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Preserved Priming of Novel Objects in Patients with Memory Disorders

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Abstract

■ Amnesic patients perform poorly on explicit memory tests that require conscious recollection of recent experiences, but frequently show preserved facilitations of performance or *priming effects* on implicit memory tasks that do not require conscious recollection. We examined implicit memory for novel visual objects on an *object decision test* in which subjects decide whether structurally possible and impossible objects could exist in three-dimensional form. Patients with organic memory disorders showed robust priming effects on this task—object decision accuracy was higher for previously studied objects than for nonstudied objects—and the magnitude of priming did not differ from matched control subjects or college students. However, patients showed impaired explicit memory for novel visual objects on a recognition test. We argue that priming is mediated by the structural description system, a subsystem of the perceptual representation system, that operates at a presemantic level and is preserved in amnesic patients. ■

Organic memory disorders can be produced by a variety of neurological conditions, including Korsakoff's syndrome, encephalitis, anoxia, ruptured aneurysms, and head injuries. Such disorders typically involve damage to hippocampus, diencephalon, or basal forebrain (cf. Butters & Stuss, 1989; Damasio, Graff-Radford, Eslinger, Damasio, & Kassell, 1985; Squire, 1987; Weiskrantz, 1985), and are characterized by an impaired ability to remember recent events and learn new information despite normal intelligence, perceptual processing, and language function (e.g., Mayes, 1988; Rozin, 1976; Squire, 1987). Because amnesic patients' memory deficits can be quite severe—interfering with their ability to remember even the most salient events of their everyday lives (e.g., Milner, Corkin, & Teuber, 1968; Schacter, 1983; Schacter, Glisky, & McGlynn, 1990)—it is tempting to conclude that such patients suffer from a global deficit that impairs all forms of memory and learning.

A major theme of recent neuropsychological research, however, is that even patients with severe memory disorders possess some preserved memory abilities. Specifically, despite their impaired ability to explicitly or consciously remember recent experiences and new information, amnesic patients often show intact *implicit memory* (Graf & Schacter, 1985; Schacter, 1987a, 1987b); that is, they show normal memory performance on tasks that do not require conscious, explicit recollection of recent experiences. Thus, for example, amnesic patients can acquire perceptual and motor skills normally (e.g., Cohen & Squire, 1980; Milner, Corkin, & Teuber, 1968), exhibit robust classical conditioning (Daum, Channon, & Canavan, 1989; Weiskrantz & Warrington, 1979), and show normal influences of prior experience on various cognitive judgments (Benzing & Squire, 1989; Johnson, Kim, & Risse, 1985).

Perhaps the most extensively investigated implicit memory phenomenon in patients with memory disorders is known as repetition or direct *priming*: facilitated identification of words or objects from reduced perceptual cues (Cofer, 1967; Tulving & Schacter, 1990). In a priming experiment, subjects are typically shown a list of words, pictures, or some similar stimulus materials, followed by an implicit memory test and an explicit memory test. On the implicit memory test, subjects are required to perform a task that does not require conscious recollection of the study list, such as *stem* or *fragment completion* (i.e., completing a word stem or fragment with the first word that comes to mind), *word identification* (i.e., identifying a word from a brief perceptual exposure), or *lexical decision* (i.e., deciding whether a letter string is a real word or a nonword). Priming is inferred when performance on previously studied items is more accurate or faster than performance on new items that were not previously studied.

On the explicit memory test, subjects are required to think back to the study list and either recall or recognize the target items. The striking finding from a large number of experiments, beginning with the classic work of Warrington and Weiskrantz, is that amnesic patients show normal priming effects (e.g., Cermak, Talbot, Chandler, & Wolbarst, 1985; Cermak, Blackford, O'Connor, & Bleich, 1988; Gabrieli, Milberg, Keane, & Corkin, 1990; Graf, Squire, & Mandler, 1984; Jacoby & Witherspoon, 1982; Moscovitch, 1982; Schacter, 1985; Schacter & Graf, 1986b; Shimamura & Squire, 1984; Tulving, Hayman, & Macdonald, 1991; Warrington & Weiskrantz, 1968, 1974; for review, see Schacter, 1987b; Shimamura, 1986).

Demonstrations of preserved priming in patients with impairments of explicit memory have important implications for theories of memory and amnesia, because they suggest that priming is mediated by a brain system that is distinct from, and can function independently of, the memory system that is necessary for explicit recollection of recent events. There is widespread agreement that amnesic patients suffer from impairment to an *episodic* (e.g., Kinsbourne & Wood, 1975; Schacter & Tulving, 1982; Tulving, 1972, 1983) or *declarative* (e.g., Cohen & Squire, 1980; Squire, 1987) memory system that normally supports explicit remembering and depends on the integrity of brain structures that are damaged in amnesia. By contrast, there is less agreement concerning the nature of the system or process that subserves priming (cf. Cermak et al., 1985; Cohen, 1984; Gabrieli et al., 1990; Graf et al., 1984; Moscovitch, Winocur, & McLachlan, 1986; Schacter, 1987b; Squire, 1987).

One approach to this latter issue is provided by a general framework for understanding dissociations between priming and explicit memory that we have put forward (Schacter, 1990; Schacter, Cooper, & Delaney, 1990; Schacter, Rapcsak, Rubens, Tharan, & Laguna, 1990; Tulving & Schacter, 1990). A central idea in this framework is that priming on implicit tests such as stem and fragment completion, word identification, or lexical decision is to a large extent a *presemantic* phenomenon. The key evidence here is that priming effects do not require semantic processing of an item at the time of study; robust priming is observed following nonsemantic study tasks, such as counting vowels and consonants in a word, that produce low levels of explicit memory (cf. Bowers & Schacter, 1990; Graf & Mandler, 1984; Graf et al., 1984; Jacoby & Dallas, 1981). However, priming does require appropriate perceptual/structural processing at both study and test: Priming effects are reduced or eliminated by changing the sensory modality of presentation between study and test (e.g., Graf, Shimamura, & Squire, 1985; Jacoby & Dallas, 1981; Schacter & Graf, 1989), little or no priming is observed between pictures and words (e.g., Weldon & Roediger, 1987), and under certain conditions, study/test changes in the exact surface form of an item can reduce the magnitude of priming (e.g., Graf & Ryan, 1990; Roediger & Blaxton, 1987; but see Carr, Brown, & Charalambous, 1989).

The foregoing observations suggest that priming effects on a variety of implicit tasks depend heavily on brain systems that operate on perceptual/structural information, but not on semantic/associative information. Independent evidence for the existence of such systems derives from a separate area of research on patients with reading deficits and object processing deficits. In the verbal domain, studies of patients who can read words aloud despite severely impaired comprehension of those words (e.g., Schwartz, Saffran, & Marin, 1980) suggest the existence of a presemantic *visual word form system*; in the object domain, studies of patients who show intact access to structural knowledge about familiar objects despite impaired access to knowledge of their functional and associative properties have pointed to the existence of a *structural description system* (e.g., Bauer & Rubens, 1985; Riddoch & Humphreys, 1987; Warrington, 1975, 1982).

We have suggested that the word form and structural description systems can be thought of as subsystems of a more general *perceptual representation system* (PRS) that plays a crucial role in priming (Schacter, 1990; Tulving & Schacter, 1990; see also Gabrieli, Milberg, Keane, & Corkin, 1990; Johnson, 1983). The general idea is that study of a word or an object creates a representation of its perceptual structure in PRS, thereby facilitating subsequent identification of the item from reduced perceptual cues; this facilitation of performance constitutes implicit memory for the item. Explicit memory for a studied word or object requires an additional episodic/declarative memory system that permits semantic elaborations about an item as well as associations between an item and its context (i.e., place/time information). By this view, the well-established finding that amnesic patients show intact priming of familiar words despite poor explicit memory can be attributed to a normally functioning visual word form subsystem. In view of evidence from neuroimaging studies that the word form system has an extrastriate occipital locus (Petersen, Fox, Posner, Mintun, & Raichle, 1989) and the fact that this cortical region is typically spared in patients with memory disorders, the priming data make neurobiological as well as psychological sense.

In the PRS framework, priming of nonverbal information is thought to depend on the structural description subsystem. Although studies of college students have provided data that are consistent with this notion (cf. Kersteen-Tucker, 1991; Kroll & Potter, 1984; Musen & Treisman, 1990; Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, Delaney, Peterson, & Tharan, 1991), there is little evidence from experiments with memory-impaired patients that directly supports the idea (for review, see Schacter, Delaney, & Merikle, 1990). Several studies have shown that exposure to line drawings of common objects facilitates amnesic patients' ability to identify fragmented pictures of the objects (Milner et al., 1968; Warrington & Weiskrantz, 1968). In these studies, however, amnesics showed less priming than did control subjects, perhaps because controls made use of explicit memory strategies not available to amnesic patients. Various other paradigms have also yielded evidence for priming of familiar objects (cf. Baddeley, 1982; Crovitz, Harvey, & McClanahan, 1981; Meudell & Mayes, 1981) and unfamiliar patterns (Cohen, Abrams, Harley, Tabor, Gordon, & Sejnowski, 1986) in amnesic patients, but it is not clear from these experiments whether priming is intact relative to controls. However, a recent study by Gabrieli et al. (1990) demonstrated intact priming of novel dot patterns in the severely amnesic patient H.M.

Although it thus seems clear that amnesic patients show some priming of nonverbal information, there is little evidence that such priming is normal, and none of the paradigms that have been used was designed with a view toward assessing the possible role of the structural description system. The purpose of the present study is to investigate priming of nonverbal information in a group of patients with organic memory disorders, using an experimental paradigm in which there are empirical grounds to argue that the observed priming effects depend on the structural description system.

The paradigm that we used has been developed and explored in experiments with college students (Schacter, Cooper, & Delaney, 1990; Schacter et al., 1991a), and involves presentation and testing of line drawings such as those depicted in Figure 1. All of the line drawings depict novel, unfamiliar objects that do not actually exist in the three-dimensional world. Half of the objects are structurally *possible*—their surfaces and edges are connected such that they *could* exist in three-dimensional form—whereas the other half are structurally *impossible* objects—they contain ambiguous lines and planes that create impossible relations that would prevent them from existing in three-dimensional form.

To assess priming or implicit memory for these objects, we developed an *object decision task* in which previously studied drawings and nonstudied drawings are briefly presented, and subjects decide whether each drawing is structurally possible or impossible; no reference is made to the prior study episode. We argued that making the possible/impossible decision requires access to information about the global, three-dimensional structure of each object. Accordingly, we reasoned that encoding of information about global object structure during a study episode should improve the accuracy of subsequent object decision performance, and that this priming effect would constitute evidence of implicit memory for novel visual objects.

Our experiments using this task have provided several lines of evidence that are consistent with these ideas. The most important findings for the present purposes are that (1) priming is observed on the object decision test following study tasks that involve encoding of global, three-dimensional structure (e.g., judging whether the object faces primarily to the left or right), but not following study tasks that involve encoding of local, two-dimensional features (e.g., judging whether the object contains more horizontal or vertical lines), (2) semantic or elaborative encoding tasks, such as generating verbal labels for the objects, yield much higher levels of explicit memory performance on a recognition test than do structural encoding tasks, but do not increase—and sometimes reduce—the magnitude of priming on the object decision test, (3) priming exhibits stochastic indepedence (Hayman & Tulving, 1989) from recognition memory, and (4) priming is consistently observed for structurally possible objects, but not for structurally impossible objects.

The fact that priming effects on the object decision test require prior structural encoding, but not semantic encoding, supports the idea that priming is based on a presemantic structural description system; the fact that priming can be dissociated from explicit recognition performance suggests that this system can operate independently of episodic/declarative memory. Within the context of these ideas, the failure to consistently observe priming for structurally impossible objects may indicate that it is difficult to compute a global structural description of an impossible object.

In view of these findings with normal subjects, the performance of patients with explicit memory deficits in the object decision paradigm should be informative. If the structural description system is spared in these patients, and can thus establish global representations of novel objects, then they should show normal priming effects, with greater priming for possible than impossible objects. If such priming is not observed, however, our ideas about the nature of the structural description system and its relation to episodic/declarative memory would have to be revised.

To address these issues, we examined implicit and explicit memory for novel objects in six patients with organic memory disorders, six matched control subjects, and six student controls. All subjects initially performed a structural encoding task (judging whether each object faces primarily to the left or to the right). They then made possible/impossible object decisions about studied and nonstudied objects, and were subsequently given an explicit recognition test for all objects.

RESULTS

Object Decision

Table 1 displays the proportions of correct object decisions made about studied and nonstudied possible and impossible objects by the three subject groups. Overall baseline performance for nonstudied objects was close to .50 for each group. However, patients with memory disorders, and matched control subjects to a lesser de-

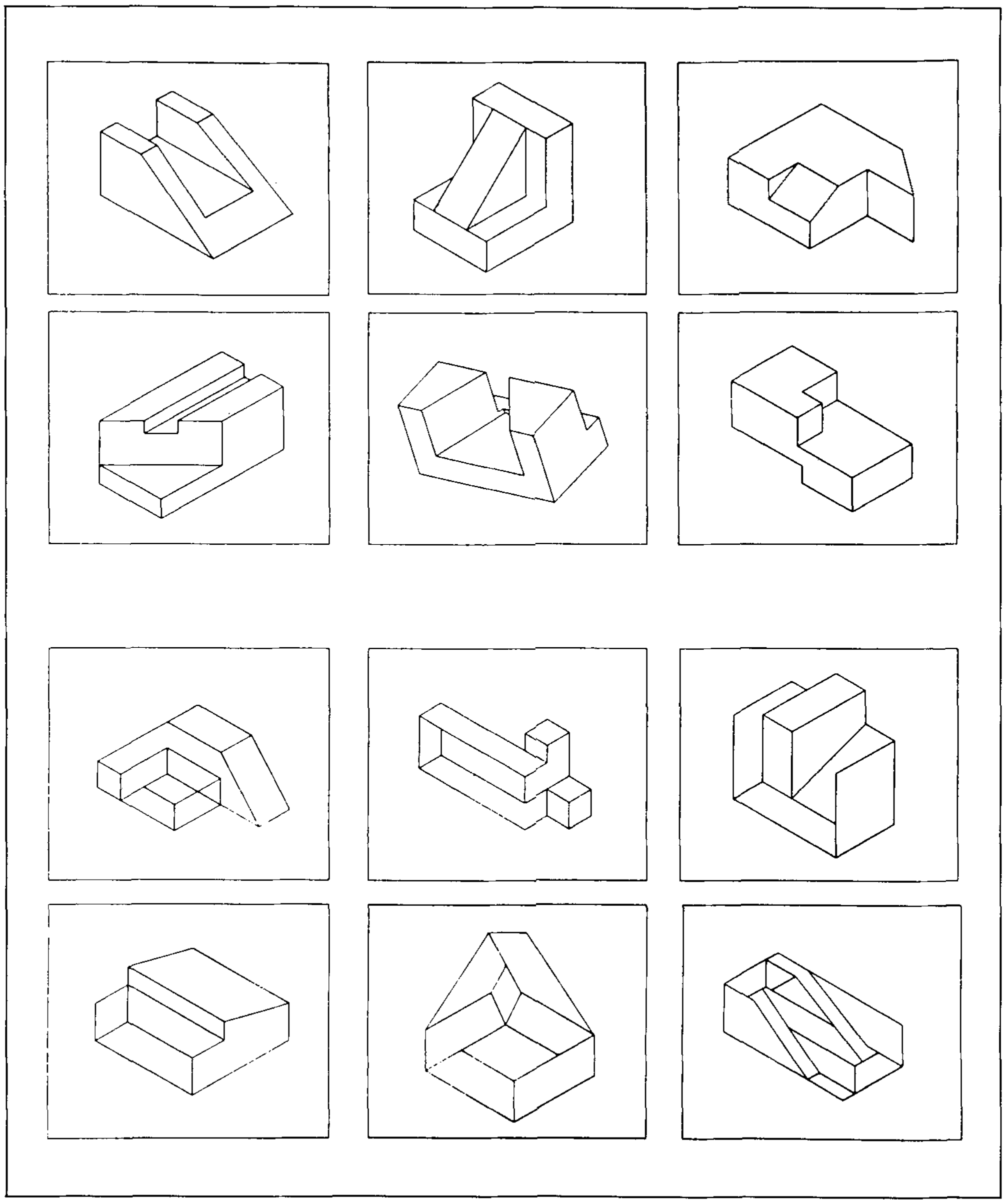

Figure 1. Representative examples of target objects that were used in the experiment. The figures in the upper two rows depict structurally possible objects that could exist in three-dimensional form; figures in the lower two rows depict structurally impossible objects that could not exist in three-dimensional form.

Table 1. Object Decision Performance for Studied and Nonstudied Objects by Three Subject Groups

Object Type	*Subject Group/Item Type*							
	Amnesic Patients		*Matched Controls*		*Student Controls*		*M*	
	S	*NS*	*S*	*NS*	*S*	*NS*	*S*	*NS*
Possible	.83	.63	.57	.48	.70	.48	.70	.53
Impossible	.38	.38	.55	.42	.48	.48	.47	.43
M	.61	.51	.56	.45	.59	.48	.59	.48

Note. Each entry indicates the proportion of correct object decisions in a particular condition. "S" refers to studied objects and "NS" refers to nonstudied objects.

Table 2. Recognition Performance for Studied and Nonstudied Objects by Three Subject Groups

Object Type	*Amnesic Patients* S	*Amnesic Patients* NS	*Matched Controls* S	*Matched Controls* NS	*Student Controls* S	*Student Controls* NS	*M* S	*M* NS
Possible	.65	.32	.70	.30	.92	.25	.76	.29
Impossible	.42	.37	.69	.38	.78	.20	.63	.32
M	.54	.35	.70	.34	.85	.23	.70	.31

Note. Each entry reflects the proportion of objects called "old" in a particular experimental condition. "S" refers to studied objects, and the corresponding proportions are *hit rates*; "NS" refers to nonstudied objects, and the corresponding proportions are *false alarm* rates.

gree, tended to use the "possible" response more often than the "impossible" response for nonstudied items, whereas college students showed a nearly equal distribution of "possible" and "impossible" responses. In view of the small number of subjects per condition ($n = 6$), these unanticipated fluctuations in the relative frequency of "possible" and "impossible" responses for nonstudied items are difficult to interpret.

The critical finding displayed in Table 1 is that the amnesic patients' performance on the object decision test was more accurate for studied objects (.61) than for nonstudied objects (.51). Moreover, the magnitude of the priming effect, as indicated by subtracting the proportion correct for nonstudied objects from the proportion correct for studied objects, was virtually identical in patients (.10), matched controls (.11), and student controls (.11). Just like normal subjects in many previous experiments, patients with memory disorders showed a large priming effect for possible objects and no priming for impossible objects. Five of the six patients showed some priming for possible objects; only the head-injured patient W.C. failed to show any evidence of priming. The student control group exhibited a nearly identical pattern of results. By contrast, the matched control group showed priming for both possible and impossible objects, with a trend toward greater priming of impossible objects. However, closer inspection of the matched controls' data revealed that the apparent priming of impossible objects is almost entirely attributable to a single subject, thus suggesting that the trend is probably an artifact of small sample size.

Analysis of variance provides statistical confirmation of the foregoing description of the results. There was a main effect of Item Type (Studied vs. Nonstudied), $F(1,15) = 6.40$, MSe = .006, $p < .03$, confirming that significant priming was observed across groups. Importantly, there was a nonsignificant main effect of Subject Group, $F(2,15) < 1$, MSe = .049, and a nonsignificant Item Type × Subject Group interaction, $F(1,15) < 1$, MSe = .006, indicating that the overall magnitude of priming did not differ across the three groups. A significant main effect of Object Type was observed, $F(1,15) = 13.14$, MSe = .006, $p < .01$, showing a higher overall proportion of possible responses than impossible responses. There was also a significant Item Type × Object Type interaction, $F(91,15) = 11.97$, MSe = .006, $p < .01$, indicating more priming of possible than impossible objects across subject groups. However, these findings were qualified by a significant Subject Group × Item Type × Object Type interaction, $F(2,15) = 5.86, p < .02$. The interaction reflects the fact that patients and student controls showed priming for possible but not impossible objects, whereas matched controls show a trend for more priming of impossible than possible objects.

Recognition memory

Data from the yes/no recognition test are displayed as hits (i.e., "yes" responses to studied objects) and false alarms (i.e., "yes" responses to nonstudied objects) for each subject group (Table 2). To correct for possible criterion differences across groups, recognition accuracy was assessed with a corrected recognition measure (hits minus false alarms). These data contrast with the object decision results, inasmuch as they show a strong effect of subject group: Recognition accuracy was lower in amnesic patients (.19) than in matched controls (.36) or in student controls (.63). Recognition was more accurate for possible than impossible objects in each subject group.

An analysis of variance on the corrected recognition scores revealed significant main effects of Subject Group, $F(2,15) = 13.11$, MSe = .044, $p < .001$, and Object Type, $F(2,15) = 11.57$, MSe = .017, $p < .005$, and a nonsignificant Subject Group × Object Type interaction, $F(2,15) = 2.29$, MSe = .017. Planned comparisons showed significantly lower levels of recognition accuracy in the patient group than in either matched controls, $t(10) = 1.85, p < .05$ or student controls, $t(10) = 5.17$, $p < .001$, and significantly lower levels of recognition accuracy in matched controls than in student controls, $t(10) = 3.26$, $p < .01$.

Relation Between Object Decision and Recognition

The foregoing results indicate that patients with memory disorders showed intact priming on the object decision test despite impaired recognition. To assess the relation between object decision and recognition performance more directly, we performed a combined ANOVA in which Type of Test was a within-subjects factor. For each subject, we entered a priming score (proportion correct for studied objects minus proportion correct for nonstudied objects) and a corrected recognition score (hits minus false alarms). The critical outcome of this combined ANOVA was a significant Subject Group × Type of Test interaction, $F(2,15) = 6.75$, $MSe = .041$, $p < .01$. The interaction is depicted graphically in Figure 2.

To examine further the relation between object decision and recognition performance, we performed contingency analyses that allow us to determine whether priming on the object decision task is dependent on, or independent of, recognition memory. In previous studies with college students, we have found that object decision priming exhibits stochastic independence from recognition performance (Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, Delaney, Peterson, & Tharan, 1991)—that is, the magnitude of the priming effect is uncorrelated with recognition performance. To assess independence, we used the Yule's Q statistic, a special case of Goodman & Kruskal's (1954) gamma correlation that applies to the analysis of data from 2 × 2 contingency tables. Q is a measure of the strength of relation between two variables that can vary from +1 (positive association) to −1 (negative association), where 0 reflects complete independence (see Hayman & Tulving, 1989, for more detailed discussion). Our contingency analysis included only possible objects, because priming of possible objects was observed in all subject groups. For each of the three groups, we constructed 2 × 2 contingency tables for studied possible objects in which each of the four cells corresponded to one of the four joint outcomes of the object decision and recognition tasks: (1) correct response on both object decision and recognition, (2) incorrect responses on both object decision and recognition, (3) correct response on object decision and incorrect response on recognition, and (4) correct response on recognition and incorrect response on object decision. The Q analysis was performed on each contingency table according to the procedure suggested by Hayman and Tulving (1989). The resulting Q values were −.099 for amnesic patients, −.119 for matched controls, and +.262 for student controls. None of the Q values differed significantly from zero (all $\chi^2 < 1$), thereby indicating that object decision priming and recognition memory were independent in each of the three subject groups. Although there was a trend for some positive association in student controls and slight negative association in patients and in matched controls, the Q value for the student controls group did not differ significantly from the Q value for either of the other groups (both $\chi^2 < 1$).

It is also perhaps worth noting that we observed independence under conditions in which the implicit memory task (object decision) preceded the explicit memory task (recognition); in our previous experiments, as well as in most other studies that have assessed stochastic independence (see Hayman & Tulving, 1989; Shi-

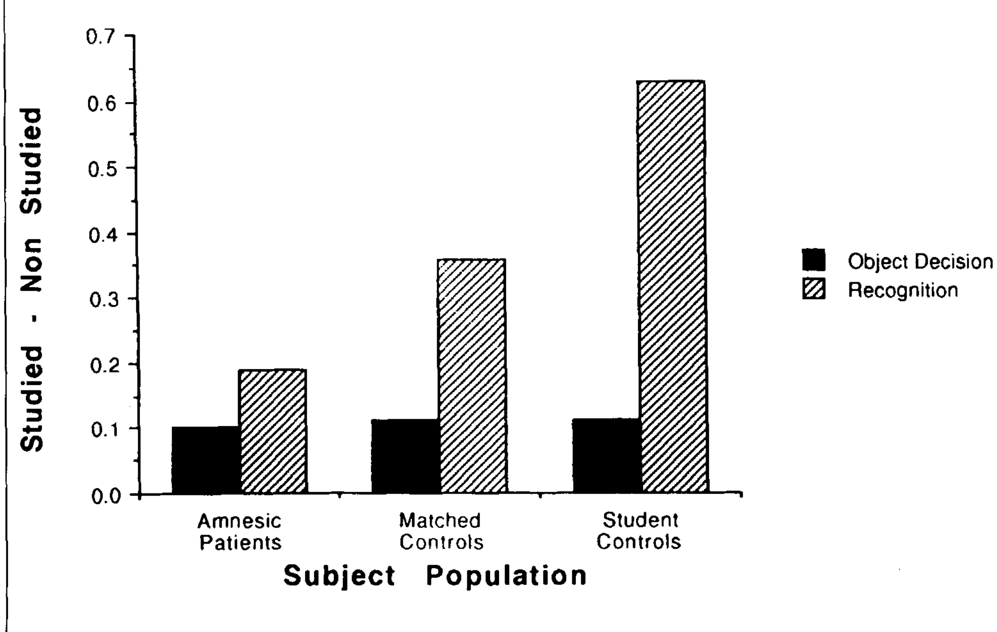

Figure 2. Object decision and recognition performance for the three subject groups. Priming scores and corrected recognition scores are depicted on the y-axis. Priming scores were computed by subtracting the proportion of correct object decisions for nonstudied items from the proportion of correct object decisions for studied items. Corrected recognition scores were computed by subtracting the proportion of "yes" responses to nonstudied items (false alarms) from the proportion of "yes" responses to studied items (hits). Priming scores remained constant across the three groups, whereas corrected recognition scores increased substantially, as indicated by a significant interaction between subject group and type of test.

Table 3. Characteristics of Individual Amnesic Patients

Patient	*Sex*	*Etiology*	*Age (years)*	*Education (years)*	*IQ*	*WMS-R*			*Recognition*	
						GM	*ATN*	*DY*	*WD*	*FC*
D.H.	F	Aneurysm	60	13	100	76	89	62	42	43
H.B.	M	Aneurysm	55	12	103	93	109	62	44	30
J.W.	M	Aneurysm	29	13	88	57	68	<50	28	43
W.C.	M	Head injury	45	15	104	86	111	58	40	40
K.K.	F	Head injury	34	14	99	72	107	67	44	39
F.K.	F	Uncertain	74	12	104	52	100	54	32	30

Note. IQ scores are full-scale IQs from the Wechsler Adult Intelligence Scale-Revised (WAIS-R). WMS-R is the Wechsler Memory Scale-Revised; scores for indices of general memory (GM), attention (ATN), and delayed recall (DR) are presented separately. The WMS-R does not provide scores below 50. In the normal population, each WMS-R index and the WAIS-R produce a mean of 100 and standard deviation of 15. Recognition memory was assessed with the Warrington Recognition Test, which is a test of immediate, two-alternative forced-choice recognition for 50 words (WD) and 50 faces (FC). Maximum number correct is 50, and chance performance is 25. Patients achieved significantly lower scores than matched controls on GM and DR from the WMS-R, and on the Warrington Recognitioin Test, but did not differ significantly from controls on age, education, or IQ (see text).

mamura, 1985), the explicit memory task preceded the implicit memory task. Dependence between priming and explicit memory has been observed in studies in which an implicit memory task (fragment completion) preceded a recognition task (Tulving, Schacter, & Stark, 1982), but this finding was likely attributable to the fact that subjects received an extra exposure to correctly completed items on the fragment completion task. In the object decision task, however, all items received the same test exposure.

DISCUSSION

The major finding of the present experiment is that structural encoding of novel visual objects produced a normal facilitation in the accuracy of object decision performance by patients with amnesic disorders. Intact priming was observed despite impaired performance on an explicit recognition test, and the priming effect showed stochastic independence from recognition memory. The independence of priming and explicit memory is also indicated by the observation that whereas explicit memory performance differed markedly across the three subject groups, the magnitude of the priming effect remained constant (Figure 2).

This pattern of results provides empirical support for the idea that implicit memory for novel visual objects, as indexed by priming on the object decision task, is mediated by the structural description system, a subsystem of PRS that is spared in amnesic patients. Explicit memory for the same objects, by contrast, appears to depend on an episodic/declarative memory system that is damaged in these patients. There is considerable evidence that this latter system can be disrupted by damage to hippocampus, diencephalon, or basal forebrain (cf. Butters & Stuss, 1989; Damasio et al., 1985; Squire, 1987; Weiskrantz, 1985). It is thus tempting to suggest that the acquisition of novel structural descriptions of unfamiliar objects does not depend on the integrity of these brain structures, but this suggestion must be interpreted cautiously because we do not have direct evidence concerning the status of hippocampal or diencephalic structures in our patients. However, three of our patients did have CT-documented damage to basal forebrain (see subjects section), and these patients showed a normal pattern of priming. An important task for future studies will be to investigate object decision priming in patients with well-documented damage to hippocampus or diencephalon.

It will also be important to determine whether normal priming of novel visual objects is observed in patients with the most severe forms of amnesia. Although our patients clearly have significant memory deficits (Table 3), as a group they performed at above-chance levels on the yes/no recognition test for novel objects (Table 2) and on forced-choice recognition tests for words and faces (Table 3). Recognition memory is partially preserved in many patients with memory disorders (e.g., Hirst et al., 1986), but does not exceed chance levels in the most severe cases of amnesia (cf. McAndrews et al., 1987; Tulving et al., 1991; Warrington & Weiskrantz, 1974). We cannot yet say whether object decision priming is preserved in severe amnesia, when patients' recognition performance is at or close to chance. It is worth noting, however, that Gabrieli et al. (1990) observed intact priming of novel patterns in the severely amnesic patient H.M. despite near chance levels of recognition performance. This finding suggests that priming of novel nonverbal information can occur in the absence of explicit memory and is consistent with the idea that the structural description system plays a major role in priming of novel visual objects.

Assuming that all or most of the priming effect is attributable to the structural description system, it is important to understand the functional properties and neuroanatomical basis of this system. Consider first studies that provide information concerning the functional properties of the structural description system. As noted in the introduction, neuropsychological investigations demonstrating dissociations between preserved structural processing and impaired semantic processing in patients with various types of object recognition deficits (Riddoch & Humphreys, 1987; Warrington, 1975, 1982; Warrington & Taylor, 1978) suggest that the structural description system operates at a presemantic level; that is, the system is not involved in processing information about an object's associative or functional properties. Our studies of object decision priming in normal subjects have provided evidence consistent with this characterization: Semantic encoding tasks, which yielded higher levels of explicit memory performance than did the left/right structural encoding task, either failed to produce a corresponding increase in priming or did not yield any priming at all (Schacter, Cooper, & Delaney, 1990). We have observed similar patterns of results with encoding tasks that require subjects to think about functions that a novel object might perform (Schacter, Cooper, & Tharan, 1991).

We have also carried out experiments that allow us to begin to characterize the nature of the structural description that is involved in object decision priming (Cooper, Schacter, Ballesteros, & Moore, 1990). In one study, we manipulated the *size* of target objects between the study phase and the object decision or recognition tests: Object size remained constant from study to test in one condition and was changed in the other condition. We found that the magnitude of the priming effect on object decision performance was entirely unaffected by the size manipulation—priming was just as large in same size and different size conditions—even though recognition memory was less accurate in the different size condition than in the same size condition. This finding suggests that the representation that supports object decision priming does not include size information—an idea consistent with prior suggestions that structural descriptions of objects code only relations among component parts (e.g., Humphreys & Quinlan, 1987). Along the same lines, we also found that priming was not reduced significantly by study/test changes in the left/right orientation of target objects: Priming remained substantial when mirror image reflections of studied objects were presented on the object decision task relative to when the same objects were presented, whereas recognition was significantly lower in the mirror image condition than in the same object condition (for similar priming results with a different paradigm, see Biederman & Cooper, 1989). As noted earlier, however, object decision priming was not observed when subjects performed study tasks that involve encoding information about the local parts of an object; priming was only observed following study tasks that focus on global object structure (Schacter, Cooper, & Delaney, 1990).

The foregoing observations indicate that the structural description that underlies object decision priming is an abstract, rather than literal, representation that preserves global structural information and remains invariant over changes in size and reflection. We assume that object decision priming would exhibit these same properties in amnesic patients, and we plan to test this assumption in future studies. If the assumption is correct, then our data suggest that amnesic patients can establish size and reflection invariant structural descriptions of novel objects that preserve information about global structure.

Whereas our experimental data allow us to develop a preliminary sketch of the properties of the system that underlie object decision priming, we have no direct evidence concerning the neuroanatomical basis of this system. Nevertheless, the functional properties that we have delineated provide suggestive clues concerning the brain stuctures that may be involved. As pointed out by Plaut and Farah (1990) in a recent review, evidence from both human and animal studies indicates that regions of inferior temporal cortex play a major role in representation of visual objects. Moreover, many of the properties of these object representations are quite compatible with the properties of object priming noted earlier: Inferior temporal regions appear to be involved in representing global aspects of object structure independently of the retinal size of the object or its left/right orientation (Plaut & Farah, 1990). Thus, object decision priming may reflect, at least in part, the establishment of a novel structural description of an object in the inferior temporal region. Consistent with this suggestion, neither our patients nor amnesic patients in general exhibit object processing deficits of the kind associated with inferior temporal damage. Indeed, magnetic resonance imaging (MRI) evidence indicates that the measured area of the temporal lobes does not differ in amnesic patients and control subjects, whereas the area of the hippocampal formation is markedly reduced in amnesics (Press, Amaral, & Squire, 1989), and temporal neocortex is reported to have been spared in patient H.M. (e.g., Gabrieli et al., 1990; Scoville et al., 1953). Accordingly, it seems plausible to suggest that inferior temporal regions could be involved in priming of novel visual objects in amnesic patients. In addition, priming of visual objects may also involve areas of extrastriate occipital cortex and parietal cortex (cf. Gabrieli et al., 1990; Schacter, 1990; Schacter, Rapscak, et al., 1990; Warrington, 1982).

Whatever the exact nature of the structural description system that supports object decision priming, our results indicate clearly that patients with explicit memory deficits can show intact priming for novel information that does not have a preexisting memory representation. Although it is widely accepted that amnesic patients show intact priming for familiar items that have preexisting memory representations (e.g., familiar words), evidence for priming of novel information is mixed. For example, evidence for priming of nonwords (e.g., *flig*) in amnesic patients was either absent or reduced in studies with Korsakoff patients (Cermak et al., 1985; Smith & Oscar-Berman, 1990). However, these patients typically have cognitive deficits that are not observed in other amnesic patients (cf. Mayes, 1988; Squire, 1987). Stronger evidence for priming of nonwords on a perceptual identification task has been observed in two non-Korsakoff patients with severe amnesia: H.M. (Gabrieli & Keane, 1988) and the encephalitic patient S.S. (Cermak, Blackford, O'Connor, & Bleich, 1988; see also Gordon, 1988 for a rather more complex pattern of results). In addition, there is evidence for intact priming of nonwords in amnesic patients when a measure of reading speed is used as an implicit memory task (Musen & Squire, 1990).

Priming of novel information has also been examined in studies that have used a paradigm developed by Graf and Schacter (1985) to examine whether amnesic patients show priming of new associations on a stem completion task after studying a list of unrelated paired associates (e.g., *window–reason*). On the one hand, several experiments have shown intact priming of new associations in patients with relatively mild memory disorders (Graf & Schacter, 1985; Mutter, Howard, Howard, & Wiggs, 1990; Schacter & Graf, 1986b) and in at least one severely amnesic patient (Cermak, Blackford, O'Connor, & Bleich, 1988). On the other hand, a number of experiments have reported reduced or absent priming of new associations in severely amnesic patients (Cermak, Bleich, & Blackford, 1988; Schacter & Graf, 1986b; Shimamura & Squire, 1989). Investigators who have assessed priming of new associations with other implicit memory paradigms have reported both positive findings (Moscovitch et al., 1986) and negative findings (Tulving et al., 1991). Finally, an experiment that assessed priming of novel information with a paradigm involving interpretation of ambiguous sentences reported evidence for some, but not normal, priming in patients with severe memory disorders (McAndrews et al., 1987).

We cannot yet specify reasons why the evidence for intact priming of novel information is mixed in the foregoing studies, which used verbal materials, yet is robust in the present experiment and in the study by Gabrieli et al. (1990), which used nonverbal materials. Although it is possible that the verbal/nonverbal nature of the target items played some role, additional differences in study tasks, type of target materials, test requirements, and patient populations make it difficult to draw firm conclusions regarding this issue. In addition, the paradigms that are used to study priming of new associations often involve some degree of semantic processing, whereas the paradigms that are used to assess priming of novel nonverbal information appear to rely almost entirely on perceptual/structural processing. Thus, for example, it has been shown that priming of new associations in the Graf and Schacter paradigm requires some degree of semantic study processing (Graf & Schacter, 1985; Schacter & Graf, 1986a), and that the ambiguous sentences paradigm used by McAndrews et al. (1987) relies heavily on semantic interpretive processes (Auble & Franks, 1979). By contrast, there is evidence that semantic processing is not required for object decision priming (Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, & Tharan, 1991) or priming of novel dot patterns (Musen, 1990).

In view of the foregoing considerations, we suggest that priming of novel verbal information is sometimes impaired in patients with memory disorders because such priming may require the acquisition of semantic/associative information and hence involves processes outside of PRS; priming of novel nonverbal information, at least as assessed by object decision and dot completion tasks, does not appear to involve processes outside of PRS. It is possible that the acquisition of novel semantic information depends on some of the same processes and structures that are involved in the acquisition of novel episodic information—processes and structures that are typically damaged in patients with memory disorders (cf. Gabrieli, Cohen, & Corkin, 1988; Schacter, 1987a; Squire, 1987; Tulving et al., 1991). These ideas are somewhat speculative and do not account for all pertinent observations, but they are generally consistent with the experimental facts and can be tested in future research.

Finally, we should note that our account, which depends crucially on the postulation of multiple memory systems, represents just one approach to the patterns of data that we have observed. A number of investigators have argued that dissociations between priming and explicit memory can be explained without postulating different memory systems (cf. Jacoby, 1983; Roediger, 1990; Moscovitch et al., 1986; Roediger & Blaxton, 1987). Although such approaches can accommodate many results that have been observed in studies with normal subjects, they have not provided compelling accounts of preserved priming effects in amnesia (e.g., Schacter, 1987b, 1990; Hayman & Tulving, 1989; Tulving et al., 1991). It is not clear just how a unitary memory system theory would explain preserved priming of novel objects in amnesic patients, but no doubt some sort of explanation could be formulated. The important point to stress is that our view provides a straightforward account of relevant findings with amnesic patients, fits well with the data concerning the characteristics of object decision priming in normal subjects (Cooper et al., 1990; Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, Delaney, Peterson, & Tharan, 1991a), and receives support from semantic/structural dissociations that have been observed in patients with object recognition deficits (Bauer & Rubens, 1985; Humphreys & Riddoch, 1987; Warrington, 1975, 1982). The availability of such converging evidence from independent lines of research suggests that theorizing in terms of multiple memory systems represents a useful approach to understanding dissociations between implicit and explicit memory.

METHOD

Subjects

Six patients, three males and three females, participated in the experiment. Three patients developed memory disorders as a result of ruptured aneurysms. Patient D.H., a 60-year-old female, and patient H.B., a 55-year-old male, each suffered ruptured aneurysms of the anterior communicating artery in 1988. CT scans revealed that D.H. had sustained damage to basal forebrain and left mesial orbitofrontal lobe, while H.B. sustained damage to basal forebrain, right mesial orbiofrontal cortex, as well as infarction at the head of the right caudate nucleus. Patient J.W., a 29-year-old male, experienced ruptured aneurysm of the anterior communicating artery in 1980; CT scan showed damage to the basal forebrain and in addition showed left mesial frontal infarction in the distribution of the anterior cerebral artery. Patient W.C., a 45-year-old male, had suffered a closed head injury in 1983 and an epileptic seizure in 1988. An MRI scan was performed on this patient in 1988 and revealed significant damage to the left frontal lobe and left temporal lobe. Patient K.K. is a 34-year-old female who received a severe closed head injury in a motor vehicle accident in 1976 and remained comatose for 10 weeks. Patient F.K. is a 74-year-old female who was referred to the Memory Disorders Clinic at the University of Arizona Health Sciences Center because her husband had observed a rather sudden and marked deterioration of memory abilities about 6 weeks earlier. The results of a thorough neuropsychological evaluation were not consistent with a diagnosis of primary degenerative dementia, but did not yield a certain diagnosis.

The patients' mean age was 50 years and they had on average 13 years of education. Their overall level of intellectual function was in the normal range, as indicated by a mean IQ of 100 on the Wechsler Adult Intelligence Scale-Revised. Mean scores on the Wechsler Memory Scale-Revised (WMS-R) revealed performance levels well below the mean of 100 observed in the normal population on indices of general memory (73), including the separate indices of visual memory (82) and verbal memory (75) that combine to form the general memory index, and delayed recall (59). Performance on the attention index (97) was within normal limits. Patients also performed poorly on the Warrington Recognition memory test, recognizing on average 38/50 previously studied words and 38/50 previously studied faces on an immediate test. Data concerning the main characteristics of individual patients are presented in Table 3.

The matched control group consisted of five females and one male. t tests indicated that these subjects did not differ significantly from patients with respect to mean age (51 years), educational level (14 years), or WAIS-R IQ (108). Control subjects showed much higher levels of performance than patients on the general memory (121), verbal memory (114), visual memory (128), and delayed recall (117) indices of the WMS-R (all $ts[10] > 5.09, p < .001$); controls also scored higher (115) than did patients on the attention index, $t = 1.94, p < .05$. In addition, control subjects scored significantly higher than patients on the Warrington Recognition Test ($t = 3.97$, $p < .01$), recognizing on average 49/50 words and 45/50 faces.

In addition to the patient group and the matched controls, six University of Arizona undergraduates (three males and three females) took part in the main experiment. Patients and controls subjects were paid $10.00 for their participation; college students participated in exchange for course credits.

Materials

The critical materials were 20 possible and 20 impossible objects that have been used and described by Schacter, Cooper, Delaney, Peterson, & Tharan (1991); representative objects are shown in Figure 1. The objects were selected by Schacter et al. on the basis of two criteria: (1) when subjects were given unlimited time to decide whether objects are possible or impossible, there was near perfect agreement about the possible/impossible nature of each object (mean percent agreement across 20 subjects was 99% for both possible and impossible objects); (2) when subjects were given brief (i.e., 100 msec) exposures to each object, object decision accuracy was low (about 55–60% correct for possible and impossible objects), thereby allowing room for priming to be observed.

The materials were divided randomly into two sets, A and B, that each contains 10 possible and 10 impossible objects. Each subject studied either Set A or Set B and was subsequently tested on both sets. The objects were presented for study and test by a Compaq 386 Deskpro computer on the screen of a 12 inch Princeton Ultrasync Monitor; they subtended a mean visual angle of 8° when viewed from 60 cm. Drawings of objects were presented in medium resolution and appeared white against a uniform dark gray background.

Design and Procedure

The main experiment consisted of four variables: Subject Group (amnesic patients, matched controls, and student controls), Item Type (studied vs. nonstudied), Object Type (possible vs. impossible), and Type of Test (object decision vs. recognition). The experiment was completely counterbalanced such that objects from Set A and Set B appeared equally often as studied and nonstudied objects for each of the three subject groups.

For each subject, the experimental session consisted of a sequence of three main phases: left/right encoding task, object decision test, and yes/no recognition test. For the left/right encoding task, each object was exposed for 5 sec on the computer monitor, preceded by a fixation point. Subjects were instructed that a series of drawings would be shown on the computer screen and that their task was to determine whether each object appeared to be facing primarily to the left or to the right. They were told that the drawings are not as simple as they might appear, so that they should use the full 5 sec to inspect each object carefully. The task began with presentation of five practice items, followed by presentation of the 10 possible and 10 impossible target items in random order. The target items were then presented again for 5 sec each and subjects made left/right judgments in the same manner. A previous experiment has shown that the number of study list repetitions does not affect the magnitude of priming on the object decision task (Schacter, Cooper, Delaney, Peterson, & Tharan, 1991, Experiment 1).

Subjects were then given the object decision test. In previous studies with college students, a 100 msec exposure rate has been used. However, pilot studies with elderly subjects indicated that baseline performance on the object decision task is lower in old subjects than in young subjects when both are tested with 100 msec exposures. Since both the patient group and the matched controls were older than the student controls in this experiment, we used different exposure rates in an attempt to equate baseline levels of object decision performance: 250 msec for patients and matched controls, and 50 msec for student controls. Presentation of each object was immediately followed by a darkened screen. The data in Table 1 indicate that we were largely successful in matching overall levels of baseline performance.

Subjects were instructed that they would be exposed to a series of drawings that would be flashed very quickly, and that they would decide whether each figure could actually exist in the real world. They were informed that some drawings represent valid, possible three-dimensional objects that could exist in the real world whereas others represent impossible figures that could not exist as three-dimensional objects in the real world, and that their task was to decide whether each figure is possible or impossible. Several examples of possible and impossible objects (none from the target set) were then shown to subjects. They were instructed that all possible objects must have volume and be solid, that every plane on the drawing represents a surface of the object, that all surfaces can face in only one direction, and that every line on the drawing necessarily represents an edge on the object. The experimenter explained the impossibilities in example objects to the subjects and answered questions as needed.

Matched controls and student controls responded with a PC mouse that they controlled with their right hand; they were told to press the left key when they thought that an object was possible and the right key when they thought that an object was impossible. Patients responded verbally in order to eliminate the possibility that they would forget which key to press. Administration of instructions took about 2 min, and subjects were reminded of task instructions thoughout test performance.

Ten practice items, five that had appeared on the study list and five that had not, were then presented at the appropriate exposure rate for each group. These drawings were followed in an uninterrupted sequence by the 20 studied and 20 nonstudied critical items, presented in a randomly determined order. Exposure of each test item was preceded by the appearance of a fixation point in the middle of the monitor. Amnesic patients told the experimenter "ready" when they were looking at the fixation point and the experimenter pressed the appropriate button to initiate the trial; matched controls and student controls initiated the trial by pressing the center button on the mouse.

Immediately following the conclusion of the object decision task, subjects were instructed for the recognition task. They were told that they would be shown a further series of drawings, some of which had been presented when they made left/right judgments and some of which had not been presented during the left/right task. Subjects were told to make a "yes" response when they remembered seeing a drawing during the left/right task and to make a "no" response when they did not remember seeing a drawing during the left/right task.

The same 10 practice items that were used on the object decision task were presented initially on the recognition test, followed by 20 studied and 20 nonstudied target figures. Drawings remained on the screen for 5 sec, and subjects were instructed to respond before the object disappeared from the screen. Patients indicated their yes/no response verbally, whereas control subjects pressed the left key to indicate a "yes" response and the right key to indicate a "no" response.

After conclusion of testing, subjects were debriefed concerning the nature of the experiment.

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