Research Article

INTACT ARTIFICIAL GRAMMAR LEARNING IN AMNESIA:
Dissociation of Classification Learning and Explicit Memory for Specific Instances

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Abstract—*The present study investigates whether the ability to classify on the basis of rules can be learned independently of memory for the specific instances used to teach the rules. Thirteen amnesic patients and 14 control subjects studied letter strings generated by an artificial grammar. Subjects were then shown new letter strings and were instructed to classify them as grammatical or nongrammatical. Amnesic patients performed as well as normal subjects. However, amnesic patients performed more poorly than control subjects on a recognition test of the exemplars that had been presented. Amnesic patients also performed more poorly than control subjects when the instructions were to base the classification on explicit comparison with the original exemplars. The results show that classification learning based on exemplars of an artificial grammar can develop normally despite impaired memory for the exemplars themselves. Whereas exemplar memory depends on interactions between neocortex and the limbic system, classification learning may depend on interaction between neocortex and the neostriatum.*

Twenty-five years ago, Reber (1967) suggested that normal subjects can learn to classify letter strings correctly without developing explicit knowledge about the basis for the classification. The "correct" letter strings were generated by an artificial, finite-state grammar. The key finding was that after inspecting a group of exemplars that adhered to the grammatical rules, subjects were able to classify new items as either "grammatical" or "nongrammatical" at well above chance levels, even when the existence of rules underlying the exemplars was not mentioned until after the exemplars had been presented. In a series of papers (see Reber, 1989, for review), Reber suggested that successful classification is based on implicit memory and that subjects acquire the basis for making correct classifications without having explicit, conscious access to their knowledge. This view has been challenged with the proposal that performance on this task is based on the conscious application of explicit (declarative) memory strategies that are imperfectly formed and only partially correct (Dulany, Carlson, & Dewey, 1984; Perruchet & Pacteau, 1990).

This issue thus concerns the question of how the ability to classify based on a fixed set of rules arises from specific experiences. One view is that the ability to classify develops gradually as instances are presented, and that the acquired knowledge is implicit and distinct from explicit memory for the individual instances. Another view is that the information that supports correct classification has no special status. It is constructed out of remembered instances and is available as explicit, conscious memory. Similar viewpoints have been expressed regarding the learning of natural categories, that is, categories not defined by a fixed set of rules. In the first view, category knowledge is distinct from memory for individual exemplars (Franks & Bransford, 1971; Hayes-Roth & Hayes-Roth, 1977; Homa & Chambliss, 1975; Posner & Keele, 1968, 1970; Reed, 1972). This view allows for (but does not require) the possibility that category level knowledge could develop entirely independently of exemplar memory. In the other view, knowledge about category membership is derived from and is based directly on the exemplars stored in memory (Hintzman, 1986; McClelland & Rumelhart, 1986; Medin & Schaffer, 1978; for review, see Estes, 1988). By this view, performance on tests directed at category level knowledge depends on and should always be associated with performance on tests of exemplar memory.

Studies of amnesic patients could decide between these two views. Amnesic patients, despite being severely impaired on conventional tests of recall and recognition, are fully intact on many other tasks of learning and memory (Hintzman, 1990; Mayes, 1988; Squire, 1987; Weiskrantz, 1987). These facts can be understood by supposing that amnesia impairs the ability to acquire one kind of memory, that is, memory for facts and events (termed declarative or explicit memory).

What is spared in amnesia is a heterogeneous group of other abilities (collectively termed nondeclarative or implicit memory), which depend on structures not damaged in amnesia, including neocortex, striatum, cerebellum, and amygdala. These other abilities have been described as skillful behaviors, conditioning and habit formation, and the phenomenon of priming (Squire, 1987; Tulving & Schacter, 1990). Among the tasks that amnesic patients have been shown to acquire normally are perceptuomotor skills (Brooks & Baddeley, 1976; Nissen & Bullemer, 1987), perceptual skills like mirror reading (Cohen & Squire, 1980), perceptual and semantic priming (Graf, Squire, & Mandler, 1984; Schacter, Cooper, Tharan, & Rubens, 1991; Shimamura & Squire, 1984), adaptation level effects (Benzing & Squire, 1989), and changes in preference and judgment that are likely based on priming (Johnson, Kim, & Risse, 1985; Squire & McKee, 1992). Nondeclarative (implicit) memory is nonconscious. Thus, performance changes as the result of experience without providing conscious access to specific prior episodes or to any memory content.

In the present study, we asked whether artificial grammar

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learning is an example of the kind of implicit learning that is spared in amnesia. If the ability to make grammaticality judgments after studying exemplars is based on implicit memory that is not accessible to consciousness, and if explicit memory does not materially contribute to these judgments, then amnesic patients should be able to make grammaticality judgments as well as normal subjects. Alternatively, if the ability to make such judgments depends on the explicit use of imperfectly formed rules or direct comparisons with stored exemplars, then amnesic patients should perform poorly.

METHODS

Subjects

The subjects were 13 amnesic patients (11 men and 3 women) and 14 control subjects (7 men and 7 women) matched for age, education, and subtest scores on the Wechsler Adult Intelligence Scale, Revised (WAIS-R). Six of the patients had diencephalic amnesia, 4 as the result of Korsakoff's syndrome (RC, VF, PN, and JW), 1 from a thalamic infarction (MG), and 1 from a penetrating brain injury (NA). Damage to the diencephalon was confirmed in all 6 cases with quantitative neuroimaging (for RC, PN, and JW, Squire, Amaral, & Press, 1990; for NA, Squire, Amaral, Zola-Morgan, Kritchevsky, & Press, 1989; for VF, Shimamura, Jernigan, & Squire, 1988; and for MG, unpublished observations). The other 7 patients had confirmed or suspected damage to the hippocampal formation. For patients WH, WI, JL, and PH, hippocampal damage was confirmed by magnetic resonance imaging (for WH, WI, and JL, Squire et al., 1990; for PH, unpublished observations). For patients AB and GD, the etiology of amnesia (anoxia or ischemia) suggests that hippocampal damage had occurred. One patient (LJ) became amnesic gradually during a 6-month period without a known precipitating event. This patient cannot be classified confidently by lesion site, but in Table 1 she has been tentatively placed in the hippocampal group. All 13 patients are well characterized neuropsychologically (Tables 1 and 2; also see Cave & Squire, 1991; Musen & Squire, 1991). The control subjects were employees or volunteers at the San Diego Veterans Affairs Medical Center, or they were recruited from the retirement community of the University of California, San Diego.

Materials

Letter strings were generated from two finite-state Markovian rule systems (A and B), termed *artificial grammars* (Fig. 1). The letter strings were formed by starting at S_1 and traversing the diagram along the arrows, adding a letter to the string with each transition, until exiting along one of the arrows leading out of the diagram. Forty-six grammatical letter strings, two to six letters in length, were generated from each rule system. Forty-six nongrammatical letter strings that violated the rule system at one position within the letter string were also generated. The rule violation occurred nearly equally often in the first, second, middle, second to last, and last positions within the nongrammatical letter strings. Examples of grammatical and nongrammatical letter strings are shown in Figure 1. Each letter string was printed on an index card.

Table 1. *Patients' characteristics*

Patient group	Age	WAIS-R IQ	WMS-R score				
			Attention	Verbal	Visual	General	Delayed
Hippocampal formation							
AB	53	104	87	62	72	54	<50
GD	50	92	109	86	88	85	60
PH	69	115	117	67	83	70	57
WH	68	113	88	72	82	67	<50
WI	77	99	92	72	82	71	58
LJ	53	98	105	83	60	69	<50
JL	71	116	122	73	83	74	58
Diencephalon							
NA	52	109	102	67	89	68	71
RC	74	106	115	76	97	80	72
VF	71	103	101	78	82	72	66
MG	59	111	113	89	84	88	63
PN	63	99	81	77	73	67	53
JW	54	98	104	65	70	57	57
Mean	62.6	104.8	102.8	74.3	80.4	70.9	58.8

Note. WAIS-R = Wechsler Adult Intelligence Scale, Revised; WMS-R = Wechsler Memory Scale, Revised. The WAIS-R and the five WMS-R indices yield a mean of 100 and a standard deviation of 15 in the normal population. The WMS-R does not provide numerical scores for subjects who score below 50. Therefore, such values were scored as 50 for computing means.

Table 2. *Patients' performance on standard tests*

Patient group	Diagram recall	Paired associates	Word recall (%)	Word recognition (%)	50 words	50 faces
Hippocampal formation						
AB	4	1-1-2	33	83	32	33
GD	7	2-1-2	36	79	43	35
PH	3	0-0-1	27	84	36	34
WH	1	0-0-0	40	84	29	24
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
Diencephalon						
NA	17	0-0-2	49	93	34	42
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
PN	2	1-1-1	29	83	31	31
JW	4	0-0-2	29	90	29	34
Mean	4.1	0.3-0.2-1.2	33.2	85.7	32.5	31.3
Control mean ($N = 8$)	20.6	6.7-6-8.9	71.3	97.6	41.1	38.1

Note. The diagram recall score is based on reproducing the Rey-Osterrieth figure (Osterrieth, 1944; maximum score = 36) 12 min after it was copied. The patients' average score for copying the figure was 27.8, a normal score (see Kritchevsky, Squire, & Zouzounis, 1988). The paired-associate score is the number of word pairs recalled on three successive trials. The word recall score is the percentage of words identified correctly across five successive study-test trials, and the word recognition score is the percentage of words identified correctly on a yes/no recognition test across five successive trials (Rey, 1964). The scores for words and faces are 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 are from Squire and Shimamura (1986). Note that NA is not severely impaired on nonverbal memory tests because his brain injury is primarily left unilateral.

Procedure

In each of the three tasks described below, subjects were first shown 23 grammatical letter strings, one at a time, for 3 s each. Half of the subjects in each group received exemplars from one of the grammars, and half received exemplars from the other grammar. Subjects were asked to try to reproduce each item using a pencil and paper immediately after it was presented. If the subject was unable to reproduce the letter string, the same letter string was presented again for 3 s, and the subject again attempted to reproduce the item. If the subject was still unsuccessful, the procedure was repeated a third time before continuing on to the next item. Subjects were usually able to reproduce the item on their first attempt (85.4% of the time for control subjects and 85.5% of the time for the amnesic patients). This entire procedure was then repeated a second time using the same 23 exemplars.

Classification task

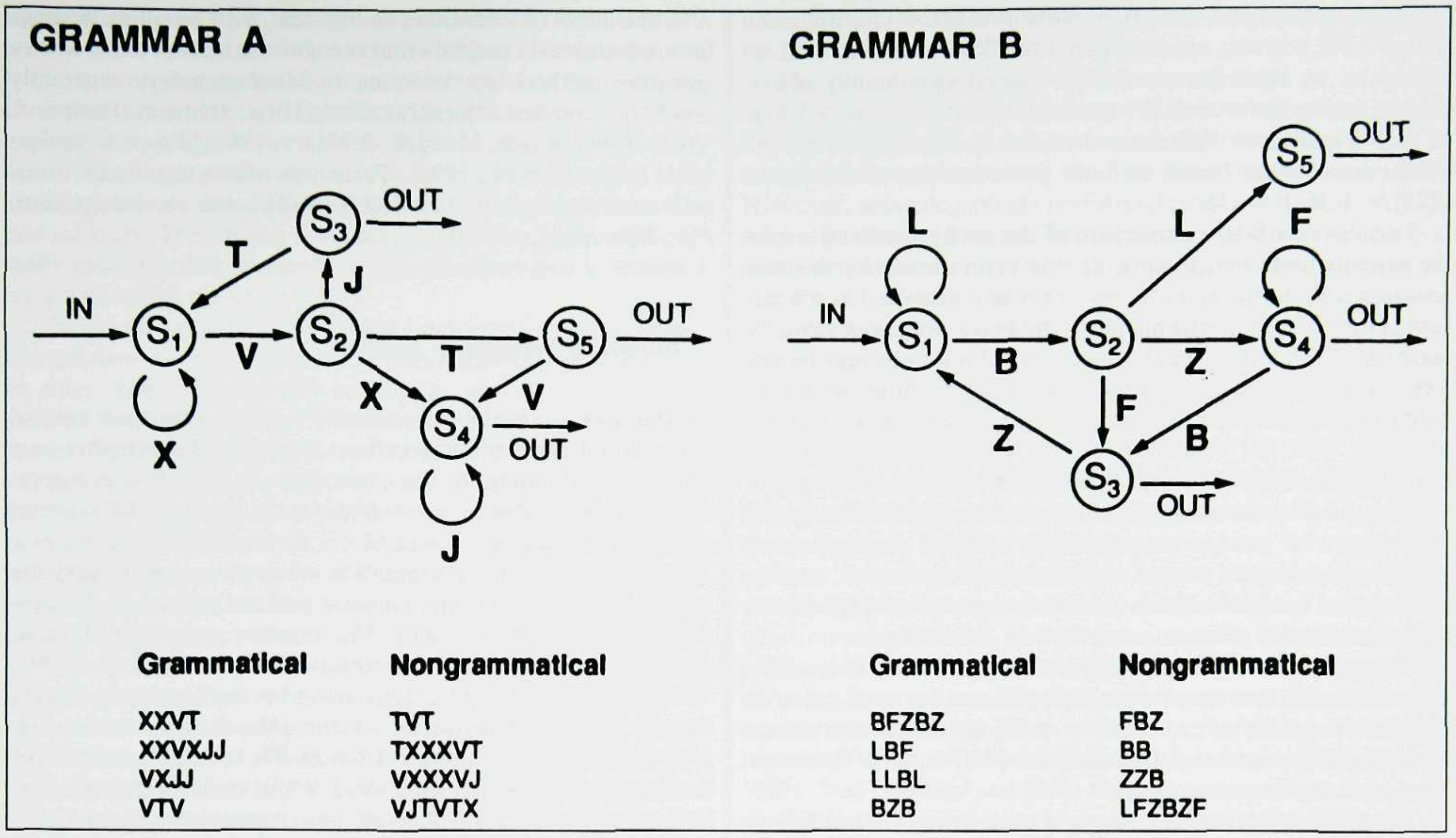
Five min after the exemplars were presented, subjects were informed for the first time that the letter strings they had seen had been formed according to a complex set of rules and that they would now be asked to try to classify new items according to whether or not the items conformed to these rules. Subjects were instructed as follows:

> The rules are very complex, so you may not be able to figure them out. You may want to go with your "gut feeling" as to whether the item follows the rules as in the first set of items.

Subjects were then shown 46 new letter strings, one at a time, which they classified as correct or incorrect depending on whether they appeared to conform to the rules. Of these new strings, 23 were grammatical and 23 were nongrammatical. The same 46 strings were then presented a second time, and subjects again classified them as grammatical or nongrammatical. Testing was not interrupted between the two presentations of the 46 items.

Recognition task

In the second phase of the experiment, subjects were presented with grammatical letter strings as in the previous phase, and were tested for their recognition memory of these letter strings 5 min later. Each subject was given letter strings derived from the grammar that had not been assigned to that subject for the classification task. That is, subjects who received Grammar A for the classification task received Grammar B for the recognition task, and the order of the assignment of Grammars A and B was counterbalanced across subjects. For amnesic patients and control subjects, the recognition test occurred an average of 46 and 44 days, respectively, after the classification



Grammatical	Nongrammatical
XXVT	TVT
XXVXJJ	TXXXVT
VXJJ	VXXXVJ
VTV	VJTVTX

Grammatical	Nongrammatical
BFZBZ	FBZ
LBF	BB
LLBL	ZZB
BZB	LFZBZF

Fig. 1. The two finite-state Markovian rule systems used in these experiments. Grammar A is taken from Abrams and Reber (1989). Listed below each diagram are examples of "grammatical" letter strings, which can be generated by the rule system, and "nongrammatical" letter strings, which violate the rule system at one letter position.

test. Grammatical letter strings were first presented to subjects for 3 s each, exactly as in the classification task, and subjects were asked to reproduce each string immediately after it was presented. After a 5-min delay, a yes/no recognition task was given. It consisted of 46 items: 23 grammatical letter strings that had just been presented and 23 new nongrammatical items. In this way, the similarity among "yes" and "no" items on the recognition test was comparable to the similarity among correct and incorrect items on the classification test. In contrast to the procedure used for the classification task, the items in the recognition task were presented only a single time.

Similarity judgment task

This task was identical to the classification task, except that subjects were given instructions to encourage them to use their explicit memory for the letter strings that had been presented. For the amnesic patients, this test occurred an average of 35 days after the recognition test; for the control subjects, 27 days. Each subject was given the same grammar as in the classification task. After presentation of the grammatical letter strings and a 5-min delay, we asked subjects to judge whether the new items were similar to, or reminded them of, the items they had just been shown. Subjects were instructed to say "yes" if an item seemed familiar or if it reminded them of one that they had seen, and they were instructed to say "no" if the item was unfamiliar or if it did not remind them of an item that they had just seen. As was the case for the classification task, 23 of these items were grammatical, and 23 were nongrammatical. The list of 46 test items was presented twice.

RESULTS

Classification Task

When the 46 new letter strings were presented for the first time, control subjects classified 66.9% of them correctly, and amnesic patients classified 63.2% of them correctly (Table 3). The performance of the two groups was not significantly different ($t[25] = 1.40$, $p > .1$), and both groups performed significantly above chance ($ts > 6.2$, $p < .001$). There was also no difference between the two groups in how well they classified

Table 3. *Percentage of correct responses (mean ± s.e.m.) for three kinds of tasks*

Task	Control subjects ($n = 14$)	Amnesic patients ($n = 13$)
Classification	66.9 ± 1.6	63.2 ± 2.1
Recognition	72.2 ± 1.8	62.0 ± 2.9**
Similarity judgment	69.9 ± 2.2	61.4 ± 2.4*

*$p < .05$. **$p < .01$.

the items the second time they were presented (control subjects, 62.9% correct; amnesic patients, 58.7% correct; $t[25] = 1.21$, $p > .1$). Both groups also performed significantly above chance during the second presentation of the items ($ts > 3.9$, $p < .01$). Finally, no difference between groups was detected when scores were based on both presentations of the items ($t[25] = 1.56$, $p > .1$).

To achieve a finer comparison of the performance of amnesic patients and control subjects, the errors made by the two groups across both presentations were also analyzed as a function of item length. Performance of the two groups was virtually identical. Both groups made more errors on strings four letters long than they did on shorter items (two to three letters in length) or longer items (five or six letters in length) (main effect of length, $F[3, 75] = 4.56$, $p < .01$; interaction of group and item length, $F[3, 75] < 1$). Thus, both groups exhibited a V-shaped function relating item length and classification accuracy. The two groups scored within 1.5% of each other on strings consisting of two to three letters, four letters, or five letters. The control subjects scored an average of 8.9% better than the amnesic patients on strings six letters long.

Subjects in both groups tended to find the same items difficult. When the test items were rank ordered for each group in terms of frequency of errors, there was a significant correlation between the two rankings (Spearman's $r[44] = .59$ for Grammar A and .46 for Grammar B, $ps < .005$).

The performance of the amnesic patients on the classification test was not related to the severity of amnesia, as assessed by their scores on the General Memory Index of the Wechsler Memory Scale (Spearman's $r[11] = -.16$) or the Delayed Index (Spearman's $r[11] = -.14$). In addition, no correlation was observed between classification performance and intelligence test scores on the WAIS-R (Spearman's $r[11] = -.21$).

In the original studies by Reber (1967, 1976), and in the present experiment, all items were presented twice for grammaticality judgments. We calculated how subjects performed on the two encounters with the same item (correct or incorrect both times, or correct one time and incorrect the other). For control subjects, 52.7% of the items were classified correctly twice (CC), 22.7% of the items were classified incorrectly twice (II), 14.3% of the items were classified correctly the first time and incorrectly the second time (CI), and 10.4% of the items were classified incorrectly the first time and correctly the second time (IC). For amnesic patients, the corresponding percentages were 44.1% (CC), 22.2% (II), 19.2% (CI), and 14.4% (IC). The pattern of scores across these four categories was similar for the two groups (multivariate analysis of variance; Wilkes-lambda = .80, $F[3, 23] = 1.88$, $p > .1$).

Recognition Task

In contrast to their normal performance on the classification task, amnesic patients were clearly impaired on the recognition memory test in comparison to control subjects (Table 3). Control subjects scored 72.2% correct, and amnesic patients scored 62.0% correct ($t[25] = 2.99$, $p < .01$). Although the amnesic patients did score significantly above chance ($t[12] = 4.1$, $p < .01$), this level of retention is consistent with previous findings for amnesic study patients that recognition tests provide a very sensitive method for detecting residual memory, especially when the retention interval is short (Hirst, Johnson, Phelps, & Volpe, 1988; Mayes, Meudell, & Neary, 1980; Musen & Squire, 1991; Schacter et al., 1991). There was also a significant interaction between group and task (classification vs. recognition; $F[1, 25] = 4.63$, $p < .05$).

Similarity Judgment Task

The amnesic patients performed more poorly than control subjects did when the instructions were to judge whether new items seemed similar to the exemplars. For the first presentation of items (Table 3), control subjects scored 69.9% correct, and amnesic patients scored 61.4% correct ($t[25] = 2.52$, $p < .05$); for the second presentation of items, control subjects scored 68.8% correct, and amnesic patients scored 61.7% correct ($t[25] = 1.99$, $p < .06$). The amnesic patients performed above chance levels on both presentations ($ts > 4.1$, $p < .01$). The difference between groups arose because control subjects improved their performance on the classification task when given similarity instructions (from 66.9% to 69.9% correct for the first presentation of the items), while amnesic patients performed more poorly when given these instructions (from 63.2% to 61.4% correct). The scores obtained by control subjects on the similarity task were, in fact, not significantly lower than their scores on the recognition task (69.9% vs. 72.2%, $t[13] < 1$, $p > .2$). In addition, the interaction between subject group and instructions approached significance (classification vs. similarity judgment tasks; $F[1, 25] = 2.96$, $p < .10$).

DISCUSSION

Amnesic patients were as able as normal subjects to classify letter strings that had been generated according to the rules of an artificial grammar. However, amnesic patients were impaired at recognizing the exemplars that had been used to teach the rules, and their classification was impaired when they were instructed to base their classifications on explicit comparison to the exemplars. These results indicate that classification learning can proceed normally without intact explicit memory, and that explicit memory for exemplars can also contribute to performance under some circumstances. Reber and others have proposed that subjects can implicitly acquire rule-based information about complex stimulus environments independently of conscious attempts to do so (Lewicki, Hill, & Bizot, 1988; Reber & Allen, 1978; Reber & Lewis, 1977). Nevertheless, there has been disagreement about whether rule-based classification learning reflects implicit memory or partially developed, imperfect explicit memory.

The present study of amnesic patients provided a method for dissociating the contributions of explicit and implicit memory to artificial grammar learning. Despite impaired recognition of the grammatical exemplars (i.e., impaired explicit memory), amnesic patients were able to distinguish grammatical from nongrammatical letter strings as well as normal subjects. If classification learning depended materially on explicit memory, for example, conscious knowledge of imperfect rules (Dulany et al., 1984), explicit knowledge of permissible bigrams (Perruchet & Pacteau, 1990), or explicit comparisons to stored exemplars, then amnesic patients should have performed more poorly than normal subjects. The finding that amnesic patients performed normally indicates that implicitly acquired information is adequate for grammatical classification.

The present results argue for the participation of at least two independent memory systems in classification learning based on rules. One system stores in explicit memory the actual instances that are presented to the subject. The other system stores implicitly information that is abstracted about the stimuli, for example, in the form of rules (Mathews et al., 1989; Reber, 1989), or acquires implicitly specific associations between stimulus features and the grammatical category (Servan-Schreiber & Anderson, 1990). Others have also emphasized the importance of specific associations between items and the grammatical category (Brooks, 1978; Brooks & Vokey, 1991).

These results may also have relevance to the process of acquiring knowledge about natural categories. Earlier work showed that normal subjects were able to classify a novel item that is prototypical of a category as well as or better than a less prototypical item that had actually been presented as a member of the category (Homa, Cross, Cornell, Goldman, & Schwartz, 1973; Posner & Keele, 1968, 1970; Strange, Keeney, Kessel, & Jenkins, 1970). Studies of amnesic patients could decide whether this ability occurs independently of memory for exemplars (see Cohen, 1981, for an early hint of such a dissociation in amnesic patients using a perceptuomotor task). Single-factor models in which classification and category judgments occur only by direct comparison with stored exemplars (Hintzman, 1986; McClelland & Rumelhart, 1986; Medin & Schaffer, 1978) predict that amnesic patients would be poorer than normal subjects at classification learning because of their impaired memory for the exemplars.

In the present study, normal subjects were able to perform better than amnesic patients when they were instructed to decide if new items reminded them of exemplars. Amnesic patients did not benefit from these instructions, presumably because their explicit memory of the exemplars was inadequate. Although the present findings show that classification based on rules can occur without recourse to stored exemplars, the results also suggest that explicit memory can sometimes assist in the classification of new items (e.g., in the similarity judgment task). Others have also suggested that both instance-based and rule-based information contribute to grammatical classification (Mathews et al., 1989; McAndrews & Moscovitch, 1985). Thus, classification learning could depend on both category level information and memory for the exemplars (also see Elio & Anderson, 1981; Fried & Holyoak, 1984). Classification may rely mainly on implicit memory when the categories are defined either by complex underlying rules or by features that are difficult to discover explicitly. However, classification may rely more heavily on memory for stored exemplars when subjects are instructed to memorize exemplars explicitly and are given extensive training with them (Brooks, 1978), or when the stimulus dimensions can be readily defined and encoded by explicit memory (Medin & Schaffer, 1978).

The present results are reminiscent of those of an earlier study (Graf, Squire, & Mandler, 1984) in which amnesic patients exhibited normal word-completion priming when asked to complete a word stem with the first word that came to mind. However, amnesic patients performed more poorly than control subjects when told to use the stems as retrieval cues for recently presented words. In the present experiment, we suppose that the classification instructions encouraged subjects to rely on implicit memory (as the completion instructions did in word-completion priming). However, instructions to access previous instances explicitly encouraged the use of declarative memory, with the result that the control subjects performed better than amnesic patients.

The amnesic patients in the present study had sustained damage to the hippocampal formation or the diencephalon. These patients are severely impaired on tests of declarative memory, including the recognition memory test for exemplars that was given in the present study. Other kinds of (nondeclarative) memory abilities, including the capacity for skill learning, priming, conditioning, and classification learning, depend on other brain structures. Nondeclarative memory is a heterogeneous collection of abilities within which additional dissociations can be found (Butters, Heindel, & Salmon, 1990; Squire, 1987). Skill learning and habit formation may depend on cortico–striatal connections (Mahut & Moss, 1984; Mishkin & Petri, 1984). For example, patients with Huntington's disease are impaired in the acquisition of perceptual and motor skills (Heindel, Butters, & Salmon, 1988; Heindel, Salmon, & Butters, 1991). In monkeys (Wang, Aigner, & Mishkin, 1990) and in rats (Packard, Hirsh, & White, 1989), lesions of the caudate nucleus impaired the learning of win-stay habits. The more cognitive tasks of interest here, such as category learning and artificial grammar learning, have features in common with habit learning in that subjects appear to learn in these cases by extracting invariance from the stimulus environment across many trials (see Sherry & Schacter, 1987). It would therefore be interesting to determine whether patients with striatal damage might have difficulty abstracting grammatical rules, yet have adequate recognition of exemplars.

The present results suggest that classification learning based on rules can rely substantially on nondeclarative memory. In the case of artificial grammar learning, the learning can be viewed as similar to classical conditioning, habit formation, and skill learning in that knowledge of a specific trial is not necessary, but rather the information that emerges across many trials is important. Classification learning based on an artificial grammar can develop across many trials without requiring explicit memory for each exemplar.

Acknowledgments—This research was supported by the Medical Research Service of the Veterans Administration, National Institute of Mental Health Grant MH24600, the Office of Naval Research, and the McKnight Foundation. B.J. Knowlton was supported by a McDonnell-Pew postdoctoral fellowship in cognitive neuroscience. We thank Joyce Zouzounis, Kathleen Fuchs, and Teresa Doksum for research assistance, and Carolyn Cave and Gail Musen for helpful comments.

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(RECEIVED 7/15/91; ACCEPTED 9/9/91)

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