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Intact and Long-Lasting Repetition Priming in Amnesia

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In 2 experiments, we evaluated the ability of amnesic patients to exhibit long-lasting perceptual priming after a single exposure to pictures. Ss named pictures as quickly as possible on a single occasion, and later named the same pictures mixed with new pictures. In Experiment 1, amnesic patients exhibited fully intact priming effects lasting at least 7 days. In Experiment 2, the priming effect for both groups was shown to depend on both highly specific visual information and on less visual, more conceptual information. In contrast, recognition memory was severely impaired in the patients, as assessed by both accuracy and response time. The results provide the first report of a long-lasting priming effect in amnesic patients, based on a single encounter, which occurs as strongly in the patients as in normal Ss. Together with other recent findings, the results suggest that long-lasting priming and recognition memory depend on separate brain systems.

It is well established that exposure to stimuli can facilitate processing of the same stimuli when they are encountered again later. This phenomenon, termed *priming*, is nonconscious and occurs independently of the ability to recall or recognize the items that have been presented (Shimamura, 1986; Tulving & Schacter, 1990). One compelling reason for treating priming as a distinct form of memory is that priming can be fully intact in amnesic patients, despite the fact that amnesic patients are severely impaired on conventional tests of learning and memory that assess declarative memory (i.e., the ability to access conscious recollections of recent encounters; Hintzman, 1990; Schacter, 1987; Squire, 1987; Weiskrantz, 1987).

The study of amnesic patients provides a favorable source of information about priming effects. Although the impairment in declarative memory is seldom if ever absolute, it is readily detected provided that floor and ceiling effects are not operating. Accordingly, whenever performance is supported significantly by declarative memory, amnesic patients should be impaired to some extent. A finding of fully intact performance in amnesia therefore provides strong evidence that the phenomenon under study is supported by nondeclarative (implicit) memory. In the present experiments, we studied amnesic patients to illuminate reports that priming-like effects in normal subjects can sometimes be extraordinarily long-lasting.

In several early studies involving both normal subjects and amnesic patients, priming effects disappeared within 2 hr after one or two exposures to study words (Diamond & Rozin, 1984; Graf & Mandler, 1984; Graf, Squire, & Mandler, 1984; Shimamura & Squire, 1984; Squire, Shimamura, & Graf, 1985). Yet, in normal subjects, priming effects have also been reported to persist 24 hr or longer after only one exposure to stimuli. These effects have been demonstrated in a number of paradigms: perceptual identification tests involving words (Jacoby, 1983; Jacoby & Dallas, 1981; Scarborough, Cortese, & Scarborough, 1977) or pictorial stimuli (Mitchell & Brown, 1988; Mitchell, Brown, & Murphy, 1990; Musen & Treisman, 1990), a test of preference judgments (Seamon, Brody, & Kauff, 1983), tests of reading speed (Moscovitch, Winocur, & McLachlan, 1986; Tardif & Craik, 1989), and tests of word-fragment completion (Sloman, Hayman, Ohta, Law, & Tulving, 1988; Tulving, Schacter, & Stark, 1982). In each case, facilitation of performance has been demonstrated at delays of 24 hr and longer after only one exposure to stimuli.

In one notable study, facilitation of word-fragment completion (e.g., an increased probability of completing __ss__ss____ after studying *assassin*) declined across time, but was still detectable after 16 months (Sloman et al., 1988). The question arises as to whether this effect or other long-lasting effects demonstrated in normal subjects depend on the same process as shorter lasting priming effects. One concern is that the test items in the word-fragment completion test have unique solutions, and performance might therefore be enhanced by using explicit memory to retrieve study words. Indeed, in previous studies of word-fragment completion (Sloman et al., 1988; Tulving et al., 1982), subjects were informed at the time of study that a memory test would be given later, and they were told at the time of the test that some of the word fragments could be completed with words from an earlier study list. Subsequently, it was shown that the severely amnesic patient KC demonstrated long-lasting facilitation (after 12 months) of word-fragment completion (Tulving, Hayman, & Macdonald, 1991). However, the patient was exposed to the same words and word fragments on many study and test occasions before the 12-month delay (21 sessions, 6 of which included both a study and a test phase). It is also not known whether the patient performed at normal levels.

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When the performance of a group of amnesic patients and a group of normal subjects was compared in the word-fragment completion task, the amnesic patients exhibited smaller and much shorter lasting word-completion effects than normal subjects (Squire, Shimamura, & Graf, 1987). Such a finding raises the possibility that explicit memory may contribute to performance at long study–test intervals. Nevertheless, amnesic patients have demonstrated long-lasting effects of single encounters in other tasks: in a picture-fragment completion task (after 24 hr and after 3 months in 1 patient; Warrington & Weiskrantz, 1968) and after 7 days in a sentence puzzle task (McAndrews, Glisky, & Schacter, 1987). However, the patients did not perform normally in either case, presumably because these paradigms offered opportunities for normal subjects to benefit from using explicit memory. Although it seems likely that nondeclarative (implicit) memory did contribute to performance, it is difficult to evaluate the magnitude or the duration of such a contribution when declarative memory also makes a substantial contribution to performance (see Cohen & Squire, 1980, for discussion of this issue).

One promising technique for exploring long-lasting priming effects involves measuring the response time required to name pictures of common objects (Carroll, Byrne, & Kirsner, 1985; Durso & Johnson, 1979; Mitchell & Brown, 1988). Mitchell and Brown (1988) reported that after naming a group of pictures on a single occasion, normal subjects named these pictures more quickly than new pictures as long as 6 weeks after they had been presented. In addition, facilitated naming latency for the previously presented pictures was unrelated to whether they were identified correctly on a conventional test of recognition memory. This finding provides strong evidence in normal subjects for very long-lasting effects of single encounters based on repetition priming. If this interpretation is correct, then amnesic patients should also exhibit long-lasting priming of picture naming, and the effect should be as strong in amnesic patients as in normal subjects. In two experiments, we evaluated picture-naming latencies in amnesic patients at relatively long intervals after a single presentation of each picture. In Experiment 1, we asked whether amnesic patients can exhibit normal and long-lasting priming effects. In Experiment 2, we varied the physical similarity of the pictures presented for study and test to determine what kind of representation supports long-lasting priming. We also asked whether the findings were the same for amnesic patients as for normal subjects.

Experiment 1

The design of the experiment was similar to one used by Mitchell and Brown (1988) in their studies of long-term priming in normal subjects. Subjects named pictures as quickly as possible in each of three sessions. On each of two occasions, 2 and 7 days after the first session, subjects named both new pictures and old pictures that were repeated from the first session. Priming was measured by comparing naming times for repeated pictures with naming times for new pictures. Recognition memory for the pictures presented in the first session was also tested.

Method

Subjects

Amnesic patients. We tested 11 amnesic patients (Table 1). Five of the patients, all men, had confirmed or suspected damage to the hippocampal formation. Four of these (WI, JL, LM, and PH) had participated in magnetic resonance imaging (MRI) studies that demonstrated marked reductions in the volume of the hippocampal formation bilaterally (Press, Amaral, & Squire, 1989; Squire, Amaral, & Press, 1990; and unpublished observations). Patients JL and WI became amnesic gradually during a period of about 2 years (for JL, 1985–1987; for WI, 1983–1985); their memory impairment has remained stable since that time. Patient LM became amnesic in 1984 as the result of a respiratory arrest that occurred during an epileptic seizure. Patient PH had a 6-year history of 1–2-min attacks (of

Table 1
Characteristics of Amnesic Patients

Patient	Lesion	Age	WAIS-R IQ	WMS-R Attention	WMS-R Verbal	WMS-R Visual	WMS-R General	WMS-R Delay
AB	HF	52	103	87	62	72	54	<50
NC	Dien	47	90	62	80	60	69	<50
RC	Dien	73	106	115	76	97	80	72
VF	Dien	70	103	101	78	72	72	66
MG	Dien	58	111	113	89	84	86	63
PH	HF	68	115	117	67	83	70	57
WI	HF	77	99	92	72	82	71	58
LJ	Unknown	53	98	105	83	60	69	<50
JL	HF	71	116	122	73	83	74	58
LM	HF	60	117	124	94	82	89	62
PN	Dien	62	99	81	77	73	67	53
Mean	—	62.8	105.2	101.7	77.4	77.1	72.8	58.1

Note. WAIS-R = Wechsler Adult Intelligence Scale—Revised; WMS-R = Wechsler Memory Scale—Revised; HF = hippocampal formation; Dien = diencephalon. The WAIS-R and each of the five indexes of the WMS-R yield a mean score of 100 in the normal population with a standard deviation of 15. The WMS-R does not provide scores for subjects who score below 50. Therefore, the three scores below 50 were scored as 50 for calculating group means.

possible epileptic origin) in association with gastric symptoms and transient memory impairment. In 1989, he suffered a series of small attacks that resulted in marked and persisting memory impairment. Magnetic resonance imaging indicated reduced size of the hippocampal formation bilaterally, particularly in the posterior third. Patient AB, who was unable to participate in MRI studies, became amnesic in 1976 after an anoxic episode during a cardiac arrest and was presumed to have hippocampal damage on the basis of this etiology. We also tested 5 patients with bilateral damage to midline diencephalic structures (Table 1). Four of these patients had alcoholic Korsakoff's syndrome (2 men and 2 women). They had participated in either an MRI study (Squire et al., 1990) or a quantitative computed tomography (CT) study (Shimamura, Jernigan, & Squire, 1988). These demonstrated marked reductions in the volume of the mammillary nuclei, reduced thalamic density, and frontal lobe atrophy. Patient MG (female) became amnesic in 1986 after a bilateral medial thalamic infarction that was confirmed by MRI. Finally, patient LJ became amnesic gradually between September 1988 and February 1989, without any known precipitating event. Her memory impairment has remained stable since that time. The present study was concerned with the performance of amnesic patients generally, and the patients are therefore considered as a single group.

The patients averaged 62.8 years of age when tested and had 13.3 years of education. Their average Wechsler Adult Intelligence Scale—Revised (WAIS-R) IQ was 105.2 (Table 1). Scores for other memory tests appear in Table 2. Note that the scores on the word-recall test in Table 2 are above zero because on this test of immediate recall several items can be retrieved from immediate memory, which is intact in amnesia. Immediate and delayed (12-min) recall of a short prose passage averaged 5.2 and 0 segments, respectively (21 segments total; Gilbert, Levee, & Catalano, 1968). The mean score on the Dementia Rating Scale (Mattis, 1976) was 133.0 (maximum possible: 144; range: 125–143). Most of the points lost on this test were from the memory subportion (M = 6.5 points lost). The average score on the Boston Naming Test was 54.5 (maximum possible: 60; range: 47–58). Scores for normal subjects on these same tests can be found elsewhere (Janowsky, Shimamura, Kritchevsky, & Squire, 1989; Squire et al., 1990).

Healthy control subjects. Nine healthy control subjects were tested (7 women and 2 men). They either were volunteers or employees at the Veterans Affairs Medical Center or were recruited from the University of California, San Diego retirement community. They were selected to match the amnesic patients with respect to age (M = 61.7; range: 54–67); education (M = 13.9 years; range: 10–18; range for amnesic patients: 9–19); and two WAIS-R subscale scores: Information (control subjects, M = 21.4; amnesic patients, M = 20.0) and Vocabulary (control subjects, M = 58.3; amnesic patients, M = 54.6). Immediate and delayed (12-min) recall of a short prose passage averaged 7.6 and 6.4 segments, respectively.

Materials and Design

The stimuli were 260 pictures (Snodgrass & Vanderwart, 1980), which had been digitized for presentation on the Macintosh computer (Brooks, 1985). The pictures were line drawings of common items (e.g., animals, toys, tools, and pieces of furniture). The 260 pictures were used in three separate test sessions. In the first session, 130 pictures were presented for naming. The second and third sessions were scheduled 2 and 7 days later. In each of the second and third sessions, 100 pictures were presented for naming, 50 pictures from the first session (old) and 50 new pictures; and 30 pictures were presented for a recognition memory test, 15 pictures from the first session (old) and 15 new pictures. Old and new pictures were randomly intermixed with the constraint that no more than 3 old or 3 new pictures occurred in succession. Of the 260 pictures, 200 were used exclusively to test naming latency, and 60 were used exclusively to test recognition memory. Across subjects, pictures appeared equally often as old and new items and equally often at the 2-day and 7-day delays. Items were divided into groups (four groups of 50 pictures

Table 2
Performance on Standard Memory Tests

Subject group	Diagram recall	Paired associate			% word recall	% word recognition	Fifty words	Fifty faces
Patient								
AB	4	1	1	2	33	83	32	33
NC	0	1	0	1	23	71	31	37
RC	3	0	0	3	19	85	37	30
VF	8	0	0	0	27	91	27	31
MG	0	0	0	2	33	71	30	34
PH	3	0	0	1	27	84	36	34
WI	0	0	0	0	29	85	31	30
LJ	3	0	0	0	40	93	33	29
JL	1	0	0	0	40	93	31	20
LM	6	1	1	3	47	97	30	37
PN	2	1	1	1	29	83	31	31
Mean	2.7	0.4	0.3	1.2	31.5	85.1	31.7	31.5
Control								
Mean	20.6	5.6	7.6	8.9	71.0	97.0	41.1	38.1

Note. The diagram recall score is based on delayed (12 min) reproduction of the Rey-Osterrieth figure (Osterrieth, 1944; maximum score = 36). The average score for copying the figure was 27.5, a normal score (Kritchevsky, Squire, & Zouzounis, 1988). The paired associate scores are the number of word pairs recalled on three successive trials (maximum score = 10 per trial). The word recall score is the percentage of words identified correctly across five successive study-test trials (Rey, 1964). The word recognition score is the percentage of words identified correctly by yes–no recognition test across five successive study-test trials. The score for words and faces is based on a 24-hr recognition test of 50 words or 50 faces (modified from Warrington, 1984; maximum score = 50, chance = 25. The mean scores for normal control subjects (n = 8) shown for these tests are from Squire and Shimamura (1986).

and four groups of 15 pictures) to achieve equal distribution of items from different categories (e.g., animals, tools, and so on) and equivalent name agreement, based on values reported by Snodgrass and Vanderwart (all groups averaged 0.55–0.56 in codability on a 0–2.55 scale, where 0 = high name agreement).

Procedure

At the first session, subjects were instructed that they would see pictures presented one at a time on a computer screen. Subjects named each of 130 pictures as quickly as possible using the first common name that came to mind. Trials were initiated by the experimenter (with approximately 2 s between trials). First, a message appeared on the screen for 500 ms informing subjects that the stimulus was about to appear. Then, the stimulus picture appeared and remained on the screen until subjects made a verbal response. The experimenter recorded the verbal response, and the computer recorded the time from the onset of the stimulus picture until the beginning of the verbal response. (The response times for Session 1 stimuli were lost because of a hardware failure.) A Lafayette voice-activated relay was used to monitor verbal responses. Subjects sat approximately 2 ft from the screen, but viewing distance was not controlled. Each naming session began with six practice stimuli, not from the Snodgrass and Vanderwart (1980) set, to familiarize subjects with the procedure.

The second and third sessions occurred 2 and 7 days, respectively, after the first session. Both sessions began with the presentation of 100 pictures for naming (50 from the first session and 50 new pictures), following the same procedure as in the first session. A yes–no recognition test was given immediately after the naming test. For recognition, subjects saw 15 old and 15 new pictures and decided, in each case, whether the picture had been presented in the first session. Subjects initiated each trial of the recognition test by pressing the space bar on the computer keyboard, and each picture remained on the screen until subjects made a response. Subjects were asked to press *z* and "/" keys on the computer keyboard to indicate their answers. The answer keys were labeled *yes* and *no*, and the key assigned as the *yes* key was counterbalanced across subjects.

In summary, subjects named 130 pictures in the first session (100 of which would appear later in naming tests and 30 of which would appear later in recognition tests). Two days and 7 days later, 50 old pictures were mixed with 50 new pictures for a second naming test, which was followed by a recognition test involving 15 old pictures and 15 new pictures.

Scoring

Naming times for items presented in the second and third sessions were averaged separately for new items and for old items that had been presented in the first session. Trials were eliminated from analysis when there was a technical error (2.3% for control subjects and 5.2% for amnesic patients), when subjects gave an incorrect name (i.e., an alternative not included in the Snodgrass & Vanderwart [1980] tables; 3.8% for control subjects and 6.3% for amnesic patients), or when subjects gave a name for an old item that was different from the name previously given by those subjects (6.3% for control subjects and 9.0% for amnesic patients). Trials with abnormally high response times were also excluded (i.e., response times greater than 2.5 times the mean of the remaining trials of that type; 1.3% for control subjects and 1.9% for amnesic patients). In this way, a total of 13.7% of the trials were excluded for control subjects and 22.4% of the trials were excluded for amnesic patients. As described in the next section, the results were similar when as few trials as possible were removed and when the data analysis was based on median response times. The difference in naming items for new items and old items (naming facilitation) was also calculated for each subject. Recognition scores were calculated as percentage correct (hits plus correct rejections divided by total number of trials). Discriminability scores (d') were also calculated.

Results

Naming Latencies

Figure 1 (top panels) presents naming latencies for old and new pictures named 2 and 7 days after the first session. The central finding was that subjects named old pictures (986 ms) faster than new pictures (1,110 ms), $F(1, 19) = 26.5$, $MS_e = 11{,}014$, $p < .001$ (analysis of variance [ANOVA] included two subject groups, two delays, and old–new). Amnesic patients and control subjects performed similarly, $F(1, 18) = 1.97$, and there were no interactions. The difference in naming latencies for old versus new pictures was similar at the 2-day and 7-day delays, $F(1, 18) = 1.1$.

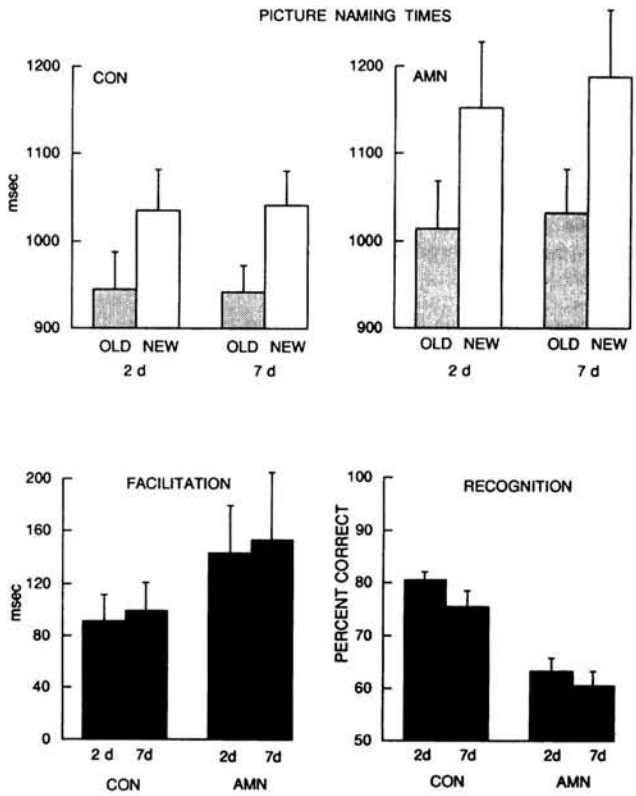

Figure 1. (upper panels) Mean response times to name pictures that had been presented 2 or 7 days previously (OLD) and pictures that had not been presented previously (NEW). (left panel) The performance of 9 healthy control subjects (CON). (right panel) The performance of 11 amnesic patients (AMN). (lower left panel) The same data presented as facilitation scores (response times to new pictures minus response times to old pictures). (lower right panel) Recognition accuracy (hits + corrected rejections/total) 2 and 7 days after presentation of the items. (Brackets show standard errors of the mean.)

We also examined the data in another way, excluding as few trials as possible. Thus, we excluded only trials that could not be measured because of a technical error and trials in which an incorrect name was given to a picture (3.2% for controls and 6.7% for amnesic patients; this more relaxed exclusion rule allowed alternative names not listed in the Snodgrass and Vanderwart [1980] tables, but excluded trials when the name given was clearly incorrect). When the data were reanalyzed in this way, the results were very similar, although the magnitude of the calculated priming effect was somewhat smaller as would be expected by including trials in which pictures were named inconsistently at study and test, sometimes with idiosyncratic names. Subjects named old pictures (966 ms) faster than new pictures (1,040 ms), $F(1, 18) = 11.6$, $MS_e = 9{,}417$, $p < .01$ (ANOVA included two subject groups, two delays, and old–new; these data were based on the mean of each subject's median response time). Amnesic patients and control subjects performed similarly, $F(1, 18) = 1.5$, and there were no interactions. The magnitude of the priming effect was similar at the 2-day and 7-day delays ($F = 1.2$).

Facilitation Scores

Facilitation scores represent the difference between response times for old and new pictures and provide a direct measure of repetition priming (Figure 1, lower left). As expected from the naming latency analysis, there was neither an effect of subject group (controls = 95.1 ms facilitation, amnesics = 147.7 ms), $F(1, 18) = 1.2$, nor any interactions with subject group (ANOVA included two subject groups and two delays). All facilitation scores were well above zero by one-sample t tests ($ps < .02$). Eight of the 9 control subjects and all 11 of the amnesic patients showed facilitation at the 2-day delay. All 9 of the control subjects and 9 of the 11 amnesic patients showed facilitation at the 7-day delay.

We also calculated the facilitation scores as means of each subject's median response time so that the results could be compared with those in other studies that presented the data in this way. In this analysis, the high response times were not excluded. The results were control subjects: 2 days, 56 ms; 7 days, 94 ms; and amnesic patients: 2 days, 120 ms; 7 days, 115 ms.

Recognition

In contrast to the finding for naming times, the two subject groups performed differently in the recognition memory test, $F(1, 18) = 40.5$, $MS_e = 67.7$, $p < .001$. The control subjects averaged 78.2% correct, whereas the amnesic patients averaged 61.5% correct. The effect of delay did not reach significance, $F(1, 18) = 2.1$. All recognition scores were significantly above chance (50%) by one-sample t tests ($ps < .005$).

The results were similar when discriminability scores (d') were calculated (at the 2-day delay, $d' = 1.9$ and 0.86 for controls and amnesics, respectively), $t(18) = 4.4$, $p < .01$ (at the 7-day delay, the corresponding values were $d' = 1.5$ and 0.65), $t(18) = 3.1$, $p < .01$.

Discussion

Amnesic patients exhibited normal repetition priming effects lasting at least 7 days after a single encounter with a set of pictures. Long-lasting repetition priming effects have been reported previously in normal subjects after a single exposure to words, pictures, or novel line patterns (e.g., Mitchell & Brown, 1988; Musen & Treisman, 1990; Sloman et al., 1988; Tulving et al., 1982). The present experiment appears to provide the first documentation of a long-lasting effect in amnesic patients from a single prior encounter, which occurs as strongly in the patients as in normal subjects. The equivalent performance of control subjects and amnesic patients in the naming task provides strong evidence that long-lasting repetition priming can occur without the support of declarative memory.

Although the amnesic patients responded numerically more slowly in their naming than the control subjects (Figure 1), this difference was not significant. Moreover, this apparent difference in baseline naming times was due to the performance of 3 of the 11 amnesic patients who responded particularly slowly. The performance of the remaining 8 patients was quite comparable to that of the control subjects. Thus the average response times for these 8 patients, for the old and new stimuli at the 2-day test, were 932 ms and 1,033 ms, respectively (controls = 944 ms and 1,035 ms). The average response times for these 8 patients for the old and new stimuli at the 7-day test were 945 ms and 1,079 ms, respectively (controls = 941 ms and 1,040 ms). These 8 amnesic patients averaged 60.2% correct on the recognition test.

Normal picture-naming priming occurred in the amnesic patients despite the fact that the patients were impaired in recognizing the pictures that had been presented previously. Thus, the normal subjects recognized the pictures that they had encountered much better than the amnesic patients, but they showed no greater repetition priming than the patients. In amnesic patients, there is independent evidence that damage has occurred to a system essential for certain kinds of learning and memory. Accordingly, the dissociation between long-lasting repetition priming and recognition memory, demonstrated in amnesic patients in the present study, provides particularly strong evidence for the existence of separate brain systems underlying these two phenomena.

Experiment 2

Having demonstrated that priming of picture naming is normal and long-lasting in amnesic patients, we next explored the nature of the memory representation supporting the priming effect. Is long-lasting repetition priming based on maintaining a representation of the exact physical stimulus or is it based on a representation that is more abstract? Are the findings for amnesic patients the same as for normal subjects?

Previous studies of perceptual priming across short delays have demonstrated the importance of presenting the same physical stimulus at both study and test. For example, priming can be reduced by changes in modality or in the exact appearance of stimuli (Graf & Ryan, 1990; Graf, Shimamura, & Squire, 1985; Jacoby & Hayman, 1987; Jolicoeur, 1985; Masson, 1986; Roediger & Blaxton, 1987). However, varia-

tion in the exact size of object pictures or their location in the visual field from one presentation to the next need not affect priming (Biederman & Cooper, in press-a, in press-b; Cooper, Schacter, Ballesteros, & Moore, 1992). Some priming also remains even when rather extreme changes are made in stimuli between presentations. For instance, priming was reduced but still present when either different views or different examples of study objects were used as test stimuli (Bartram, 1976; Biederman & Cooper, 1991; Warren & Morton, 1982). Moreover, priming can also occur when the physical stimulus is completely different for the two exposures, for instance, when the stimulus is first a word and later a picture or vice versa (Durso & Johnson, 1979; Hirshman, Snodgrass, Mindes, & Feenan, 1990; Kirsner, Milech, & Stumpfel, 1986; Scarborough, Gerard, & Cortese, 1979; Weldon & Roediger, 1987).

These findings suggest that priming can be supported not only by highly specific information, but also by more abstract information that does not incorporate details about the physical appearance of objects. Yet, all these conclusions are based on studies of repetition priming across intervals of only a few minutes between study and test sessions. No information is available about priming at longer delays. To what extent does detailed physical information remain important in long-term priming? Is the priming that can be measured across days supported by both detailed physical information and more abstract information as is the case for priming effects that are measured after a few minutes?

Biederman and Cooper (1991) demonstrated both visual and nonvisual priming across a delay of approximately 7 min. In a picture-naming task similar to the one in Experiment 1 of the present study, the most priming occurred when items in Session 2 were either degraded drawings of pictures that were identical to the drawings presented in Session 1 or degraded drawings that preserved object shape primitives (*geons*, see Biederman, 1987) of the pictures presented in Session 1 (visual priming). A smaller but substantial amount of priming was found when the items in Session 2 were different examples of pictures from Session 1 (e.g., an upright and a grand piano; nonvisual priming). Thus, priming occurred when concrete, specific information about the pictures was repeated as well as when the link between the pictures in the two sessions was less visual and more conceptual.

The purpose of Experiment 2 was to determine the relative importance for long-lasting priming of highly specific, visual information and less visual, more conceptual information. We presented pictures in one session and then in a second session, 2 days later, we tested priming in each of four different conditions: (a) no change in the pictures between Sessions 1 and 2, (b) the pictures changed in size, (c) the pictures changed in shading, and (d) the pictures changed from one example to another example (token) of the same item (e.g., two kinds of dogs). Finally, the time to name these pictures (regardless of how they were changed) was compared with the time needed to name completely new pictures. Recognition memory for the pictures presented in the first session was also assessed. To obtain comparable measures for both priming and recognition, we calculated the time required for each recognition response, together with the accuracy of each response.

Method

Subjects

Amnesic patients. The same patients were tested as in Experiment 1, except that LM was not available for testing. The patients saw the same stimuli that they had seen in Experiment 1 or variations of these stimuli (see *Materials and Design* section). The amnesic patients participated in Experiment 2 an average of 32 weeks (range: 25–41 weeks) after participating in Experiment 1. This interval was apparently long enough for the priming effect observed in Experiment 1 to subside. Specifically, the average naming latency for the 40 new items in Experiment 2, which had also been presented in an identical way to all patients in Experiment 1 (1,152 ms), was very similar to the naming latency for all the new items in Experiment 1 (1,170 ms).

Healthy control subjects. Twenty control subjects (12 women and 8 men) were selected in the same way as in Experiment 1. They matched the 10 amnesic patients with respect to age (control subjects, $M = 60.8$ years, range: 49–73; patients, $M = 63.7$); education (control subjects, $M = 14.3$ years, range: 10–18; patients, $M = 13.1$); and two WAIS–R subscale scores, Information (control subjects, $M = 22.0$; patients, $M = 20.5$) and Vocabulary (control subjects, $M = 56.5$; patients, $M = 54.6$).

Materials and Design

Experiment 2 consisted of two sessions. In the first session, 130 pictures were presented for naming. Of these, 100 provided materials for a naming test in Session 2 (to measure priming), and 30 provided materials for a test of recognition memory in Session 2. In the second session, 2 days later, a total of 200 pictures were presented for naming, and a total of 60 pictures were presented for a yes–no recognition memory test. Of the 200 pictures presented for naming in Session 2, 100 were new pictures, and 100 were *old* pictures based on pictures presented in Session 1. They were identical to pictures presented in the first session, were changed in size or shading, or were different examples (tokens) of the original pictures (e.g., a picture of a beagle instead of a retriever, both of which would be identified as *dog*). The set of 100 *old* pictures was constructed by assigning 10 pictures to each of 10 possible conditions, whereby pictures could vary from Session 1 to Session 2 (Table 3). Thus, pictures could appear in Session 1 exactly as they appeared in the Snodgrass and Vanderwart (1980; SV) set and then appear in the same way in Session 2 (SV, SV) or they could change in size, shading, or token (SV, large; SV, shaded; SV, different token). Alternatively, pictures could appear in Session 1 as a variation of an SV picture and then appear either in the same way in Session 2 (large, large; shaded, shaded; different token, different token) or in Session 2 exactly as in the SV set (large, SV; shaded, SV; different token, SV). In this way, the 100 *old* pictures presented in Session 2 consisted of 40 pictures that were the same as in Session 1 and 60 pictures that appeared in a different size ($n = 20$), a different shading ($n = 20$), or as a different example (token; $n = 20$).

The 100 new pictures presented in Session 2 also varied in the same way as the 100 *old* pictures (i.e., 40 were original pictures from the SV set, 20 were large, 20 were shaded, and 20 were different examples [tokens] of the pictures from the SV set). The 100 *old* and 100 new pictures presented in Session 2 were mixed randomly with the constraint that no more than three items of any kind (new, unchanged, size change, shading change, or token change) occurred in succession. Across subjects, pictures appeared equally often as *old* and new items. In addition, items were divided into groups (20 groups of 10 pictures for naming tests and 2 groups of 30 pictures for recognition tests) to achieve approximately equal distribution of items

Table 3
Assignment of Pictures in Experiment 2

Session 1 pictures	Session 2 pictures	
	Old	New
	Naming latency	
10 SV	10 SV	10 SV
10 SV	10 Large	10 Large
10 SV	10 Shaded	10 Shaded
10 SV	10 Tokens	10 Tokens
10 Large	10 Large	10 Large
10 Large	10 SV	10 SV
10 Shaded	10 Shaded	10 Shaded
10 Shaded	10 SV	10 SV
10 Tokens	10 Tokens	10 Tokens
10 Tokens	10 SV	10 SV
	Recognition	
9 SV	9 SV	9 SV
7 Large	7 Large	7 Large
7 Shaded	7 Shaded	7 Shaded
7 Tokens	7 Tokens	7 Tokens

Note. SV = pictures from the Snodgrass and Vanderwart (1980) set; Large = pictures from the SV set made 50% larger; Shaded = pictures from the SV set filled with uniform gray shading; Tokens = different examples of pictures bearing the same name as pictures in the SV set (e.g., a beagle instead of a retriever, both of which would be called *dog*). For the naming latency test, pictures remained the same from Session 1 to 2; changed in size, shading, or token; or were entirely new. For the recognition test, pictures either remained the same from Session 1 to 2 or were entirely new.

from different categories and equal name agreement (*M* codability = .51 to .64).

The 60 pictures used for the recognition test consisted of 30 new items (9 were pictures from the SV set, 7 were large, 7 were shaded, and 7 were different tokens) and 30 *old* items, presented exactly as they had appeared in the first session (9 were pictures from the SV set, 7 were large, 7 were shaded, and 7 were different tokens that had been presented in the first session). All 60 pictures were intermixed with the constraint that no more than 3 items of any one kind occurred in succession.

The *large* items were made 150% original size using a Macintosh drawing program. A random sample of 12 of the items from the SV set averaged 4.3° of visual angle wide and 3.5° high (at a viewing distance of 24 in.). When made larger, these same items averaged 6.2° wide and 5.3° high. Items that changed in shading were filled with a uniform light gray using the same program. The different tokens were obtained from commercial clip-art sets for the Macintosh.

Procedure

The procedure was virtually identical to that in Experiment 1. Thus, subjects named pictures of items displayed on a computer screen as quickly as they could. At the beginning of the first session, subjects were told that they would see pictures of objects displayed on a computer screen and that some of the pictures would be larger than others and that some would be shaded. Examples of these variations were pointed out during five practice trials. Subjects were asked to attend to the detailed appearance of each picture, but were told that their primary task was to name the pictures as quickly as possible. In Session 1, subjects named 130 pictures. In Session 2, subjects named 200 pictures (100 that had been presented 2 days previously intermixed with 100 new pictures). Sixty of the *old* pictures had changed in size, shading, or token, but subjects were not told of these changes before testing.

After the naming test in Session 2, a recognition memory test was given. The recognition test involved 30 items that had been named 2 days previously, which did not change in any way, intermixed with 30 new items. The procedure was identical to the recognition test in Experiment 1, except that subjects were also asked to respond as quickly as possible, and the computer recorded the response times.

Scoring

Response times for naming pictures in both Session 1 and Session 2 were recorded and scored. For control subjects, an average of 16.3% of the trials from Session 1 were eliminated before data analysis (6.3% technical errors, 8.6% incorrect names, and 1.4% unusually long response times). For amnesic patients, an average of 21.7% of the trials were eliminated (6.9% technical errors, 13.6% incorrect names, and 1.2% unusually long response times). In Session 2, an average of 15.4% of trials were eliminated for control subjects (2.7% technical errors, 5.2% incorrect names, 6.3% different names used at Sessions 1 and 2, and 1.2% unusually long response times). For amnesic patients, an average of 23.4% of trials were eliminated (5% technical errors, 7.6% incorrect names, 10.3% different names used at Sessions 1 and 2, and 0.5% unusually long response times).

Naming times for pictures presented in Session 2 were computed separately, according to whether the pictures were new, unchanged from Session 1, changed in size, changed in shading, or changed in token. The trials that were eliminated in Session 2 were evenly distributed across these five conditions (for the amnesic patients, range: 18–30%; for the control subjects, range: 12–21%). Finally, as in Experiment 1, the results were not changed when trials with high response times were included and the data were calculated on the basis of the mean of each subject's median response time.

The recognition responses were scored as in Experiment 1. In addition to recognition accuracy, response times were recorded by the computer. The response time was the interval from the presentation of a stimulus on the screen until a response key was pressed.

Results

Naming Times

Figure 2 (top panels) shows mean naming latencies for pictures presented in Session 1 and in the five conditions of Session 2. The data for the first session were first analyzed with an ANOVA involving the two groups and the four kinds of stimuli: normal, large, shaded, and token. Control subjects and amnesic patients performed similarly (1,050 ms and 1,134 ms, respectively), $F(1, 28) = 2.2$, and there was no interaction of subject group and stimulus type ($F < 1$). In addition, the different kinds of stimuli (normal, large, shaded, and tokens) produced nearly equivalent baseline naming times (normal = 1,079 ms; big = 1,066 ms; shaded = 1,067 ms; and tokens = 1,100 ms), $F(3, 84) = 1.1$.

Next, naming times for pictures presented in Session 2 were submitted to an overall ANOVA that included subject group and the five types of stimuli (no change, size change, shade change, token change, and new). The two subject groups performed similarly ($F < 1$), and there was no interaction of subject group and stimulus type ($F < 1$). The effect of stimulus type was significant, $F(4, 112) = 12.0$, $MS_e = 5{,}656$, $p < .001$.

The amnesic patients did respond a little more slowly than the control subjects, but this numerical (nonsignificant) dif-

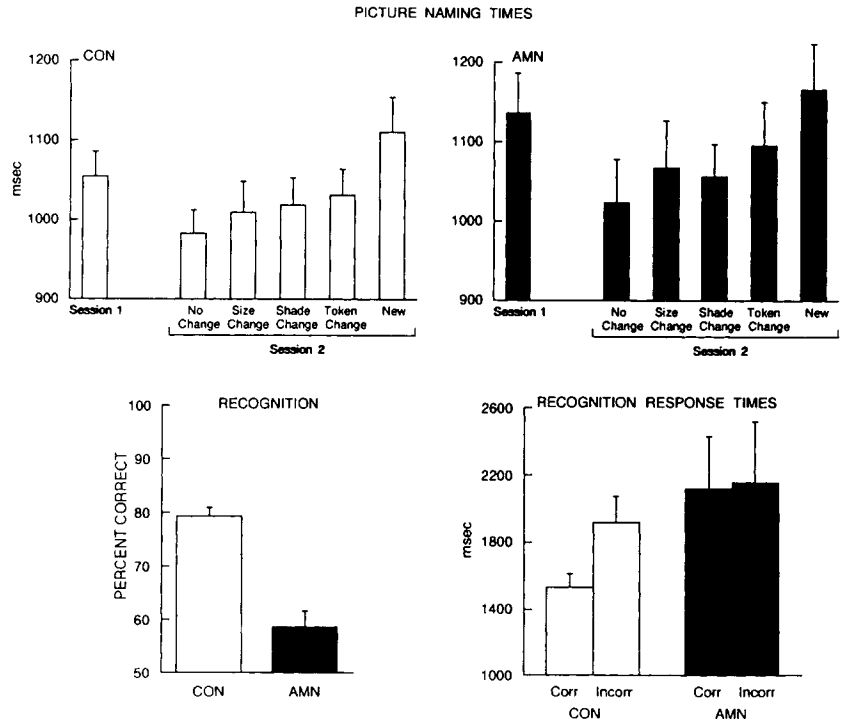

Figure 2. (upper panels) Mean response times (in milliseconds) to name pictures in Session 1 (the first time pictures were seen) and in Session 2 (2 days later). Half of the pictures presented in Session 2 were related to pictures named in Session 1. They were identical to those seen in Session 1 (no change), differed in size or shading, or were a different stimulus picture that elicited the same name as the picture used in Session 1 (e.g., a beagle instead of a retriever [token change]). The other half of the pictures presented in Session 2 were new. (left panel) The performance of 20 healthy control subjects (CON). (right panel) The performance of 10 amnesic patients (AMN). (lower left panel) Recognition memory performance (hits + correct rejections/total) for pictures presented 2 days previously. (lower right panel) Mean response times to make recognition decisions. (Corr = response times when the response was correct [hits and correct rejections]; Incorr = response times when the response was incorrect [misses and false alarms]. Brackets show standard errors of the mean.)

ference was due largely to the performance of 2 of the patients. (One of the 3 patients who responded slowly in Experiment 1 [LM] did not participate in Experiment 2.) The response times of the remaining 8 amnesic patients were very similar to the response times of the control subjects (amnesic patients: Session 1 = 1,090 ms, no change = 968 ms, size change = 990 ms, shade change = 1,019 ms, token change = 1,054 ms, new = 1,119 ms; controls: Session 1 = 1,054 ms, no change = 983 ms, size change = 1,009 ms, shade change = 1,018 ms, token change = 1,030 ms, new = 1,111 ms). These 8 amnesic patients scored 59.6% correct on the recognition test.

The naming times for pictures in each of the five conditions of Session 2 (unchanged, size change, shade change, token change, and new) were next considered in more detail using ANOVAs with planned contrasts. Because there was no overall group difference, all subjects were considered together in these analyses. Seven different contrasts were performed, and the significance level was accordingly set at $p < .007$ (Bonferroni correction = .05/7). First, each group of *old* pictures, *which were derived from* pictures presented in Session 1 (no change, size change, shade change, or token change) were named more quickly than new pictures ($ps < .002$). This result shows that priming occurred for pictures that appeared unchanged in Session 2 as well as for pictures that were related either physically (no change, size change, or shade change) or conceptually (token change) to pictures presented previously. Next, to determine how changing the pictures from Session 1 to Session 2 affected priming, naming times for pictures that were identical in Session 1 and Session 2 (no change) were compared with naming times for the pictures that changed (size change, shade change, and token change). The pictures that did not change were named more quickly than pictures that changed in token (996 ms vs. 1,051 ms), $F(1, 29) = 17.0$, $MS_e = 2{,}649$, $p < .001$, and marginally more quickly than pictures that changed in shading (1,031 ms), $F(1, 29) = 7.25$, $MS_e = 2{,}492$, $p = .012$. The difference between naming times for unchanged pictures (996 ms) and pictures that changed in size (1,029 ms) was not significant, $F(1, 24) = 2.9$.

The results were similar when priming was assessed by comparing Session 2 naming times with Session 1 naming times, instead of with naming times for the new pictures that were presented in Session 2 (five contrasts, significance level set at $p < .01$; Figure 2, top panels). Thus, subjects named pictures in Session 2 more quickly than in Session 1 when

the pictures in Session 2 were identical to the pictures in Session 1 (no change) as well as when the pictures were presented in a different size or shading than in Session 1 ($ps < .01$). Pictures that changed in token in Session 2 were named numerically faster than the pictures named in Session 1, but this difference was not significant (996 ms vs. 1,129 ms), $F(1, 29) = 3.2$, $MS_e = 4{,}186$, $p = .09$. Finally, pictures presented for the first time in Session 2 (new pictures) were named more slowly than the pictures named in Session 1 (1,129 ms and 1,080 ms, respectively), $F(1, 29) = 6.4$, $MS_e = 5{,}345$, $p = .017$.

Recognition

In marked contrast to the normal performance of amnesic patients as measured by picture-naming times, the patients were severely impaired on the recognition memory test. They were less accurate than normal subjects at recognizing the pictures that had been presented previously (Figure 2, lower left; 58.8% vs. 79.4%), $t(28) = 6.8$, $p < .001$. Both groups scored significantly above chance (50%) by one-sample t tests ($ps < .02$). Figure 2 (lower right panel) shows the response times for each group for items answered correctly and items answered incorrectly. A two-way ANOVA (two groups and correct–incorrect) showed that correct responses were made more quickly than incorrect responses, $F(1, 28) = 6.1$, $MS_e = 103{,}082$, $p < .05$, and that the two subject groups did not differ significantly in overall response time (1,727 ms for control subjects and 2,144 ms for amnesic patients), $F(1, 28) = 2.2$. The important finding was that control subjects responded more quickly when their response was correct than when it was incorrect (389 ms), but the amnesic patients responded only 45 ms faster when they were correct than when they were incorrect, $F(1, 28) = 3.8$, $MS_e = 103{,}082$, $p = .06$ (for the interaction of subject group and correct–incorrect). The results were similar when discriminability scores were calculated (for controls, $d' = 1.85$; for amnesics, $d' = 0.53$), $t(28) = 6.4$, $p < .01$.

Discussion

This experiment was designed to determine whether long-lasting picture-naming priming in amnesic patients and control subjects requires repetition of the same physical stimulus or whether priming is observed even when the repeated picture is different from the original one. The finding that amnesic patients performed the same as control subjects strongly suggests that the basis for long-lasting priming was the same in the two groups and provides additional evidence that none of the priming effects observed here depend on access to declarative memory.

The importance of repeating the exact physical stimulus was evaluated by comparing naming latencies for pictures that remained the same from Session 1 to Session 2 with naming latencies for pictures that varied in their physical characteristics. Pictures that remained the same between Sessions 1 and 2 were named more rapidly than pictures that changed from one example of an item to another example of the same item (token change). In addition, the pictures that remained the same were named marginally faster than pictures that changed in shading. Finally, in agreement with previous studies of picture priming in normal subjects (Biederman & Cooper, 1991), changing the size of pictures from Session 1 to Session 2 did not measurably reduce the priming effect.

The possible contribution to priming of less visual, more conceptual information (including word retrieval) was evaluated by comparing naming latencies for pictures that were different tokens in Sessions 1 and 2 with naming latencies for new pictures. In this comparison, different tokens were named more rapidly than new pictures. It should be noted, however, that even different tokens of objects are often physically similar. Accordingly, although different tokens of the same object did elicit priming, it is difficult to determine how much of the priming is due to truly nonvisual, conceptual information and how much is due to the fact that some degree of physical similarity between the stimuli was maintained.

Taken together, the results obtained here for long-lasting priming are in agreement with previous studies of picture-naming priming involving much shorter intervals, which also demonstrated both specific visual and nonvisual (conceptual) priming (Biederman & Cooper, 1991; Brown, Neblett, Jones, & Mitchell, 1991). The present results show that both these components of priming (visual and nonvisual) are long-lasting and that both occur at full strength in amnesic patients. Because of the variability in the data due to the relatively few number of amnesic patients that could be tested, it is possible that small differences between groups could have been present but not detected in this experiment. Nevertheless, the available information is consistent with the conclusion that picture-naming priming is mediated by a set of related processes, all of which are spared in amnesia.

One unexpected finding was that the new pictures in Session 2 were named significantly more slowly than the pictures presented in Session 1. Previous studies of picture priming (Carroll et al., 1985; Durso & Johnson, 1979; Mitchell & Brown, 1988) compared old pictures with new pictures in Session 2 and did not include comparisons with Session 1 naming times. Perhaps the mixing of new and old pictures in Session 2 slowed responses to the new pictures. This finding merits further study.

Although normal subjects and amnesic patients exhibited equivalent facilitation of picture-naming latencies 2 days after a single presentation of the pictures (i.e., priming), the two groups performed very differently on a recognition memory test of the pictures that had been presented. Normal subjects were able to identify correctly more of the pictures than the amnesic patients (79.4% vs. 58.8%). Importantly, recognition performance differed markedly in the two groups even when the same measure (response time) was used to assess both recognition and priming. The normal subjects were quicker to make a recognition decision for items that they classified correctly than for items that they classified incorrectly (389 ms). However, amnesic patients were generally guessing, as demonstrated by the fact that correct and incorrect recognition decisions were made at about the same speed (45 ms difference). In addition, the amnesic patients discriminated

the old from the new items more poorly than the control subjects ($d' = 0.53$ vs. $d' = 1.85$). This dissociation between picture naming and picture recognition in the amnesic patients strongly suggests that different memory systems are supporting performance in the two tasks.

General Discussion

Experiment 1 demonstrated picture-naming priming in amnesic patients that was both long-lasting and fully intact. Priming occurred in the patients despite the fact that on a test of recognition memory, they were markedly impaired at identifying the material that had been presented. This result provides strong evidence that long-lasting influences on performance can occur after a single encounter with a stimulus and without significant support from declarative memory. This finding constitutes independent and strongly confirming evidence for the earlier view, based on studies of normal subjects, that a single stimulus presentation can produce priming effects lasting 7 days or more (Mitchell & Brown, 1988; Mitchell et al., 1990; Musen & Treisman, 1990; Sloman et al., 1988; Tulving et al., 1982).

Experiment 2 showed that long-term priming (after 2 days) was based both on highly specific, visual information and on less visual, more conceptual information. Priming was greatest when the exact physical characteristics of the stimulus were maintained from study to test. However, some priming also occurred when the stimuli were changed in various ways, even when a picture changed from one example to another of the same object (token change). The results were identical for normal subjects and amnesic patients, indicating that these determinants of priming are independent of declarative memory. Finally, despite exhibiting intact priming effects, the amnesic patients were impaired on a recognition memory test, even when priming and recognition were assessed in exactly the same way (i.e., by measuring response time).

These results for long-lasting priming are in full agreement with previous studies of picture-naming priming across intervals of just a few minutes (Biederman & Cooper, 1991). Thus, representations that include detailed visual information about the originally presented physical stimuli remain important for priming after a delay of 2 days just as they are important for priming after a delay of minutes. It would be interesting to compare priming directly with declarative (explicit) memory in this regard, because it is generally supposed that even after rather short retention delays, performance on recall and recognition tests comes to depend less on detailed physical information and more on conceptual (abstract) information (cf. Anderson, 1980).

Priming must depend on brain structures and connections other than those essential for declarative memory, which are damaged in amnesia (i.e., in the medial temporal lobe and midline diencephalon). Recent evidence from positron emission tomography (PET) suggests that word-stem completion priming of visually presented words can depend on changes in cortical sensory processing systems in right extrastriate cortex (Squire et al., 1992). The locus of change was the same as in an earlier PET study involving the passive presentation of visual words (Petersen, Fox, Posner, Mintun, & Raichle, 1988). Subsequently, it was shown that this change was related to the visual features of the words, rather than to their orthographic regularity (Petersen, Fox, Snyder, & Raichle, 1990).

Related studies in normal subjects using divided-visual-field techniques also indicate that the right hemisphere is important for word-stem completion priming when stimuli maintain the same modality and typecase from study to test, as occurred in the PET study (Marsolek, Kosslyn, & Squire, 1992). These two studies together provide evidence for form-specific priming of words in the right posterior cerebral hemisphere. Similar systems may be important in nonverbal priming, as suggested in the proposal that a structural description system underlies perceptual priming of novel objects (Schacter, Cooper, & Delaney, 1990; Tulving & Schacter, 1990). It has also been suggested that a left hemisphere *word form area* (Petersen et al., 1990) is the locus for the perceptual priming of words (Schacter, 1990; Tulving & Schacter, 1990). This locus could be important when priming is based on more abstract representations of words (e.g., when priming occurs despite changes in letter case or type font; see Marsolek et al., 1992).

Considering the large number of identified visual areas, which are likely specialized for various and specific dimensions of visuospatial processing (Felleman & Van Essen, 1991; Kaas, 1989; Ungerleider & Desimone, 1986; Zeki & Shipp, 1988), it is plausible that priming of pictures could depend on any of a number of different mechanisms in either the left or the right cerebral hemisphere. For example, it should be expected that form-specific picture priming (i.e., the priming that occurs when the same picture is used at study and test, but not when different exemplars [tokens] are used) depends on changes in right posterior cortex. In addition, the priming that remains when different exemplars (tokens) of objects are used at study and test might depend on changes in left posterior cortex. These possibilities are amenable to experimental test.

In any case, priming appears to depend in part on posterior cortex, and this region must be capable of undergoing rather long-lasting change, independent of the structures damaged in amnesia. Indeed, some areas associated with priming (e.g., the locus associated with information about the visual features of words; see Squire et al., 1992) are at relatively early stages of visual information processing and must constitute a small subset of the cortical areas involved in representing a word in explicit memory. Thus, it seems likely that in terms of the flow of information in cerebral cortex, repetition priming occurs well before the interaction that takes place between cortical representations and the limbic-diencephalic regions essential for declarative memory. The anatomical data so far available about priming and recognition memory are consistent with the multiple-systems view of memory (Schacter, 1990; Squire, 1987; Squire & Zola-Morgan, 1991; Weiskrantz, 1987) and with the idea that long-lasting priming and recognition memory depend on separate brain systems.

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