Neuropsychology
1998, Vol. 12, No. 3, 340–352

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0894-4105/98/$3.00

Preserved Priming Across Study–Test Picture Transformations in Patients With Alzheimer's Disease

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Picture-naming priming was examined across different study–test transformations to explore the nature of memory representations of objects supporting implicit memory processes in patients with Alzheimer's disease (AD). Although severely impaired in explicit memory for pictures and words, AD patients demonstrated normal priming across perceptual transformations in picture orientation (Experiment 1) and picture size (Experiment 2) and across symbolic transformations from words to pictures (Experiment 3). In addition, the priming across alterations in picture size was invariant. This demonstrates that AD patients have preserved implicit memory for high-level, abstract representations of objects.

Alzheimer's disease (AD) is characterized by a progressive deterioration of the hippocampus, basal forebrain, and neocortical—temporal, parietal, and frontal—regions (Arnold, Hyman, Flory, Damasio, & Van Hoesen, 1991; Brun & Englund, 1981). These neuroanatomical insults cause multiple cognitive deficits in language, reasoning, and memory. The most characteristic behavioral hallmark of the disease is a profound deficit in explicit memory, the conscious recollection of new facts or events learned in a recent experience (Graf & Schacter, 1985). Explicit memory is typically measured by tests of recall and recognition.

Despite a profound impairment in explicit memory, AD patients have shown examples of preserved implicit memory. Implicit memory refers to unconscious or unintentional retrieval of information learned in a recent experience (Graf & Schacter, 1985), and it has been assessed via repetition priming. Repetition priming is a change in the processing of a stimulus due to prior exposure to that stimulus or a related stimulus. Repetition-priming tasks involve a study phase during which stimuli are encoded and a test phase during which a task is performed on studied items (old) as well as new items that provide a baseline measure of performance. The measure of priming is the difference in performance with old versus new items, a difference that must reflect memories gained for old items encoded during the study phase.

Although an extensive amount of research on repetition priming in AD patients has been conducted with verbal tasks, revealing both normal (e.g., mirror reading: Deweer, Pillon, Michon, & Dubois, 1993; perceptual identification of words and pseudowords: Keane, Gabrieli, Fennema, Growdon, & Corkin, 1991 and Keane, Gabrieli, Growdon, & Corkin, 1994, respectively; homophone spelling: Christensen & Birrell, 1991) and impaired (e.g., category exemplar generation: Monti et al., 1996; word-association generation: Salmon, Shimamura, Butters, & Smith, 1988) priming effects, very little research has been done with nonverbal or pictorial materials. In the studies that have been conducted, AD patients have shown intact priming on tasks of picture naming (Gabrieli et al., 1997) and picture-fragment identification (Corkin, 1982; Gabrieli et al., 1994). The interpretation of the findings on picture-fragment identification, however, are less clear, because, in some cases, AD patients have demonstrated either no priming (Bondi & Kaszniak, 1991) or impaired priming (Heindel, Salmon, & Butters, 1990). Gabrieli and colleagues (1994) have postulated that AD patients appear impaired relative to control participants because the nature of the task encourages participants to

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This research was supported in part by National Institutes of Health Grants MH 40041, R01AG11121, P02AG09466, and P30AG10161 and by National Institute on Aging Grant AG11121. This study also was supported in part by a Medical Research Service of the Department of Veterans Affairs grant and by Alzheimer's Association Grant IIRG-94-059.

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elicit the use of explicit memory to which control participants have access but AD patients do not (for a more extensive discussion, see Verfaillie, Gabrieli, Vaidya, Croce, & Reminger, 1996).

The pictorial and verbal tasks on which AD patients have displayed intact repetition priming are thought to be perceptually driven. Perceptually driven tasks rely primarily on the analysis of stimulus form at study and test. Although AD patients have exhibited intact perceptual implicit memory across a variety of tasks, it is not known whether the perceptual analysis they perform to acquire the perceptual memory is similar to that of the normal population. Elucidating the nature of perceptual memory representations in AD will provide evidence in ascertaining whether the perceptual analysis in which AD patients engage is similar to that in which normal participants engage.

Very little is known about how perceptual memories are represented in AD. No study has examined priming in AD on perceptually driven tasks with either pictures or words whose perceptual features varied across study and test. Therefore, it is unknown whether a memory representation of a stimulus is specific to the stimulus in that it supports only the exact stimulus on which the representation was based, or whether a memory representation of a stimulus is perceptually abstract in that the representation extends to a version of the same stimulus that has been modified on some physical dimension such as orientation or size. The aim of the present study is to examine whether perceptual memory representations of pictures of objects in AD are perceptually abstract or specific.

Findings in human and nonhuman primates that illuminate the neural correlates to the perceptual-learning mechanism underlying picture priming are relevant to understanding the nature of implicit memory representations. Lesion studies with monkeys have demonstrated that areas in the inferior temporal cortex are crucial for object identification, and these cortical areas have been shown to be involved in late stages of visual processing (Dean, 1976; Desimone, Albright, Gross, & Bruce, 1984; Gross, 1973a, 1973b; Ungerleider & Pribram, 1977; Wilson, 1968). Moreover, electrophysiological studies with monkeys have shown that inferior temporal cortical cells that respond to complex patterns such as faces (of human and nonhuman primates) are insensitive to changes in size of stimulus or position in visual field (Desimone et al., 1984). These same cells, however, are less responsive to in-depth rotations of a face stimulus that alter the basic structure of the face.

The findings in picture priming with human primates parallel the pattern of findings in monkeys. Picture priming is invariant across study–test changes in size (Biederman & Cooper, 1992), left–right orientation, and position of visual field (Biederman & Cooper, 1991) but is reduced when transformations alter the structural parts of an object from study to test (e.g., Biederman & Gerhardstein, 1993; Srinivas, 1993). The observation that the characteristics of picture priming reflect the behavior of cellular activity of the inferior temporal cortex suggests that perceptual priming with pictures in human primates occurs at a later and more abstracted, rather than an earlier and more sensory, stage of visual processing.

Based on the findings in nonhuman primates, the pattern of neuropathology in AD raises the possibility that AD patients would fail to show normal invariant priming across perceptual alterations. Postmortem studies with AD patients have shown the inferior temporal region to be severely affected, whereas the occipital and occipitotemporal cortical areas, mediating earlier stages of visual processing, appeared relatively preserved (Arnold et al., 1991; Lewis, Campbell, Terry, & Morrison, 1987). The inferior temporal region, being severely compromised, is believed to be inflicted early on in the progression of AD, whereas the occipital regions that remain relatively intact are thought to be affected later in the disease process. The topography of neuropathology in AD patients has led researchers to believe that the perceptual-learning mechanism underlying perceptual priming with pictures may be supported by visual cortices involved in early stages of visual processing that are relatively uncompromised in early-stage AD patients (e.g., Gabrieli et al., 1994, 1997; Keane et al., 1991). Because these neural regions are known to be sensitive to surface properties of a stimulus (Desimone & Ungerleider, 1989), a memory representation of a stimulus supported by such brain areas could be specific to the details of that stimulus.

Based on the literature relevant to understanding the nature of perceptual memory representations of objects in AD, it is unclear as to whether the representations would be specific or perceutally abstract. To illuminate the nature of perceptual memory representations of objects in AD patients, we examined picture priming across transformations in orientation and size. If picture priming in AD does not translate across study–test changes in pictures, then, unlike normal participants, abstract implicit memory representation in AD is compromised. On the other hand, if picture priming in AD transfers across study–test changes and is invariant relative to priming produced across identical study–test pictures, then picture priming may be mediated by the same perceptual-learning mechanism that mediates perceptually abstract implicit memory representations in the normal population. Evidence for the latter hypothesis would suggest that the neural substrates involved in perceptually abstract memory representations of objects, which traditionally have been thought to be functionally and neuroanatomically part of advanced stages of visual processing, are preserved in early-stage AD.

Transfer of priming was examined using picture-naming tasks. Experiments 1 and 2 examined, respectively, whether picture-naming priming would transfer normally in AD patients across different orientations and sizes of a picture. In Experiment 3, picture-naming priming was examined across words (labels of pictures) and pictures to investigate whether priming would transfer across a symbolic transformation.

Experiment 1

This experiment examined whether AD patients would demonstrate normal picture-naming priming across the same

pictures presented in different orientations. First, participants named pictures presented in 1 of 12 different orientations. Second, participants performed a three-choice recognition task. Last, participants renamed studied pictures presented in orientations different from those seen in the first presentation.

Method

Participants

Patients diagnosed with probable AD (5 men and 10 women) and normal control (NC) participants (5 men and 7 women) were recruited from Rush Alzheimer's Disease Center (RADC) in Chicago, Illinois (see Table 1). The two groups did not differ significantly on age ($t < 1.5$) or education ($t < 1.5$). All t-test analyses in this and all subsequent experiments are two-tailed unless specified otherwise. All patients were diagnosed as having probable AD based on the clinical criteria outlined by the National Institute of Neurological and Communicative Disorders and Stroke and Alzheimer's Disease and Related Disorders Association (McKhann et al., 1984). Each participant received a standard diagnostic evaluation consisting of a medical history, neurological examination, neuropsychological testing, electrocardiogram, and chest X-ray. In addition, magnetic resonance imaging scans of the brain and routine blood tests were administered to AD patients. The inclusion criteria for AD patients entailed a history of progressive cognitive decline with onset between the ages of 50 and 90, impaired episodic memory (indicated by a score of 5 or less on the Consortium to Establish a Registry for Alzheimer's Disease delayed Word List Recall measure (Welsh, Butters, Hughes, Mohs, & Heyman, 1991), and an impairment in at least one other cognitive area. The inclusion criteria for normal participants were that the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) scores be ≥26 and delayed Word List Recall be ≥6. NC participants had higher MMSE scores than AD participants, $t(25) = 9.19$, $p < .0001$. The exclusion criteria for all participants included disturbed consciousness, history of major psychiatric disorder, history of other disorders believed to contribute to cognitive impairment, and use of antidepressant or anxiolytic medications.

Table 1
Descriptive Characteristics for Alzheimer's Disease (AD) and Normal Control (NC) Participants in Experiments 1, 2, and 3

Group	Age (range)	Education (range)	MMSE (range)
	Experiment 1		
AD (n = 15)			
M	71.0 (51–81)	12.8 (8–21)	20.8 (13–26)**
SD	8.9	3.4	3.0
NC (n = 12)			
M	71.0 (54–76)	12.8 (9–20)	29.1 (28–30)
SD	6.9	3.5	2.9
	Experiment 2		
AD (n = 12)			
M	72.6 (56–82)	14.6 (9–21)	22.4 (18–26)*
SD	7.8	4.0	2.5
NC (n = 9)			
M	70.3 (60–76)	13.0 (10–20)	29.2 (26–30)
SD	6.4	2.8	1.4
	Experiment 3		
AD (n = 16)			
M	70.8 (57–82)	13.8 (7.5–18)	21.9 (20–25)**
SD	7.2	3.1	1.6
NC (n = 16)			
M	71.8 (62–86)	14.9 (12–19)	29 (27–30)
SD	5.9	2.3	0.9

Note. MMSE scores are based on a maximum score of 30. MMSE = Mini-Mental State Examination.
*$p < .001$. **$p < .0001$.

Materials and Design

The stimuli consisted of 84 digitized pictures of common objects and animals whose canonical position was an upright orientation at 0° in the visual field. These pictures were obtained from the Snodgrass and Vanderwart (1980) norms and had a mean name agreement H value of 0.41 (range, 0.00–1.77). Each picture was rotated with MacPaint software 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, and 330° around the picture plane so that each picture was represented in 12 different orientations. Twelve different study forms were constructed so that across forms all 12 orientations of a picture were represented. Each form consisted of 72 pictures with 6 different pictures at each of the 12 orientations and the remaining 12 pictures from the set of 84 that were used for the subsequent recognition task only. Each of the 12 recognition-task pictures were presented in 1 of the 12 orientations in each form. Across study forms, the recognition pictures were represented in each of the 12 orientations. The order of pictures in the study forms was pseudorandomized with the restriction that no more than two pictures with the same orientation be presented in consecutive trials. Eight practice pictures were included at the beginning of each list. The test forms were identical to the study forms except that the 12 recognition-task pictures were omitted. Two different forms were used for each phase (study and test) of the picture-naming task so that the pictures in the study phase were old pictures presented in different orientations in the test phase. The phase variable was counterbalanced across participants. For the three-choice recognition task, one test form was constructed. It consisted of the 12 recognition pictures from the set of 84. For each picture, two foils with upright orientations at 0° were selected pseudorandomly from Snodgrass and Vanderwart (1980) norms.

Procedure

A single session of testing involved three different testing blocks administered in succession: (a) picture-naming study phase, (b) three-choice recognition task, and (c) picture-naming test phase. Participants were tested individually on a MacIntosh Plus computer in a quiet room. In the picture-naming study phase, participants were instructed to name as quickly and as accurately as possible rotated pictures that appeared on the computer screen. Each trial consisted of a fixation point that appeared at the center of the screen for 250 ms, a blank interval of 250 ms, the appearance of a picture, and the disappearance of the picture when a participant provided a response. Responses were detected by a hand-held microphone connected to a Lafayette voice-activated relay connected to the computer where response latencies were recorded to the millisecond. Each trial was initiated by the examiner, who also recorded the response and any error made on each trial. These procedures for recording responses, latencies, and naming errors were the same for all subsequent experiments. Practice trials were administered before presentation of test items for this and all subsequent experiments. The recognition task was administered 10 min after

the picture-naming study phase. Participants were asked to identify which of three pictures they had seen earlier by pointing to the picture. Each display consisted of one old and two new (foil) pictures presented in the 0° orientation in the left, center, and right positions on the computer monitor. The old picture appeared equally often in each position. The pictures remained on the screen until the participant provided a response, and it was recorded by the examiner, who advanced each trial. Immediately afterwards, the picture-naming test phase was administered. The instructions and procedures were identical to those in the study phase.

Results and Discussion

Picture Naming

The dependent measures were means of median naming latencies in milliseconds for pictures in the study and test phases. Response latencies were discounted if they met any of the following criteria: (a) latencies for pictures that were neither the dominant nor a nondominant name included in the Snodgrass and Vanderwart (1980) norm list; (b) latencies recorded prematurely due to extraneous noise made by the participant (e.g., "uh," "um," or coughs); and (c) latencies for responses at study that did not match responses for corresponding items at test and vice versa. The ranges in percent for naming, participant, and matching errors collapsed across orientation and phase were 0–67% (M = 23%, SD = 19%), 0–27% (M = 14%, SD = 8%), and 13–22% (M = 19%, SD = 3%), respectively, for AD patients and 0–58% (M = 9%, SD = 10%), 3–20%, (M = 9%, SD = 6%), and 10–22% (M = 14%, SD = 4%), respectively, for NC participants.

For the remaining valid responses, median naming latencies were computed for pictures in each of the 12 orientations (0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, 330°) in study and test phases, separately, for each participant. Because clockwise and counterclockwise rotations of the same degree produce similar reaction times and therefore are typically combined (e.g., Maki, 1986; Tarr & Pinker, 1989), response latencies for symmetrical rotations of 30°, 60°, 90°, 120°, and 150° were collapsed. The nonsignificant results from t tests comparing mean naming latencies for rotations of the same magnitude (30° vs. 330°, 60° vs. 300°, 90° vs. 270°, 120° vs. 240°, and 150° vs. 210°) for each phase for AD (study, $ts < 1.5$; test, $ts < 1.0$) and NC (study, $ts < 1.0$; test, $ts < 1.5$) groups confirmed that there were no differences between latencies for clockwise and counterclockwise rotations. The mean latencies for the seven orientations (0°, 30°, 60°, 90°, 120°, 150°, 180°) for AD and NC participants are presented in Table 2. The means were analyzed in a 2 × 2 × 7 repeated-measures analysis of variance (ANOVA) with group (AD vs. NC) as a between-subjects variable and phase (study vs. test) and orientation (0° vs. 30° vs. 60° vs. 90° vs. 120° vs. 150° vs. 180°) as within-subject variables.

Participants named test pictures (M = 1,062 ms, SD = 234 ms) faster than study pictures (M = 1,179 ms, SD = 644 ms), demonstrating the presence of a priming effect, $F(1, 15) = 4.97$, MSE = 781,733.42, $p < .05$. The main effect of group was not significant, $F(1, 15) < 2.5$. Parti-

Table 2
Mean Median Naming Latencies and Naming Errors for Study and Test Pictures for Alzheimer's Disease (AD) and Normal Control (NC) Participants

Group	Study							Test						
	0°	30°	60°	90°	120°	150°	180°	0°	30°	60°	90°	120°	150°	180°
AD														
Naming latencies (ms)	1,129	1,082	1,149	1,190	1,426	1,495	1,384	970	1,046	1,344	1,182	1,219	1,257	1,045
Naming errors (%)	7.2	22.8	27.2	32.2	33.9	41.1	19.4	10.0	14.4	22.8	21.1	27.2	30.0	12.8
NC														
Naming latencies (ms)	920	933	1,008	1,006	1,136	1,153	1,678	891	970	978	995	1,021	1,116	1,026
Naming errors (%)	4.9	11.1	7.6	11.1	11.1	13.2	9.0	4.2	5.6	11.8	9.7	14.6	9.7	2.1

cipants were generally slower at naming pictures that were rotated further from the upright position (0°, M = 965 ms, SD = 167 ms; 30°, M = 998 ms, SD = 165 ms; 60°, M = 1,097 ms, SD = 308 ms; 90°, M = 1,077 ms, SD = 205 ms; 120°, M = 1,179 ms, SD = 229 ms; 150°, M = 1,234 ms, SD = 340 ms; 180°, M = 1,295 ms, SD = 1,118 ms), $F(6, 90) = 2.41$, $MSE = 459{,}463.36$, $p < .05$. There were no interactions, Fs < 1.5. The critical result was that the pattern of priming for the different orientations was not significantly different between the AD and NC groups.

Naming error percentages were analyzed using the same 2 × 2 × 7 repeated measures ANOVA design previously mentioned to examine whether the pattern of errors differed between AD and NC participants and to examine whether priming effects could have been due to speed–accuracy trade-offs. Priming was revealed by fewer errors made in the test phase (M = 15%, SD = 15%) than in the study phase (M = 19%, SD = 19%), $F(1, 25) = 20.32$, $MSE = 0.149$, $p < .001$ (see Table 2). AD patients (M = 23%, SD = 19%) made more naming errors than NC participants (M = 9%, SD = 10%), $F(1, 25) = 15.26$, $MSE = 1.84$, $p < .001$. As pictures were rotated further from the upright position, participants tended to make more naming errors, $F(6, 150) = 14.34$, $MSE = 0.195$, $p < .001$. AD patients tended to make more errors than the NC group as the pictures were rotated further from the upright position, $F(6, 150) = 4.02$, $MSE = 0.055$, $p < .001$. The reduction in the number of errors made at test (AD: M = 20%, SD = 16%; NC: M = 8%, SD = 10%) in comparison to those made at study (AD: M = 26%, SD = 20%; NC: M = 9.7%, SD = 11%) was greater in AD patients than in NC participants, $F(1, 25) = 8.01$, $MSE = 0.059$, $p < .01$. There were no other interactions, Fs < 2.0. Thus, the reduction in naming errors across study and test for each orientation was similar in AD and NC participants. Further, priming effects in AD and NC participants in this and the following experiments did not reflect trade-offs between speed and accuracy.

Recognition

Percentages for correctly recognized pictures in the three-choice recognition task were computed for each participant. AD patients (M = 75%, SD = 15%) were impaired in comparison to NC participants (M = 94%, SD = 5%) in recognizing pictures seen at study, $t(25) = 4.15$, $p < .0001$.

Despite impaired explicit memory for pictures, AD patients demonstrated normal priming effects across transformations in picture orientation. The present findings are consistent with prior studies with normal participants showing priming across different orientations of pictures (Jolicoeur, 1985; Jolicoeur & Milliken, 1989). AD patients made more naming errors than NC participants, and their naming was more affected by orientation than that of the NC participants. Despite the disproportional influence of orientation on naming accuracy in AD patients, the orientation effect on picture-naming priming did not differ between AD and NC groups.

Experiment 2

In Experiment 2, we examined whether picture priming in AD is invariant to size transformations as it is in both normal participants (Biederman & Cooper, 1992) and amnesic patients (Cave & Squire, 1992). In the study phase, participants named pictures in one of two sizes. In the test phase, they named new pictures and repeated pictures that were presented either in the same or a different size as in the study phase. Afterwards, participants performed a yes–no recognition task on pictures seen for the first time in the test phase of the picture-naming task and on new pictures that had not been shown before.

Method

Participants

Patients diagnosed with probable AD (3 men and 9 women) and NC participants (5 men and 4 women) were recruited from the RADC and are described in Table 1. Selection of participants was based on the same inclusion and exclusion criteria used in Experiment 1. The two groups did not differ on age ($t < 1.0$) or education ($t < 1.0$). NC participants had higher MMSE scores than AD participants, $t(19) = 7.84$, $p < .001$.

Materials and Design

The stimuli consisted of 96 digitized pictures of common objects and animals selected from the Snodgrass and Vanderwart (1980) norms. The pictures had a mean name agreement H value of 0.41 (range, 0.00–1.77). The pictures were presented either in a small or a large size. The small pictures were no larger than 3 × 3 in. (7.5 × 7.5 cm). The large pictures were created by enlarging the small pictures 150% of their original size (no larger than 7.5 × 7.5 in. [19 × 19 cm]) using MacPaint software. Three study forms (A, B, and C) each consisting of a list of 32 pictures were constructed. Because name agreement has been shown to affect naming latency and magnitude of priming (Mitchell, 1989), each study form was divided pseudorandomly into two lists of 16 pictures each having H values of 0.41, so that name agreement was balanced. One of the two lists of 16 pictures was presented as small pictures and the other was presented as large pictures. The pictures in each study form were pseudorandomly ordered so that no more than two pictures of the same size were presented in succession. Six practice pictures were included at the beginning of each study form.

Three different test forms (A + B, B + C, and A + C) were constructed by combining two different study forms so that for a given participant half the pictures would be old and the other half would be new. Of the pictures that were old, half (eight small and eight large) of the pictures were shown in the same size as in the study phase, and the remaining half (eight small and eight large) were shown in a different size. The pictures for the test lists were pseudorandomly ordered with the restriction that there not be more than four pictures from the same study list or four pictures of the same size in consecutive trials.

Three different yes–no recognition test forms (A + B, B + C, and A + C) were constructed by combining two different study forms so that half the pictures would be old pictures and the other half would be new pictures that were never shown either in the study or test phases of the picture-naming task. The old pictures were new items seen for the first time in the picture-naming task. For example, if a participant received picture-naming study Form A

and test Form A + B, then the participant would receive yes–no recognition Form B + C. Of the pictures that were old, half (eight small and eight large) the pictures were shown in the same size as in the picture-naming test phase, and the remaining half (eight small and eight large) were shown in a different size. Across participants, every picture was presented equally often as an old–same, old–different, and new item in both the recognition and picture-naming tasks.

Procedure

Testing involved three phases administered in succession during a single session of testing: (a) picture-naming study, (b) picture-naming test, and (c) yes–no recognition. For all sessions, participants were tested individually on a MacIntosh Plus computer in a quiet room. For picture-naming study and test, participants were instructed to quickly and accurately name pictures that appeared on the computer screen. In the yes–no recognition phase, participants were asked to respond "yes" if they had seen the picture in the naming task they had just completed and "no" if they had not seen the picture. They were instructed to ignore size differences, if they existed, between the pictures being presented and the ones that were seen earlier. Each trial consisted of a picture presented at the center of the computer monitor that remained on the screen until the trial was advanced by the examiner.

Results and Discussion

Picture Naming

Naming latencies from the test phase only were analyzed. Response latencies were discounted according to the same criteria as in Experiment 1 of this study. The ranges in percent for naming, participant, and matching errors were 2–25% (M = 10%, SD = 7%), 2–44% (M = 14%, SD = 11%), and 3–22% (M = 14%, SD = 8%), respectively, for AD patients and 0–6% (M = 2%, SD = 2%), 0–20% (M = 6%, SD = 7%), and 0–38% (M = 15%, SD = 12%), respectively, for NC participants.

For the remaining valid responses, median naming latencies were computed for old–same, old–different, and new pictures of small and large sizes, separately, for each participant. Means of the median naming latencies were analyzed initially in a 2 × 2 × 3 ANOVA with group (AD vs. NC) as a between-subjects variable and picture size (small vs. large) and picture type (old–same vs. old–different vs. new) as within-subject variables. Because the main effect of picture size was not significant and did not interact with other variables (Fs < 0.5), it was omitted as a variable. Subsequently, mean latencies were analyzed in a 2 × 3 ANOVA with group and picture type as variables.

AD patients (M = 1,051 ms, SD = 239 ms) were slower to name pictures than NC participants (M = 811 ms, SD = 93 ms), $F(1, 19) = 9.57$, $MSE = 889{,}337.26$, $p < .01$ (see Table 3). Naming latencies differed significantly among old–same (M = 920 ms, SD = 198 ms), old–different (M = 903 ms, SD = 181 ms), and new (M = 1,022 ms, SD = 274 ms) pictures, $F(2, 19) = 11.72$, $MSE = 87{,}383.34$, $p < .0001$. There was no interaction between group and picture type, $F(1, 2) < 0.5$. There was priming for old–same (M = 102 ms, SD = 131 ms), $t(20) = 3.59$, $p < .01$, and old–different (M = 119 ms, SD = 132 ms), $t(20) = 4.16$, $p < .001$, pictures. Probability values were adjusted to .025 for error rates according to the Bonferroni inequality (.05/2) in all cases that involved two t tests in this and the following experiments.

Table 3
Mean Median Naming Latencies and Naming Errors for Old–Same, Old–Different, and New Pictures for Alzheimer's Disease (AD) and Normal Control (NC) Participants in Experiment 2

Group	Old–same	Old–different	New
AD			
Naming latencies (ms)	1,029	994	1,131
Naming errors (%)	9.4	8.9	10.4
NC			
Naming latencies (ms)	775	781	877
Naming errors (%)	2.1	2.1	1.7

To examine whether differences existed in priming for old–same and old–different pictures between AD and NC participants, we analyzed priming scores as both absolute scores and as percentages, because AD patients were significantly slower to name pictures than NC participants. Priming percentages for old–same and old–different pictures were obtained by dividing the difference between median naming latencies for new pictures and old–same and old–different pictures, respectively, by the median naming latency for new pictures. The resulting mean magnitudes of priming in milliseconds and percent were analyzed in two separate 2 × 2 ANOVAs with group (AD vs. NC) as a between-subjects variable and picture type (old–same vs. old–different) as a within-subject variable. No significant main effects or interactions for priming were revealed in either the latency (Fs < 1.0) or percent (Fs < 1.0) analyses (see Figure 1).

AD patients made more errors than NC participants, $F(1, 19) = 7.96$, $MSE = 0.18$, $p < .01$. There were no other significant main effects or interactions, Fs < 1.5 (see Table 3).

Recognition

Overall corrected recognition (hits minus false alarms) percentages for pictures collapsed across picture type and picture size were computed for each participant. The AD group performed significantly worse than the NC group in recognizing previously seen pictures, $t(19) = 6.61$, $p < .0001$ (see Table 4).

Despite AD patients' severe deficit in recognition memory, they demonstrated normal priming effects measured in both absolute and percentage terms. The critical finding was that priming effects were similar for old–same and old–different pictures, indicating that priming was invariant to study–test changes in picture size in both AD and NC participants.

Experiment 3

The purpose of this experiment was to examine whether the findings of normal priming across perceptual transforma-

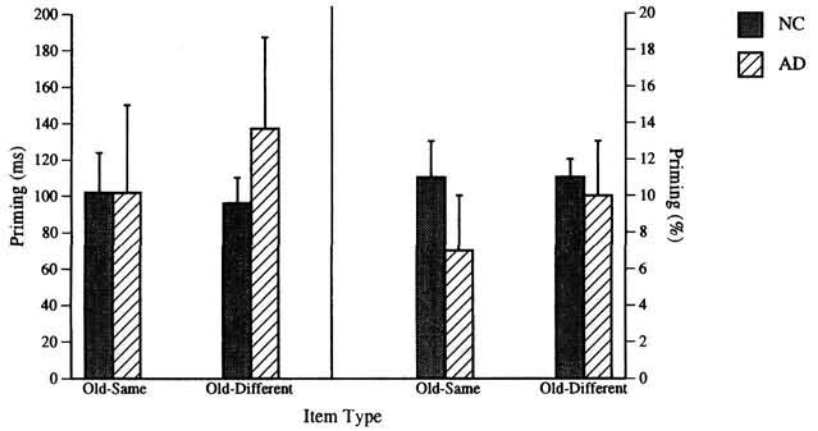

Figure 1. Magnitude of priming in milliseconds and percentage for old–same (pictures seen in the same size as at study) and old–different (pictures seen in a different size than at study) item types for Alzheimer's disease (AD) and normal control (NC) participants in Experiment 2.

tions in Experiments 1 and 2 would extend to transformations in the symbolic representation of an object such as from words to pictures. Word-to-picture priming is not believed to be mediated by perceptual processes involved in repeated picture-naming (picture-to-picture) priming. Word-to-picture priming has been found consistently (with the exception of Brown, Neblett, Jones, & Mitchell, 1991) to be reduced relative to picture-to-picture priming. This reduction is a reflection of the perceptual overlap across study and test pictures in picture-to-picture naming that is not present in word-to-picture naming (Durso & Johnson, 1979; Lachman & Lachman, 1980; Park & Gabrieli, 1995). The priming effect produced by word-to-picture naming is believed to be mediated by conceptual processes, lexical processes, or both, because words and pictures share a common conceptual referent and verbal label. Therefore, this paradigm provides a window into the nonperceptual processes operating in AD patients. If AD patients exhibit normal word-to-picture priming, then some nonperceptual processes, that is of conceptual nature, lexical nature, or both, involved in picture naming are intact in AD.

In the study phase, participants named pictures and read words. In the test phase, participants named repeated pictures, pictures corresponding to studied words, and new pictures. Participants also performed a word-stem completion task on three-letter stems of words that were presented as pictures in the picture-naming test phase and new stems. In some prior studies, AD patients have demonstrated impaired word-stem completion priming (e.g., Bondi & Kaszniak, 1991; Bondi, Kaszniak, Rapcsak, & Butters, 1993; Heindel, Salmon, Shults, Walicke, & Butters, 1989; Gabrieli et al., 1994, 1997; Keane et al., 1991; Randolph, 1991; Salmon et al., 1988; Shimamura, Salmon, Squire, & Butters, 1987), but others have found intact priming (e.g., Christensen & Birrell, 1991; Deweer et al., 1994; Dick & Kean, 1989; Fleischman et al., 1997; Grosse, Wilson, & Fox, 1990; Partridge, Knight, & Feehan, 1990; Scott, Wright, Rai, Exton-Smith, & Gardiner, 1991). Consequently, it is difficult to predict how the AD patients may perform. Inclusion of the word-stem completion task enabled us to compare performance on two different tasks that involved nonperceptual processes in the same sample of AD patients.

Table 4
Percentages for Hits and False Alarms (FA) for Yes–No Recognition Tasks in Experiments 2 and 3

	Experiment 2		Experiment 3		
Group	Hits	FA	Hits–picture	Hits–word	FA
AD					
M	75	28.4	80	29	24
SE	5.5	5.9	16.5	5.4	4.2
NC					
M	96	3.1	95	30	6.7
SE	1.5	0.9	1.4	5.6	2.1

Note. AD = Alzheimer's disease; NC = normal control.

Method

Participants

Patients (13 men and 3 women) diagnosed with probable AD and NC participants (9 men and 7 women) were recruited from the Palo Alto Veterans Affairs hospital in California and the RADC (see Table 1). The two groups did not differ significantly on age ($t < 1.0$) or education ($t < 2.0$). NC participants had higher MMSE scores than AD patients, $t(30) = 15.96$, $p < .0001$.

Materials and Design

Stimuli were 160 digitized pictures of common objects and animals and names of those pictures selected from the Snodgrass and Vanderwart (1980) norms. The pictures were divided into four study lists (A1, B1, C1, and D1) of 40 items each. The pictures that were selected based on their clarity were balanced as best as possible for name agreement. The H values for lists A1, B1, C1, and D1 were 0.43, 0.44, 0.42, and 0.43, respectively. For each list, half the items were words (names) of pictures and the other 20 were pictures. The words were seen in lowercase, 24 point, New Century Schoolbook font. Pictures and words were block randomized so that for every eight items there were four pictures and four words

with the constraint that neither pictures nor words could appear in more than three consecutive trials. Each list was preceded by six practice items, and two items were added to the beginning and the end of each list to reduce serial position effects. A second version of each list (A2, B2, C2, and D2) was created so that pictures in the original list would be seen as words and vice versa.

Two test lists were constructed by randomly combining two study lists (A and C, B and D). The H values for the combined A and C and B and D lists were 0.43 and 0.44, respectively. All items in the test phase were presented as pictures. For each test form, items from the two study forms were block randomized so that for every eight items there were four pictures from each study form. Therefore, in each eight-item block, half the pictures were old and half were new. Of the old items, two were seen as pictures and two were seen as words in the study phase. No more than three pictures from the same study form or three repeated pictures or picture analogues of words appeared in consecutive trials. Four items, two from the practice list of each study form, were added to the beginning of the list for practice. The same study and test forms for the picture-naming task were used for the yes–no recognition task. For both the picture-naming and recognition tasks, items were counterbalanced across participants for picture and word format and old and new picture type at test.

The word-stem completion task consisted of 48 three-letter stems derived from words four to nine letters in length that were selected from the four study forms (12 from each form) of the picture-naming task. The constraints for selecting the target words for stems were that no word shared the first three letters with any other target word and that each word-stem had 10 or more entries in the *Merriam-Webster Dictionary* (1974). Because the target words were selected from each study form, half were old words that represented names of pictures that were seen previously in the test phase of the picture-naming task, and the remaining half were new words that served as baseline items. The stems were block randomized so that every eight-item block consisted of two stems from each of the four different picture-naming task study forms. Therefore, each eight-item block included four old and four new items. Four practice items were included at the beginning of the task. The stems were seen in lowercase, 24 point, Geneva font. The 16 participants allowed for counterbalancing of stems across new and old word-stem types.

Procedure

Testing involved three successive sessions: (a) picture naming, (b) word-stem completion, and (c) yes–no recognition. For all tasks, participants were tested individually on a MacIntosh IIci in a quiet room.

Picture naming. Participants were assigned randomly to one of eight picture-naming study–test list combinations: A1 and C, A2 and C, C1 and A, C2 and A, B1 and D, B2 and D, D1 and B, and D2 and B. During the study phase, participants were instructed to name each picture and to read each word quickly and accurately. Each trial consisted of a fixation point appearing at the center of the screen for 500 ms, a blank interval of 600 ms, the appearance of a picture or word, and the disappearance of the picture or word when a response was provided by the participant.

Word-stem completion. Participants were asked to provide the first word, excluding proper nouns, that came to mind that began with the three-letter stem presented on the computer monitor. A trial consisted of the appearance of a stem that remained on the screen until the examiner advanced to the next trial. If an incorrect response was provided (e.g., "alright" for the stem all _), then the examiner restated the instructions for the participant to provide another response. If an incorrect response was given a second time, then the trial was scored as incorrect. The examiner recorded each response.

Yes–no recognition. Testing involved a study and test phase. Participants were pseudorandomly assigned to one of the eight picture-naming study–test list combinations with the restriction that the combination not be the one used for the picture-naming task. Procedures and instructions for the study phase were identical to those in the study phase of the picture-naming task. In the test phase, participants were instructed to respond "yes" to a picture if they had previously named it or read the word corresponding to it and "no" if they had not. Pictures were presented in the same manner as in the picture-naming task.

Results

Picture Naming

Only latencies from the test phase were analyzed. Response latencies were excluded according to the same criteria as in Experiment 1, and latencies also were excluded if they were prematurely recorded because of machine errors. Machine errors occurred when items flashed on the screen too quickly for participants to see. Latencies for these items were always recorded as less than 100 ms. The ranges in percent for naming, participant, matching, and machine errors were 4–20% (M = 10%, SD = 8%), 0–19% (M = 5%, SD = 5%), 0–8% (M = 2%, SD = 3%), and 0–4% (M = 1%, SD = 1%), respectively, for AD patients and 0–10% (M = 4%, SD = 5%), 0–5% (M = 2%, SD = 1%), 0–6% (M = 2%, SD = 2%), and 0–8% (M = 1%, SD = 2%), respectively, for NC participants.

For valid responses, median naming latencies were computed for picture, word, and new pictures for each participant. Means of the median naming latencies were analyzed in a 2 × 3 ANOVA with group (AD vs. NC) as a between-subjects variable and picture type (picture vs. word vs. new) as a within-subject variable.

AD patients (M = 1,002 ms, SD = 138 ms) were slower to name pictures than NC participants (M = 876 ms, SD = 86 ms), $F(1, 30) = 9.52$, $MSE = 385{,}256.69$, $p < .01$ (see Table 5). Naming latencies were significantly different between picture (M = 889 ms, SD = 138 ms), word (M = 929 ms, SD = 124 ms), and new (M = 998 ms, SD = 145 ms) pictures, $F(2, 30) = 53.09$, $MSE = 97{,}761.13$, $p < .0001$. There was no interaction between group and picture type, $F(2, 30) < 2.5$. Priming for picture (M = 109 ms, SD = 56

Table 5
Mean Median Naming Latencies and Naming Errors for Picture, Word, and New Pictures for Alzheimer's Disease (AD) and Normal Control (NC) Participants in Experiment 3

Group	Picture	Word	New
AD			
Naming latencies (ms)	956	980	1,071
Naming errors (%)	9.9	9.4	10.6
NC			
Naming latencies (ms)	823	879	925
Naming errors (%)	2.8	3.1	5.2

ms) and word (M = 69 ms, SD = 74 ms) items was revealed by faster naming of picture, $t(31) = 10.95$, $p < .0001$, and word, $t(31) = 5.28$, $p < .0001$, items than new pictures.

For each participant, priming scores were calculated in absolute and percentage terms, because AD patients were slower to name pictures than NC participants. Priming scores in milliseconds and percent were calculated in the same manner as in Experiment 2. The resulting mean magnitudes of priming in milliseconds and percent were analyzed in two separate 2 × 2 ANOVAs with group (AD vs. NC) as a between-subjects variable and picture type (picture vs. word) as a within-subject variable.

More priming was evidenced when pictures were studied as pictures (M = 109 ms, SD = 56 ms) than as words (M = 69 ms, SD = 74 ms), $F(1, 30) = 19.31$, MSE = 25,620.00, $p < .0001$ (see Figure 2). The main effect of group was not significant, $F(1, 30) < 2.0$, $p = .18$. More important, the interaction between group and picture type was not significant, $F(1, 30) < 3.5$, $p = .09$, suggesting that the pattern of picture-to-picture and word-to-picture priming in AD patients was not different from that of NC participants. The ANOVA on priming effects in percent paralleled the latency results (see Figure 2). Picture-to-picture priming (M = 11%, SD = 5%) was greater than word-to-picture priming (M = 7%, SD = 7%), $F(1, 30) = 21.44$, MSE = 0.03, $p < .0001$. The main effect of group was not significant, $F(1, 30) < 1.0$, and there was no interaction between group and picture type, $F(1, 30) < 3.6$, $p = .07$.

AD patients made more naming errors than NC participants, $F(1, 30) = 17.84$, $MSE = 0.10$, $p < .001$ (see Table 5). Neither main effect of picture type nor an interaction between group and picture type was significant, Fs < 1.0.

Word-Stem Completion

Items were discounted if correct responses were not provided at study (test phase of the picture-naming task). For valid responses, word completions were considered correct if they matched exactly or if they were plurals of target words. For each participant, the percentages of stems accurately completed to target words were calculated for old and new items. The percentages were analyzed in a 2 × 2 ANOVA with group (AD vs. NC) as a between-subjects variable and picture type (old vs. new) as a within-subject variable.

There was no difference between AD and NC groups in the percentage of word-stems completed as evidenced by a nonsignificant main effect of group, $F(1, 30) < 0.5$ (see Table 6). Priming was indicated by a greater percentage of old (M = 27%, SD = 10%) than new (M = 18%, SD = 8%) stems completed to target words, $F(1, 30) = 21.78$, MSE = 13.2, $p < .0001$. Moreover, there was no interaction between group and picture type, $F(1, 30) < 1.0$, revealing that priming effects for AD and NC groups were similar. Priming scores were significant in both AD, $t(15) = 2.90$, $p < .01$, and NC, $t(15) = 3.66$, $p < .001$, participants.

Recognition

Corrected (hits minus false alarms) recognition percentages were computed for each participant and were analyzed in a 2 × 2 mixed design with group (AD vs. NC) as a between-subjects variable and study format (picture vs. word) as a within-subject variable. AD patients were significantly less accurate in comparison to NC participants in recognizing previously seen pictures, $F(1, 30) = 57.24$, $MSE = 1.04$, $p < .0001$ (see Table 4). Pictures that were studied in picture format were better recognized than when they were studied in word format, $F(1, 30) = 199.68$, $MSE = 5.27$, $p < .0001$. There was no interaction between study format and group, $F(1, 3) < 3.5$, $p = .09$, indicating that both NC and AD participants recognized pictures previously studied as pictures better than pictures previously studied as words.

Discussion

Three main findings emerged from this experiment. First, the AD patients demonstrated normal word-to-picture prim-

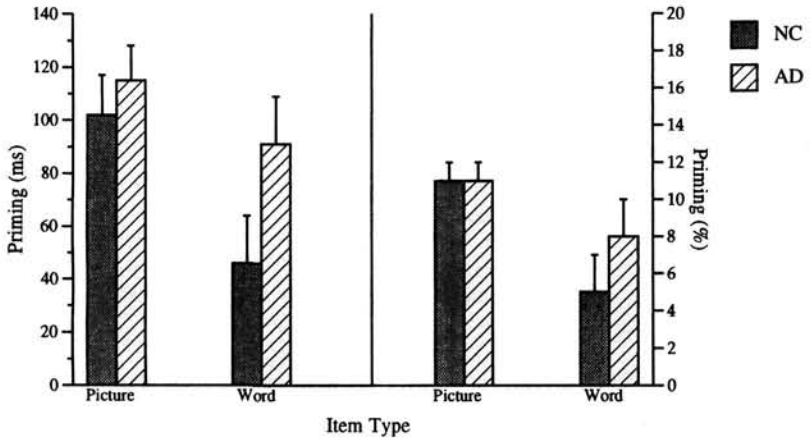

Figure 2. Magnitude of priming in milliseconds and percentage for picture (pictures seen as pictures at study) and word (pictures of words seen at study) item types for Alzheimer's disease (AD) and normal control (NC) participants in Experiment 3.

Table 6
Percentage of Stems Completed for Old and New Items and Priming Scores for Alzheimer's Disease (AD) and Normal Control (NC) Participants

Group	New item	Old item	Priming (%)
AD	18	25	7
NC	18	29	11

ing measured in either absolute or percentage terms despite their impairment in recognizing previously studied pictures and words. Second, AD patients showed normal word-stem completion priming. Third, AD patients showed normal picture-to-picture priming, consistent with a prior finding (Gabrieli et al., 1997).

Although AD priming appeared essentially normal, there was one trend that suggested a difference in the priming effects between AD and NC participants. The interaction effect of group and picture type (picture vs. word) was nearly significant when priming was analyzed both in absolute ($p = .09$) and in percent ($p = .07$) terms. The advantage of picture-to-picture priming over word-to-picture priming was smaller in AD (24 ms or 3%) than in NC

representations that support picture priming in early-stage AD patients are not specific to surface features of an object. Rather, as in the normal group, picture priming appears to depend on changes in abstract representations of the structural description of objects. Despite severe impairment in explicit memory, the perceptual analysis underlying picture priming appears to operate normally in AD patients.

Abstract memory representations of picture priming may be supported by what Schacter and Tulving (Schacter, 1990; Tulving & Schacter, 1990) proposed to be a structural description system that mediates visuoperceptual processing of the form and structure of objects. Although the neuroanatomical bases of the structural description system have not yet been fully elucidated, findings from a positron emission tomography (PET) study strongly suggest that the neural correlates to perceptually abstract memory representations are the occipital and posterior temporal regions (Blaxton et al., 1997). Regional cerebral blood flow was measured while normal participants performed a picture-to-picture and word-to-picture priming task. The perceptual component of picture priming, represented by the reduction in word-to-picture relative to picture-to-picture priming, activated bilateral posterior regions of the brain that included bilateral

imagining the names, word-stem completion priming was most likely supported by lexical processes and not at all or minimally supported by perceptual processes.

Normal priming occurred despite the fact that AD patients displayed a deficit in picture naming. In all three experiments, AD patients made significantly more naming errors than NC participants, and this deficit in naming interacted with perceptual difficulty in Experiment 1 and lexical retrieval in Experiment 3. In Experiment 1, AD patients made disproportionately more naming errors as pictures were rotated further from the upright position. This result is consistent with a prior study that showed an inverse relationship between naming accuracy and perceptual difficulty (Kirshner, Webb, & Kelly, 1984). The naming deficit observed in AD is not considered to be a result of a perceptual impairment but rather is thought to stem from loss of semantic information about objects, from impaired lexical access of the names for objects, or from both of these causes (for a review, see Nebes, 1989). Following from this, the interaction between naming error rates and orientation in Experiment 1 reflects the difficulty in accessing names of pictures, and in some instances the failure to do so, when pictures are presented in noncanonical orientations.

In Experiment 3, AD patients exhibited greater word-to-picture priming than NC participants. As discussed earlier, the hyperpriming may have resulted from AD patients' receiving the picture names (words) at the study phase, which subsequently facilitated retrieval for the names of pictures that otherwise would have been very difficult or impossible for them to retrieve from picture stimuli. In fact, when naming was not part of a task that entailed lexical retrieval of a word as in word-stem completion, AD patients exhibited normal priming and retrieval of words. Baseline word-stem completion performance was identical in AD and NC groups. It seems that lexical processes were normal in these AD patients, but the processes only appeared abnormal when they interacted with AD patients' naming deficits.

Because pictures on which AD patients made naming errors were eliminated from the analyses, our findings on priming were based only on pictures with names that were accessible. It is difficult to make strong claims about the normalcy of priming when such priming occurs in the context of a naming deficit. This limitation of our findings is of particular concern regarding Experiment 1, where AD patients made many more errors in naming as picture orientations departed from the upright position. The AD error rates in Experiments 2 and 3 were relatively modest (about 10%), and therefore the preservation of priming is more certain in these studies.

Overall, our findings demonstrate that AD patients can display normal priming across a variety of perceptual alterations in stimuli including size, orientation, and symbolic representation (word or picture). These findings provide evidence that, similar to the normal population, perceptual memory representation in early-stage AD patients is abstract rather than specific. Hence, the perceptual analysis that AD patients perform in acquiring a perceptual memory of an object appears to be similar to the analysis in which the normal population engages.

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Received February 24, 1997
Revision received November 17, 1997
Accepted November 18, 1997 ■

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