---|---|---|---|---|---|---|
| | | | | | Cerad Imm[a] | Cerad Delay[b] |
| Full sample | | | | | | |
| NC | 16 | 73.4 (6.1) | 13.2 (1.8) | 29.3 (.93) | 23.1 (5.1) | 8.3 (1.2) |
| AD | 16 | 72.4 (9.0) | 13.0 (2.1) | *19.8 (3.4) | *9.6 (4.1) | *1.3 (4.1) |
| Subsample | | | | | | |
| NC | 10 | 73.5 (5.7) | 12.8 (1.6) | 29.2 (.79) | 22.9 (5.4) | 8.4 (.70) |
| AD | 9 | 69.3 (10.0) | 13.0 (2.3) | *19.3 (3.2) | *9.7 (4.4) | *1.1 (1.7) |

*Note*. NC = Normal Control; AD = Alzheimer's Disease; Educ = Education; MMSE = Mini-Mental Status Examination; CERAD = Consortium to Establish A Registry for Alzheimer's Disease; Imm = Immediate. [a] Number correct out of 30. [b] Number correct out of 10. Standard deviations in parentheses. *$p < .001$

https://doi.org/10.1017/S1355617701777016 Published online by Cambridge University Press

opportunity to complete the word-stem. If an incorrect response was again made, an error was scored. The experimenter recorded the participant's response and advanced to the next trial, which began after a 500 ms pause. For the test phase of the recognition task, participants were told they would be performing a test of their memory for the words that they had just read. They were instructed to say "yes" if they remembered reading the word in the previous list and to say "no" if they did not remember reading the word in the previous list. A card with the phrase, "Did You Read This Word? Yes or No" was placed on the keyboard to remind participants of the task instruction. When the experimenter was confident that the participant understood the instructions, the first trial was initiated. A word appeared centrally on the computer monitor. The experimenter recorded the participant's response and advanced to the next trial, which began after a 500 ms pause.

## RESULTS

### Data Analysis

Primary analyses examined the effects of AD on implicit and explicit task performance using repeated measures analyses of variance (ANOVA). Group (NC/AD) was the between-participants factor and item type (unstudied/studied or hits/false alarms) was the within-participants repeated factor. *T* tests were employed for *post-hoc* planned comparisons. Secondary analyses examined the relationship between priming, age, global cognitive status, and episodic memory within each of the NC and AD groups using multiple regression. Global cognitive status was measured using the MMSE (Folstein et al., 1975) which yields a dementia severity score on a 30-point scale, with lower scores indicating more severe cognitive impairment. The independent measure of episodic memory used in the regression analyses was Delayed Recall from the CERAD battery (Morris et al., 1989).

#### *Study phase*

A study-phase response was considered correct if the word was read accurately (i.e., all syllables in the word were pronounced). Encoding accuracy was high for the NC and AD groups (*M*s = 100% and 98%, respectively). This small difference was significant [$F(1,30) = 5.4$, $p = .01$], however, and test-phase performance was thus conditionalized on study-phase accuracy.

#### *Test phase*

*Implicit Memory.* Priming was calculated as the difference between performance with studied and unstudied targets. Because there was a group difference in baseline performance on both implicit memory tasks, analyses were performed on the absolute (studied-unstudied) and on the proportional (studied-unstudied/unstudied) priming scores. The results were similar and only absolute priming is reported.

*Word Naming.* Two scores were obtained in the word-naming task: time to name, in milliseconds, words that had been (1) studied, and (2) not studied (baseline). Response latencies were discounted due to machine error or participant response error (e.g., extraneous noise made by the participant such as "um" or "uh"). The NC and AD groups had 1.2% and 8.6% of the total latencies excluded, respectively. The distributions of the word-naming data were skewed, particularly for the AD group, so analyses were based on log-transformed scores.

Priming occurred for the groups [main effect of item type: $F(1,30) = 29.0$, $p < .0001$], but differed in magnitude [main effect of group: $F(1,30) = 7.45$, $p < .05$; Group × Item Type interaction: $F(1,30) = 5.49$, $p < .05$]. Planned comparisons indicated that significant priming occurred for each of the NC [$t(15) = 2.9$, $p = .01$], and AD [$t(15) = 3.1$, $p < .01$] groups independently. The significant group difference was due to an abnormally high priming magnitude for the AD group ($M = 93$ ms) compared to the NC group ($M = 28$ ms; 95% CI = −130.584, 96.077).

Baseline and priming latencies were negatively correlated in the AD group ($r = -.63$, $p < .01$), suggesting that the abnormally high priming was an artifact of significantly slowed baseline naming performance. A subsample (see Table 1 for demographic and psychometric information) equated for baseline performance was created by selecting all NC participants with mean baseline latencies greater than 700 ms ($n = 10$) and all AD participants with mean baseline latencies less than 900 ms ($n = 9$). Within this subsample, the NC and AD groups were equated for baseline latency ($p = .57$), age ($p = .27$) and education ($p = .82$). One-way ANOVA of the log-transformed priming scores indicated that when the groups were equated for baseline performance, priming occurred for each of the groups independently (both *p*s < .01), and there was no significant effect of disease on word-naming priming, (AD $M = 46$ ms, NC $M = 43$ ms, $p = .75$; 95% CI = −39.308, 32.469).

*Word-Stem Completion.* Two scores were obtained in the word-stem completion task: percentage of target word stems for words that had been (1) studied, and (2) not studied (baseline). Responses were accepted as correct if they were identical or a plural of the target word. Error rates were 2% and 8% for the NC and AD groups, respectively.

Significant priming occurred for both the NC [$M = 25\%$; $t(15) = 7.18$, $p < .01$] and the AD [$M = 7\%$; $t(15) = 2.83$, $p = .01$] groups [main effect of item type: $F(1,30) = 55.9$, $p < .0001$], although priming magnitude was significantly impaired for the AD group [main effect of group: $F(1,30) = 8.0$, $p < .01$]; Group × Item Type interaction: $F(1,30) = 17.3$, $p < .001$; 95% CI = .088, .257]. AD word-stem completion priming was also impaired in the subsample of participants that were equated for baseline word-naming latency [NC $M = 27\%$, AD $M = 8\%$; $F(1,17) = 9.5$, $p < .01$; 95%

https://doi.org/10.1017/S1355617701777016 Published online by Cambridge University Press

**Table 2.** Implicit memory

| | | Word-Naming (ms) | | Word-Stem Completion (%) | |
|---|---|---|---|---|---|
| Group | *N* | Baseline *M* (*SD*) | Studied *M* (*SD*) | Baseline *M* (*SD*) | Studied *M* (*SD*) |
| Full sample | | | | | |
| NC | 16 | 731 (90) | 703 (83) | .03 (.02) | .28 (.14) |
| AD | 16 | *903 (246) | *810 (153) | *.06 (.04) | *.13 (.08) |
| Subsample | | | | | |
| NC | 10 | 789 (38) | 746 (64) | .04 (.02) | .31 (.16) |
| AD | 9 | 774 (87) | 728 (104) | *.07 (.04) | *.15 (.10) |

*Note*. NC = Normal control; AD = Alzheimer's disease; *$p < .001$ for NC *vs.* AD.

CI = .063, .334]. Indeed, in this subsample of AD patients, word-stem completion priming magnitude was not significantly different from zero ($p = .11$).

Table 2 provides the implicit memory results for the full sample and the subsample. Secondary regression analyses on the word-stem completion priming data revealed that there was a nonsignificant effect of age ($b = -.276$, $SE = .006$, $p = .36$), explicit memory ($b = -.019$, $SE = .035$, $p = .95$), or global mental status ($b = -.184$, $SE = .045$, $p = .56$) within the NC group. For the AD group, there was no effect of global mental status ($b = .135$, $SE = .006$, $p = .50$), but there was a robust effect of age ($b = -.692$, $SE = .002$, $p < .01$). A median split of the AD group revealed a priming magnitude of 13% for AD patients younger than age 75. Priming magnitude for AD patients 75 years of age and older was sharply reduced to 1%. This difference was significant [$t(47) = 11.56$, $p < .0001$].

*Explicit Memory.* Two scores were obtained in the recognition task: percentage (1) hits (saying "yes" to studied words), and (2) false alarms (saying "yes" to unstudied words). A corrected recognition score was calculated as the difference between hits and false alarms.

The main effect of item type achieved significance [$F(1,30) = 538.6$, $p < .001$], and there was a trend toward a main effect of group ($p = .14$). Planned comparisons revealed that the groups did not differ on hit accuracy ($p = .29$), but that the AD group committed significantly more false alarm errors [$F(1,30) = 13.3$, $p = .001$]. The corrected recognition score of the AD group was significantly impaired compared to that of the NC group [*M*s = .26 and .61, respectively; Group × Item Type interaction: $F(1,30) = 33.0$, $p < .001$]. The explicit task results can be found in Table 3.

## DISCUSSION

This study tested a distinction between two forms of repetition priming in AD, identification priming measured by a word-naming task, and production priming measured by a word-stem completion task. There were two primary findings. First, priming on the word-stem completion task was significantly reduced in the AD patients. Coupled with advanced age, AD virtually eliminated word-stem completion priming. Second, after accounting for slowed baseline performance, priming on the word-naming task was intact in the same AD patients.

Word-stem completion is the most widely studied form of priming in AD, and the results of many experiments are mixed (see Fleischman & Gabrieli, 1998). However, when a high level of statistical power is achieved through meta-analytic methods, this form of priming appears to be impaired in AD (Meiran & Jelicic, 1995), and the results of this study support that finding. The AD impairment in word-stem completion priming found in this study is unlikely to be accounted for by the explicit memory deficit for at least two reasons. First, there is an extensive literature establishing that performance on the version of the word-stem completion task used in this study is fully intact in patients with focal amnesia (e.g., Cermak et al., 1988; Diamond & Rozin, 1984; Gabrieli et al., 1994; Graf & Schacter, 1985; Graf et al., 1984, 1985; Schacter & Graf, 1986; Shimamura & Squire, 1984; Squire et al., 1987; Warrington & Weiskrantz, 1968, 1970). Second, for the NC group, there were no correlations between word-stem completion priming and episodic memory measured by the independent test of CERAD Word List Recall or between word-stem completion priming and recognition memory measured by the matched yes/no recognition task ($r = .40$, $p = .12$).

Increasing age had a debilitating effect on the word-stem completion priming of participants in this study who had AD, although it did not affect participants without the dis-

**Table 3.** Explicit memory

| | | Hits (%) | False Alarms (%) |
|---|---|---|---|
| Group | *N* | *M* (*SD*) | *M* (*SD*) |
| NC | 16 | .76 (.14) | .15 (.11) |
| AD | 16 | .69 (.26) | *.43 (.29) |

*Note*. NC = Normal control; AD = Alzheimer's disease; *$p < .001$ for NC *vs.* AD.

https://doi.org/10.1017/S1355617701777016 Published online by Cambridge University Press

ease. In a study of word-stem completion priming in young, old, and AD participants, Fleischman et al. (1999) found a significant difference in priming (collapsed across encoding conditions) between young and old participants, but no effect of advancing age within either the old group or within the AD group. In the current study, as in Fleischman et al. (1999), advancing age within the old group did not predict word-stem completion priming. However, unlike the findings of Fleischman et al. (1999), advancing age did predict word-stem completion priming in the AD group. The mean age and age range of the AD patients was similar across the two studies, thus the reasons for the discrepancy are unclear. The interaction between age and diagnosis is an understudied phenomenon in AD priming, and further examination is warranted because the interplay of these two participant factors (Fleischman & Gabrieli, 1998; Fleischman et al., 1997) may be contributing to the variability in results between independent studies of word-stem completion priming in AD.

Dementia severity did not have an effect on the word-stem completion priming of the AD group in this study. Although a number of studies have reported that global cognitive status does not influence this form of priming in AD (e.g., Deweer et al., 1994; Dick et al., 1989; Partridge et al., 1990), other studies have reported that it does, indeed, have an impact (e.g., Fleischman et al., 1999; Gabrieli et al., 1994; Heindel et al., 1989; Salmon et al., 1988; Shimamura et al., 1987). In the study reported by Fleischman et al. (1999), AD patients with MMSE scores between 16–25 (mild severity) had a mean priming magnitude of 11%, whereas AD patients with MMSE scores 26 and over (very mild severity) had a mean priming magnitude of 16%. In the current study, 88% of the AD patient sample had MMSE scores between 16–25, and a priming magnitude of 8%, very close to the 11% found by Fleischman et al. (1999). The fact that a dementia severity effect was found by Fleischman et al. (1999) and not found in the current study is not surprising because Fleischman et al. (1999) employed a very large patient sample with a wide range of dementia severity, whereas the current study limited the patient sample size and the variance on the MMSE measure was truncated (only mild AD patients were included).

Word-naming priming magnitude was higher in the AD group compared to the NC group. "Hyperpriming" is a phenomenon that is often seen in AD on tasks of short-lived semantic priming (Chertkow et al., 1989, 1994; Nebes et al., 1988; Ober et al., 1991), and has been noted in studies of word-naming repetition priming (e.g., Balota & Duchek, 1991; Margolin et al., 1996). There is currently debate about the cognitive mechanisms underlying hyperpriming in AD. Two such mechanisms that are known to be diminished in AD and are thought to be contributing to hyperpriming are semantic (Chertkow et al., 1989, 1994; Margolin et al., 1996; Nebes et al., 1988) and attentional (Ober & Shenaut, 1988; Ober et al., 1991; Shenault & Ober, 1996) processing. Whether or not the hyperpriming that occurred for the AD group in this study was due to inefficiency of attentional allocation or degradation of semantic networks cannot be addressed by the current results.

When baseline latencies of the two groups were matched on the word-naming task, the abnormally high AD priming magnitude was eliminated, and there was no group difference in priming. There have been four previous studies of word-naming repetition priming in AD. In these studies, AD priming magnitude was reported to be at levels similar or slightly higher than that of the normal control group (Balota & Duchek, 1991; Grober et al., 1992; Margolin et al., 1996; Ober et al., 1991). Thus, there is now a consistent body of evidence that word-naming priming is preserved in AD (at least as can be determined in the context of slowed baseline performance).

A distinction between perceptual and conceptual processing in priming has frequently been invoked to explain differential priming performance across tasks in AD (Blaxton, 1989). Many studies (see Fleischman & Gabrieli, 1998) have shown that AD priming is intact on tasks that emphasize visual perceptual processing, such as word-identification, picture and word naming, and lexical and object decision. In contrast, priming is impaired on tasks that emphasize conceptual (meaning-based) processing such as word association and category exemplar generation. However, a number of findings exist that are not easily accommodated by the perceptual/conceptual framework. First, AD does not generally impair conceptual priming because dissociations between conceptual priming tasks for AD patients have been reported. Gabrieli et al. (1999) reported impaired priming on category exemplar generation and intact priming on category exemplar verification. Both of these tasks measured the integrity of semantic representations using counterbalanced materials and the same AD patients. Second, AD patients show preserved conceptual priming in word association for highly associated word pairs, despite impaired priming for dominant category exemplars (Vaidya et al., 1999). Third, AD does not generally spare perceptual priming because (1) evidence exists for an AD priming deficit for degraded pictures (Heindel et al., 1990), and (2) dissociations between perceptual priming tasks for AD patients have been reported. For example, AD patients who were intact on word-identification (Keane et al., 1991) or picture naming (Gabrieli et al., 1999) priming were impaired on word-stem completion priming. The results of the current study add to this body of evidence by demonstrating a dissociation between AD priming on two predominantly perceptual tasks that incorporated identical encoding conditions and fully counterbalanced materials. Thus, it appears that there are other processes that are linked to the success or failure of both perceptual and conceptual priming in AD, and the current data suggest that two of those processes may be identification and production.

The results of this study do not elucidate the psychological mechanisms that drive identification and production priming. However, it has been suggested in other studies that allocation of attentional resources may play a key role in the distinction between these two forms of priming. Gab-

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rieli and colleagues (Gabrieli et al., 1999) have shown that priming in two production tasks, word-stem completion and category exemplar generation, is reduced by half in young participants when attention is divided at encoding. Dividing attention had virtually no effect on the priming performance of these same participants in two identification tasks, picture-naming and category exemplar verification. It was further demonstrated in this study, using identical materials and tasks, that the presence of mild AD had the same effect on production *versus* identification priming as did study-phase division of attention in young participants. Although AD reduces ability in multiple cognitive domains, attentional deficit is one of the earliest symptoms of the disease (reviewed in Parasuraman & Haxby, 1993).

Most production tasks require the selection of a response or responses from an array of potentially accurate responses, and may place heavier, or qualitatively different, demands on attentional resources than identification priming. Indeed, neuroimaging studies have shown that left frontal lobe activation increases as response competition increases in production tasks (Desmond et al., 1998; Thompson-Schill et al., 1997). Response competition does not occur in identification tasks because there is only one response, which is provided at retrieval. Thus, one candidate cognitive mechanism that may be driving the distinction between production and identification forms of priming is attention. A clear definition of identification and production priming, in terms of underlying psychological and neural mechanisms, awaits further studies.

The functional dissociation reported here between identification and production forms of priming in mild AD finds support in neuroimaging activation studies that have linked stimulus identification with posterior cortical regions and stimulus generation with anterior cortical regions (reviewed in Posner et al., 1988). Posterior cortical regions are relatively preserved early in the course of AD (e.g., Damasio et al., 1990), and so is identification priming (e.g., Fleischman et al., 1995; Gabrieli et al., 1999; Ober et al., 1991; Park et al., 1998; Postle et al., 1996), whereas anterior cortical regions are damaged in AD (e.g., Damasio et al., 1990), and production priming is impaired (e.g., Gabrieli et al., 1999; Monti et al., 1996; Salmon et al., 1988).

It is important to note, however, that neuroimaging evidence exists for a supporting role of prefrontal cortex in identification priming (e.g., Gabrieli et al., 1996). There are at least three possibilities for reconciling those imaging findings and the hypothesis that prefrontal cortex plays a special role in production priming. The first and most interesting possibility is that of regional specificity within the prefrontal cortex. Most identification priming tasks have shown activation predominantly in the left inferior frontal gyrus (e.g., Demb et al., 1995; Gabrieli et al., 1996). In contrast, for word-stem completion, selection demands lead to activation in the middle frontal gyrus (Desmond et al.,1998). Multiple investigators have stressed the distinctions between ventral and dorsal prefrontal activations, and that distinction (or others) could reconcile these findings. Second, both forms of priming may depend upon the same region, but to different degrees. Thus, reduced function in a given area may be able to support some processes (perhaps those linked to identification priming), and fail to support other processes (perhaps those linked to production priming). Third, it remains possible that reduced activations in prefrontal cortex reflect a benefit from priming-induced plasticity in other brain regions (e.g., temporoparietal cortex), and do not reflect the essential neural circuitry underlying that sort of priming. It is generally accepted that not all activations for a given task reflect the essential neural circuitry supporting performance on that task. Only lesion evidence can identify such essential circuitry.

Three caveats regarding the results of this study are noted. First, word-naming priming and word-stem completion priming are measured by latency and accuracy, respectively, creating a potential confound between response measure and priming process. That is, it is possible that the preservation of priming on word-naming does not reflect intact identification processes, but rather some factor relating to the latency measure. Likewise, word-stem completion priming may be impaired not because it is tapping impaired production processes, but because it is measured by accuracy. If this were the case, however, it is difficult to explain why one of the most widely replicated findings of preserved AD priming in the literature is on a task that employs accuracy as the response measure, word-identification (Abbenhuis et al., 1990; Fleischman, et al., 1995; Keane et al., 1991, 1994; Koivisto et al., 1996; Russo & Spinnler, 1994). Nonetheless, this potential confound between priming measure and priming process mandates a cautious interpretation of the current and previous findings, and poses a challenge to future priming studies.

Second, the findings may reflect differences in task difficulty, with priming being impaired on the more difficult task. There is, however, no evidence that AD patients found the word-stem completion task more difficult than the word-naming task. AD patients had very low and similar error rates on the two tasks, 8.6% for the word-naming task and 8.0% for the word-stem completion task. AD patients had a slightly better than normal performance on baseline word-stem completion, the task on which they had impaired priming. AD patients had a slower than normal performance on baseline word-naming speed, the task on which they exhibited intact priming. It is unlikely, therefore, that differential difficulty between the two priming tasks accounted for their dissociation.

Third, it should be noted that the dissociation reported in this study is based on the performance of a relatively small subsample of participants. This places a limitation on the generalizability of the results to the larger AD population.

The results of this study revealed intact word-naming priming and impaired word-stem completion priming for patients with mild AD. This functional dissociation converges with previous neuropsychological studies of AD and neuroimaging activation studies of normal participants, to support a distinction between identification and production

https://doi.org/10.1017/S1355617701777016 Published online by Cambridge University Press

processes in repetition priming. The distinction may contribute towards the development of a more precise model of the neural and cognitive organization of implicit long-term memory.

## ACKNOWLEDGMENTS

This research was supported by NIA Grants AG13018 and AG10161 to Rush-Presbyterian-St. Luke's Medical Center and AG11121 and AG12995 to Stanford University.

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