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Artificial Grammar Learning Depends on Implicit Acquisition of Both Abstract and Exemplar-Specific Information

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The contributions of exemplar-specific and abstract knowledge to artificial grammar learning were examined in amnesic patients and controls. In Experiment 1, grammatical rule adherence and chunk strength exerted separate effects on grammaticality judgments. Amnesic patients exhibited intact classification performance, demonstrating the same pattern of results as controls. In Experiment 2, amnesic patients exhibited impaired declarative memory for chunks. In Experiment 3, both amnesic patients and controls exhibited transfer when tested with a letter set different than the one used for training, although performance was better when the same letter sets were used at training and test. The results suggest that individuals learn both abstract information about training items and exemplar-specific information about chunk strength and that both types of learning occur independently of declarative memory.

One important issue that has emerged from recent studies of learning and memory concerns the possibility that information can be learned implicitly and independently of awareness. A second issue concerns how knowledge acquired about concepts and categories is represented, that is, whether it is based on abstract rules or more concrete and instance-specific information (Seger, 1994; Shanks & St. John, 1994; Squire, Knowlton, & Musen, 1993). Both these issues have been studied extensively by using the artificial grammar learning paradigm (Reber, 1967). In a typical artificial grammar learning task, a series of letter strings are presented that are constructed according to a finite-state rule system (Mathews et al., 1989; Reber, 1967, 1989). After viewing the letter strings, individuals are able to classify new letter strings according to whether or not they adhere to the "grammatical" rules but are unable to describe the rules in much detail. In the context of artificial grammar learning, the two issues identified above concern whether classification judgments are based on implicit (nondeclarative) memory or on explicit (declarative) memory for the information acquired during training and whether grammaticality judgments are based on abstract rules or on simpler, concrete information that is specific to the examples presented during training.[1]

Although these two questions are independent, they have often been considered together. Thus, evidence that artificial grammar learning is based on learning abstract rules has sometimes been interpreted to imply that grammaticality judgments are based on implicit memory. Similarly, evidence that instance-specific information is being learned has sometimes been interpreted as implying that grammaticality judgments are based on explicit (declarative) memory.

According to an early view of artificial grammar learning, individuals are abstracting a veridical representation of the grammatical rules used to make classification judgments (see Reber, 1989, for a review). By this view, the grammatical rules are complex and are not accessible to awareness. Knowledge of the rules cannot be acquired declaratively. Yet, it has also been demonstrated that individuals can acquire some awareness of the underlying grammatical rules. For example, in one study, the participants were able to indicate which part of a letter string violated the grammatical rules by crossing out the

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[1] This second issue concerns how individuals represent their grammatical knowledge. By one view, individuals learn exemplar-specific information. For example, they could base their grammaticality judgments on comparisons with training items stored in memory, or they could use information about which letter groups (chunks) appear frequently in the training set. By another view, individuals learn something more abstract. For example, they might acquire a partially veridical representation of the grammatical rules during training. In the context of the present experiments, we consider such rule-based knowledge to be abstract because it would not be particularly sensitive to the specific exemplars presented during training. We recognize that some kinds of rule-based knowledge would be rather concrete (e.g., legal letter strings can begin with *X*). However, other kinds of rule-based knowledge merit the term *abstract* in a broader sense, in that the knowledge would be independent of the particular letters used for training (see Experiment 3).

invalid segments of the letter string (Dulany, Carlson, & Dewey, 1984). In another study, the participants were able to complete stems of grammatical letter strings to form legal strings (Dienes, Broadbent, & Berry, 1991). Thus, there has been disagreement about whether grammaticality judgments are supported by implicit memory or by fragmentary, partially correct, explicit (declarative) memory.

The issue of whether grammaticality judgments depend on explicit or implicit memory has been addressed by testing amnesic patients on the artificial grammar task. Because these patients have selectively impaired declarative memory, and apparently intact nondeclarative memory (Squire, 1992), normal artificial grammar learning by these patients would demonstrate that declarative memory does not play a material role in making classification judgments. In fact, amnesic patients do exhibit normal classification performance (Knowlton, Ramus, & Squire, 1992; Knowlton & Squire, 1994), suggesting that whatever declarative knowledge is acquired about an artificial grammar is epiphenomenal to making classification judgments.

The finding that grammaticality judgments do not depend on declarative memory is consistent both with an abstractionist view that grammatical rules are used to classify new items and with the view that exemplar-specific information is used. Previously (Knowlton & Squire, 1994), we identified three possible bases for classification judgments: (a) the learning of abstract rules (Reber, 1989); and (b) exemplar-specific learning, which permits individuals to judge the similarity between whole test items and specific training items (Vokey & Brooks, 1992). This second alternative (b) also includes distributed retrieval accounts of classification performance, in which classification depends on the number of training items retrieved from memory that are similar to each test item (Vokey & Brooks, 1992; Whittlesea & Dorken, 1993). The third alternative (c) is exemplar-specific learning that summarizes across the training exemplars such that individuals use acquired information about which letter bigrams and trigrams (chunks) are permissible or which appear frequently in the training set (Perruchet & Pacteau, 1990; Servan-Schreiber & Anderson, 1990). In a sense, information about chunk frequency could be considered abstract in that it is abstracted (summarized) across the training items. However, in the sense already described (see Footnote 1), chunk-strength information is not abstract in that it is specific to the training items presented.

It is important to note that the proposal that artificial grammar learning is implicit is compatible with the possibility that grammaticality judgments depend on exemplar-specific information. Indeed, many kinds of nondeclarative (implicit) memory depend on very specific information. For example, in the case of priming, specific items are processed more fluently after an earlier presentation; moreover, in the case of simple classical conditioning, associations are gradually formed between specific stimuli (for reviews see Schacter, Chiu, & Ochsner, 1993; Squire et al., 1993).

In the typical artificial grammar learning study, the three factors identified above (abstract rule learning, item similarity, and chunk information) are confounded so that it cannot be determined which factor is influencing grammaticality judgments. In two earlier studies, the first two factors (rule learning and item similarity) were examined separately by constructing test items such that the grammatical status of an item was independent of whether the item was similar to a specific training item (McAndrews & Moscovitch, 1985; Vokey & Brooks, 1992). These studies appeared to demonstrate that both grammatical status and the similarity of test items to training items influenced grammaticality judgments. However, it was subsequently shown that the effect of item similarity was confounded with the effect of chunk strength (chunk strength refers to the frequency with which bigrams and trigrams in the test items had appeared in the training set; Knowlton & Squire, 1994). Specifically, test items that were similar to specific training items also contained more chunks that had appeared frequently among the training items than did test items that were not similar to any training items. When test items were constructed so that chunk strength was equivalent for similar and nonsimilar items, the effect of item similarity disappeared (Knowlton & Squire, 1994). Thus, the similarity between whole test items and training items does not itself appear to play an obligatory role in grammaticality judgments. In our study, like others, we did not determine whether abstract rule knowledge made an independent contribution to grammaticality judgments because the grammatical items had more chunks that were frequently repeated in the training items than did the nongrammatical items.

Two other studies suggested that both abstract and exemplar-specific information can influence grammaticality judgments. In one study (Mathews et al., 1989), participants successfully transferred their grammatical knowledge to test items constructed with a different set of letters than the set used for training. Such transfer would appear to require abstract knowledge; however, because several hundred training trials were given before the transfer test, it is possible that abstract knowledge emerged only as a result of the extensive training. In addition, although transfer to a new letter set did occur, performance was even better when the test items were constructed with the same letters used during training. This finding suggests that information specific to the training letter set was also learned. In a second study (Gomez & Schvaneveldt, 1994), transfer of grammatical knowledge to a new letter set was demonstrated by using more limited training conditions. Thus, individuals can apparently learn abstract information in an artificial grammar learning task without receiving extensive training.

The basis for artificial grammar learning could be clarified further by comparing directly the influence of rule adherence and exemplar-specific information on grammaticality judgments following limited training procedures. Although there is evidence for both kinds of contribution, it is not clear what their relative importance is. Furthermore, it remains unclear whether both kinds of information can be acquired implicitly. In the present study, we examined the relative contributions of rule-based and exemplar-specific information to artificial grammar learning. In addition, by comparing the performance of amnesic patients and controls, we asked whether both kinds of information can be learned implicitly. In Experiment 1, we constructed test items so that adherence to grammatical rules was balanced (unconfounded) with the frequency with which the bigrams and trigrams in the test items had appeared in the training set. In Experiment 2, we examined whether amnesic patients acquired sufficient declarative knowledge about permissible bigrams and trigrams to account for their intact grammatical classification ability. In Experiment 3, we examined how abstract grammatical knowledge is by testing the ability of amnesic patients and controls to transfer grammatical knowledge to new letter sets.

Experiment 1

Typically, items that are grammatical have higher chunk strength than nongrammatical items because nongrammatical items contain impermissible chunks that did not occur at all in the training items. To examine independently the effects of chunk strength and rule adherence on grammaticality judgments, we constructed the test items in Experiment 1 such that grammatical and nongrammatical items were equal in chunk strength. In this way, grammaticality and chunk strength of the test items were not confounded, and we were able to examine the separate effects on grammaticality judgments of grammatical rule adherence and chunk strength.

Method

Participants

Amnesic patients. We tested 11 amnesic patients, all of whom had participated in previous studies of artificial grammar learning in our laboratory (Knowlton & Squire, 1994; Knowlton et al., 1992). Four of the patients were amnesic as a result of alcoholic Korsakoff's disease. Damage to the diencephalon was confirmed in these patients by using magnetic resonance imaging (MRI) or quantitative computed tomography (for R.C., P.N., and J.W., Squire, Amaral, & Press, 1990; for V.F., Shimamura, Jernigan, & Squire, 1988). Two other patients became amnesic as the result of damage to the diencephalon: in one case because of a penetrating brain injury (N.A.) and in the other case because of a thalamic infarction (M.G.). In both cases, diencephalic damage was confirmed by an MRI (for N.A., Squire, Amaral, Zola-Morgan, Kritchevsky, & Press, 1989; for M.G., unpublished observations). The remaining 5 patients became amnesic as the result of confirmed damage to the hippocampal formation. Hippocampal damage was confirmed by an MRI in patients W.H. and J.L. (Squire et al., 1990), in patient P.H. (Polich & Squire, 1993), and in patient L.J. (unpublished observations). For patient A.B., the etiology of the lesion (anoxia) strongly suggests hippocampal damage.

All 11 patients were well characterized neuropsychologically. Immediate and delayed recall of a short prose passage averaged 5.0 and 0 segments, respectively (21 total segments, Gilbert, Levee, & Catalano, 1968). The mean score on the Dementia Rating Scale (Mattis, 1976) was 132.5 (range = 125–139, maximum score = 144). Most of the points lost by the patients were on the memory subportion of the test (mean points lost = 6.9). The mean score on the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983) was 55.5 (range = 47–59, maximum score = 60). Scores for normal individuals on these tests can be found elsewhere (Janowsky, Shimamura, Kritchevsky, & Squire, 1989; Squire et al., 1990; see Tables 1 and 2 for scores on additional neuropsychological tests).

Controls. The 18 controls were either employees or volunteers at the San Diego Veterans Affairs Medical Center or members of the retirement community of the University of California, San Diego. They were selected to match the amnesic patients with respect to age (M = 63.8 years, range = 51–71), education (M = 14.4 years, range = 12–18; for amnesic patients, M = 13.7 years, range = 9–20), and two subscales of the Wechsler Adult Intelligence Scale—Revised (WAIS–R, Wechsler, 1981): Information (for controls M = 21.1, range = 14–29; for amnesic patients, M = 21.3, range = 15–27) and Vocabulary (for controls M = 56.7, range = 48–65; for amnesic pa-

Table 1
Characteristics of Amnesic Patients

Lesion and patient	Age[a]	WAIS–R IQ	WMS–R				
			Attention	Verbal	Visual	General	Delay
Diencephalon							
N.A.	55	104	102	67	89	68	71
R.C.	77	106	115	76	97	80	72
V.F.	74	103	93	77	65	67	64
M.G.	61	97	92	97	77	89	72
P.N.	66	99	81	77	73	67	53
J.W.	55	98	104	65	70	57	57
Hippocampal formation							
A.B.[b]	56	104	87	62	72	54	<50
P.H.	71	115	117	67	83	70	57
W.H.	71	113	88	72	82	67	<50
J.L.	74	116	122	73	83	74	58
L.J.	56	98	105	83	60	69	<50
M	65.1	104.8	100.5	74.2	77.4	69.3	59.5

Note. The WAIS–R and the WMS–R indices yielded a mean score of 100 in the normal population, with a standard deviation of 15. The WMS–R does not provide scores for individuals who score below 50. Therefore, the three scores below 50 were scored as 50 for calculating a group mean. WAIS–R = Wechsler Adult Intelligence Scale—Revised (Wechsler, 1981); WMS–R = Wechsler Memory Scale—Revised (Wechsler, 1987).

[a] Age is indicated in years. [b] The lesion site has not radiologically been confirmed but is strongly supported by the etiology of amnesia.

Table 2
Performance of Patients on Standard Memory Tests

Lesion and patient	Diagram recall	Paired associates	Word recall (%)	Word recognition (%)	50 words	50 faces
Diencephalon						
N.A.	17	0–0–2	49	93	34	42
R.C.	3	0–0–3	19	85	37	30
V.F.	8	0–0–0	27	91	27	31
M.G.	0	0–0–2	33	71	30	34
P.N.	2	1–1–1	29	83	31	31
J.W.	4	0–0–2	29	90	29	34
Hippocampal formation						
A.B.	4	1–1–2	33	83	32	33
P.H.	3	0–0–1	27	84	36	34
W.H.	1	0–0–0	40	84	29	24
J.L.	1	0–0–0	40	93	31	20
L.J.	3	0–0–0	40	93	33	29
M	4.2	0.18–0.18–1.2	33.3	86.4	31.7	31.1
M (control, *n* = 8)	20.6	6.0–7.6–8.9	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 the amnesic patients 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/trial). The word recall score is the percentage of words identified correctly on five successive study–test trials (Rey, 1964). The word recognition score is the percentage of words identified correctly by yes–no recognition 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 healthy controls shown for these tests are from Squire and Shimamura (1986). Note that patient N.A. is not severely impaired on nonverbal memory tests because his brain injury is primarily left unilateral.

tients, *M* = 56.7, range = 50–65). Immediate and delayed recall of a short prose passage averaged 7.4 and 5.3 segments, respectively.

Materials

Grammatical letter strings were generated from the finite-state Markovian rule system shown in Figure 1A. The letter strings were formed by traversing the diagram from the in arrow to the out arrow, adding a letter at each transition from one state to the next. Twenty-three training items and 16 test items, two–six letters in length, were generated from the rule system. Nongrammatical test items were generated by introducing an error in each of 16 different grammatical items.

The 32 test items were constructed so that chunk strength was equal for grammatical and nongrammatical items. Chunks were defined as the bigrams and trigrams that appeared in the item. Thus, the item *XXVXJ* consisted of the chunks *XX*, *XV*, *VX*, *XJ*, *XXV*, *XVX*, and *VJX*. The associative strength of a chunk was defined as the number of times it had appeared in the training items. The chunk strength of each test item was calculated by averaging the associate strengths of each chunk in the item. There was an equal number of high and low chunk-strength items among both grammatical and nongrammatical items. For the grammatical items, the mean chunk strength was 7.2; for the nongrammatical items, the mean chunk strength was 7.0. The Appendix lists the test items that were used within each of the four categories (grammatical and high chunk strength [GH], grammatical and low chunk strength [GL], nongrammatical and high chunk strength [NGH], and nongrammatical and low chunk strength [NGL]). Normally, grammatical items would have higher chunk strength than nongrammatical items because nongrammatical items often consist of chunks

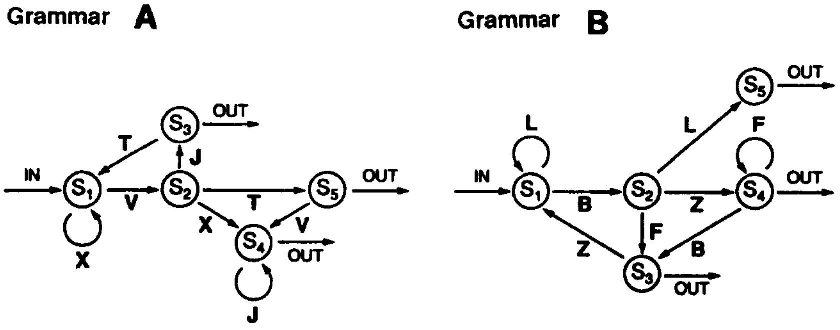

Figure 1. Grammar A was used in Experiment 1 (from Abrams & Reber, 1989). Both Grammars A and B were used in Experiments 2 and 3 (Grammar B from Knowlton, Ramus, & Squire, 1992). S_1–S_5 indicate the five possible states that could occur during generation of grammatical letter strings.

with zero chunk strength. In the present study, to balance chunk strength and grammaticality, we included grammatical test items that consisted of chunks that had appeared infrequently during training, and we included nongrammatical items that contained many permissible chunks.

The training and test items were printed on individual index cards. The four types of test items (GH, GL, NGH, and NGL) were presented in a mixed order.

Procedure

Participants were presented with each training item one at a time for 3 s each. After the item was removed from view, the participant attempted to reproduce the item on a piece of paper. If the participant did not reproduce the item correctly, he or she was shown the item again and was given a second chance to reproduce it. If the participant was still unable to reproduce the item, he or she was shown the item a third time and made a third attempt to reproduce it before moving on to the next item. Participants were quite accurate at reproducing the items. Controls correctly completed 88.3% of the items on the first attempt and 97.6% of the items in three attempts; whereas amnesic patients correctly completed 86.2% of the items on the first attempt and 95.4% of the items in three attempts. The set of 23 training items was repeated once, for a total of 46 items. Testing began 5 min after the training phase.

Before the test, participants were informed that the items they had just seen had been generated by a set of rules, which allowed only certain letters to follow other letters, and that with a new set of items their task was to decide whether each item was or was not formed according to the same rules. Participants were told that the rules were very complex and that they should base their judgments on a "gut feeling" as to whether each test item obeyed the rules. The test items were then displayed one at a time, and the participant judged the item to be correct or incorrect.

Results

For both groups, the 16 grammatical test items (GH and GL items) were endorsed more often than the 16 nongrammatical test items (NGH and NGL items) (Table 3). The amnesic patients performed similarly to the controls. The controls endorsed 63.5% of the grammatical items and 41.5% of the nongrammatical items, $t(17) = 5.27$, $p < .01$. The amnesic patients endorsed 62.5% of the grammatical items and 43.8% of the nongrammatical items, $t(10) = 3.28$, $p < .01$. In addition, both groups of participants endorsed the high chunk-strength items (GH and NGH items) more often than the low chunk-strength items (GL and NGL items). Controls endorsed 59.7% of the high chunk-strength items and 45.3% of the low chunk-strength items, $t(17) = 3.10, p < .05$; whereas amnesic patients endorsed 59.1% of the high chunk-strength items and 47.2% of the low chunk-strength items, $t(10) = 3.84, p < .05$; see Table 3.

Table 3
Endorsement Rates for Each Type of Test Item

Test item	Controls *M*	Controls *SEM*	Amnesic patients *M*	Amnesic patients *SEM*
Grammatical				
High chunk strength[a]	64.6	3.7	61.4	3.6
Low chunk strength[a]	62.5	6.0	63.7	4.3
Nongrammatical				
High chunk strength[a]	54.9	5.6	56.8	6.4
Low chunk strength[a]	28.1	3.8	30.7	3.9
All 16 grammatical items	63.5	3.5	62.5	3.0
All 16 nongrammatical items	41.5	4.1	43.8	4.2
All 16 high chunk-strength items	59.7	4.0	59.1	2.1
All 16 low chunk-strength items	45.3	3.9	47.2	3.3

Note. Scores indicate the mean percentage and standard error of each item type endorsed by each group.
[a] 8 items.

For the controls, the effect size was .50 for rule adherence and .39 for chunk strength, as calculated by point-biserial correlations. For amnesic patients, the effect size was .52 for rule adherence and .27 for chunk strength. For both groups, the effect sizes for the two measures did not differ ($Zs < 1.14$, $ps > .2$, and the groups did not differ on either measure ($Zs < 0.52, ps > .2$).

Table 3 lists the endorsement rates for both groups for each of the four types of test items. These endorsement rates were further analyzed by using a three-way analysis of variance (ANOVA; Group [one vs. two] × Rule Adherence [grammatical vs. nongrammatical] × chunk strength [high vs. low]). The ANOVA yielded main effects of grammatical status, $F(1, 27) = 34.26$, $MSE = 331.71$, $p < .01$, and chunk strength, $F(1, 27) = 16.6, MSE = 284.42, p < .01$. There was no effect of group and no interaction of group with either of the other two variables ($Fs < 1$). The significant interaction between grammaticality and chunk strength, $F(1, 27) = 17.54, MSE = 273.9$, $p < .01$, reflected the fact that chunk strength exerted most of its effect on nongrammatical items.

Discussion

Both chunk strength and adherence to grammatical rules influenced grammaticality judgments to a similar degree. The results indicate that relatively concrete information specific to the training exemplars (i.e., chunk strength) can be used to make grammaticality judgments and that in addition more abstract information about the grammatical rules can also be used.

The performance of the amnesic patients was virtually identical to that of the controls. Thus, the amnesic patients were as sensitive as the controls to the two variables under study: chunk strength and grammatical rule adherence. The results thus confirm earlier findings that amnesic patients exhibit normal classification ability in artificial grammar learning tasks (Knowlton & Squire, 1994; Knowlton et al., 1992). In addition, the present results demonstrate that amnesic patients rely on the same kinds of information to make their grammaticality judgments as controls do. Concrete information specific to the training exemplars can be learned implicitly as well as other information that is based on grammatical rule adherence.

The significant interaction between chunk strength and rule adherence indicated that these two variables do not influence grammaticality judgments independently. The effect of chunk strength was substantial for nongrammatical items but was negligible for grammatical items. Thus, items that adhered to grammatical rules were readily endorsed regardless of their chunk strength; whereas nongrammatical items, which contained errors, were likely to be endorsed only if they had high chunk strength. These results suggest that adherence to grammatical rules may be the dominant factor in grammatical classification judgments. However, it is possible that chunk strength could influence grammaticality judgments to a greater extent under other circumstances, for example, if the chunk-strength difference between high and low items were larger than in the present study.

The fact that chunk strength influenced grammaticality judgments only for nongrammatical items raises one other interesting issue. We have assumed that it is the chunk strength of the nongrammatical items that determined whether they were endorsed. However, an alternative possibility is that the type of error that occurred in the nongrammatical items might be important. A test item can be nongrammatical either because it contains impermissible chunks, that is, chunks that violate the grammatical rules, or because it contains valid chunks that appear in impermissible locations. A test item that contained impermissible chunks, which do not contribute to chunk strength, would tend to have a lower average chunk strength than an item with permissible chunks in impermissible locations, which do contribute to chunk strength. Indeed, in a previous study participants rejected nongrammatical items containing impermissible chunks more readily than items with chunks in impermissible locations (Gomez & Schvaneveldt, 1994). These considerations raise the possibility that the apparent effect of chunk strength on grammaticality judgments is actually due to the type of error contained in the nongrammatical test items.

To examine separately the influence of chunk strength and error type on the endorsement of nongrammatical items, we performed a 2 × 2 × 2 ANOVA (Group [one vs. two] × Chunk Strength [high vs. low] × Error Type [impermissible chunk or impermissible location]; see Table 4). There was no effect of group and no interaction of group with either of the other two variables (*F*s < 1). The important findings were that there was an effect of chunk strength, $F(1, 27) = 18.24$, $MSE = 570.1$, $p < .01$, reflecting the higher endorsement rate for high-chunk items in comparison to low-chunk items, and there was also an effect of error type, $F(1, 27) = 10.31$, $MSE = 680.3$, $p < .01$, reflecting the higher endorsement rate for items with location errors in comparison to items with impermissible chunks. However, there was no interaction between these two variables ($F < 1$), suggesting that each operates independently. Thus, it is true that items containing impermissible chunks are rejected more readily than items with chunks in impermissible locations. However, the overall chunk strength of an item also influences endorsement rates for nongrammatical items, regardless of whether the item contains an impermissible chunk or a chunk in an incorrect location.

Table 4
Endorsement Rates for Nongrammatical Items by Chunk Strength and Error Type

	Controls		Amnesic patients	
Item type	*M*	*SEM*	*M*	*SEM*
High strength and location error	60.0	7.3	61.8	6.3
High strength and chunk error	42.6	7.0	51.5	12.2
Low strength and location error	41.7	7.3	45.5	8.1
Low strength and chunk error	25.0	4.1	25.8	5.2

Note. Scores indicate the mean percentage and standard error of each type of nongrammatical item that was endorsed by the two groups.

Experiment 2

In an earlier study (Knowlton et al., 1992), amnesic patients performed normally when making classification judgments, although they were impaired at recognizing the letter strings that had been used as training exemplars. This dissociation between classification and recognition performance was intended to demonstrate that declarative memory for training exemplars does not contribute measurably to grammaticality judgments. Yet, the results of Experiment 1, together with the findings from another recent study (Knowlton & Squire, 1994), suggest that information about the chunks that appeared in the training set is more important for grammaticality judgments than information about whole letter strings (see also Perruchet & Pacteau, 1990). If information about the whole letter strings that appeared as training exemplars does not contribute materially to grammaticality judgments, then showing that amnesic patients have impaired recognition memory for the whole training exemplars would not provide a compelling demonstration that artificial grammar learning is independent of declarative knowledge. The more relevant question is whether amnesic patients exhibit impaired recognition memory for the chunks that appeared in the training items.

In Experiment 2 we tested recognition memory for the chunks (the bigrams and trigrams) that appeared in the training set. If amnesic patients exhibit impaired recognition memory for the chunks from the training set, then their ability to use information about chunk strength to achieve normal classification performance is likely based on implicit memory.

Method

Participants

Amnesic patients. Nine amnesic patients were tested (all except W.H. and J.L. from Experiment 1). For each patient, at least 5 months intervened between Experiments 1 and 2 ($M = 5.8$ months).

Controls. Twelve individuals, who did not participate in Experiment 1, served as controls. These individuals averaged 62.6 years of age and 14.1 years of education. They scored 22.5 on the Information subtest and 56.7 on the Vocabulary subtest of the WAIS–R. Immediate and delayed recall of a short prose passage averaged 7.2 and 5.7 segments, respectively.

Materials

The 23 training letter strings used in Experiment 1 (Grammar A) were used as one set of study items, and 23 training letter strings from a second artificial grammar (Knowlton et al., 1992; Grammar B; Figure 1) were used as a second set of study items. The test items consisted of 46 bigrams and trigrams (chunks). Of these, 23 had appeared within the training items, and 23 others were constructed with the same letters but had not appeared as part of any of the training items. For Grammar A, the correct items on the test consisted of 9 bigrams and 14 trigrams, and the incorrect (distractor) items consisted of 6 bigrams and 17 trigrams. For Grammar B, the correct test items consisted of 10 bigrams and 13 trigrams, and the incorrect (distractor) items consisted of 5 bigrams and 18 trigrams. The training and test stimuli were printed on individual index cards, and the correct and incorrect items were intermixed in the test list.

Finally, the average chunk strength of the correct items on the recognition test was 8.3, about the same as the chunk strength of the grammatical test items in Experiment 1 (8.6). Thus, the test items on the recognition test in Experiment 2 and the test items on the classification test in Experiment 1 were equated for their salience, as measured by chunk strength.

Procedure

The training procedure was the same as in Experiment 1. Half of the participants were tested with Grammar A, and half were tested with Grammar B. Participants were shown each training item for 3 s and then attempted to reproduce the item from short-term memory. Controls were correctly able to complete 91.1% of the items in the first attempt and 97.3% of the items after three attempts. Amnesic patients were correctly able to complete 83.6% of the items in the first attempt and 96.9% of the items after three attempts. After a 5-min delay, the participants were told that they would be seeing items two–three letters in length, and their task was to decide for each item whether it had appeared as part of any of the letter strings presented during training. The test items were then presented one at a time on index cards, and participants judged whether the item had or had not appeared in the training set.

Results

The controls performed better than the amnesic patients on the chunk recognition test (67.4% ± 2.7% correct vs. 57.7% ± 3.6% correct, $t(19) = 2.20, p < .05$). Moreover, the amnesic patients scored only marginally above chance levels, $t(8) = 2.14, p = .06$. For both groups, performance was similar for participants receiving Grammar A and for participants receiving Grammar B ($ts < 1.7, ps > .10$).

Discussion

In a recognition memory test for the chunks that appeared during training, amnesic patients performed more poorly than controls did. Because amnesic patients nevertheless performed normally on the grammatical classification task, their capacity to perform the classification task was unlikely to depend on their residual declarative memory. Perruchet (1994) also emphasized the importance of chunk-strength information in artificial grammar learning. He proposed that chunks can partially be memorized and that this accounts for classification performance. Our finding that amnesic patients cannot memorize the chunks, but can nevertheless perform as well as controls at the classification test, suggests that the information about chunk strength that supports classification judgments is nondeclarative (implicit) and that explicit knowledge of chunks is epiphenomenal to classification performance.

Experiment 3

In Experiment 1, grammatical items were endorsed more readily than nongrammatical items, even when the chunk strength of the test items was equivalent for grammatical and nongrammatical items. These results suggest that classification judgments were influenced by how well the test items adhered to the grammatical rules. However, there are other possibilities. Specifically, the effect of grammatical rules on classification judgments might have arisen because some exemplar-specific information other than chunk strength, as we measured it, correlated with the grammatical status of the items, and this exemplar-based information influenced classification judgments. For instance, participants might have learned the associative strength of chunks larger than trigrams, or some chunks may have gained more associative strength than others during training because of differences in the salience of particular letter groups. Accordingly, Experiment 1 could not demonstrate conclusively that information about the grammatical rules plays a role in grammaticality judgments.

In addition, even if information about grammatical rules were acquired, Experiment 1 did not address the question of how abstract such rule knowledge might be. In one sense, rules could be more abstract than chunk strength information because they are not specific to particular training items. However, rules could also be rather concrete in that they could refer to particular letters or combinations of letters (e.g., legal letter strings can begin with *X*).

In Experiment 3, we examined directly whether abstract, rule-based information can influence grammaticality judgments by testing the ability of individuals to transfer grammatical knowledge to items constructed with different letters. If individuals are basing their classification judgments solely on concrete information about the training items, then there should be little or no transfer to a new letter set. If, however, abstract knowledge of the grammatical rules is influencing classification judgments, then individuals should exhibit above-chance performance when they are tested with items constructed from a letter set different than the one used for the training items.

In several studies researchers have examined the ability of normal individuals to transfer grammatical knowledge to items formed with novel letters. In one study, participants memorized six lists of grammatical letter strings, improving their performance with each successive list. Participants exhibited no decrement in performance when the next set of lists consisted of grammatical items formed from a different letter set, but memorization performance was poorer if the items were constructed from a new grammar (Reber, 1969).

In another study, participants were given extended training with grammatical letter strings (several hundred trials of training across a 4-week period) and were then able to exhibit significant transfer of their knowledge on a classification test that was constructed from a new letter set (Mathews et al., 1989). In a third study, participants also transferred classification performance to a new letter set (Brooks & Vokey, 1991). In this case, all of the test items were constructed from a new letter set, and the grammaticality of the test items and their similarity to training items were independently manipulated. (A test item was considered similar to a training item if it was analogous to a training item except at one letter position, for example, *MXVVVM* was considered similar to *BDCCCD*). Participants endorsed grammatical items more than nongrammatical items. The finding of interest was that participants were more likely to endorse similar test items than nonsimilar test items. This effect of item similarity suggested that participants were drawing analogies between specific test items and specific training items (Brooks & Vokey, 1991). However, it seems possible that this finding depended on the unusual training procedure used, which might have encouraged participants to remember explicitly the specific training items they had encountered. Specifically, the presentation of training items was self-paced so that participants viewed the training items until they believed they could confidently recall each one. In addition, only 16 training items were used, each presented four times, so that memory for the training items would be expected to be good. Perhaps the transfer effect, that is, the transfer to test items that were analogous to training items, depended on the ability of participants to memorize the training items. Together, these three studies are consistent with the idea that participants can learn abstract rules, but it remains unclear whether more limited training conditions can also result in the learning of abstract rules and, in particular, whether such learning is implicit.

In a few recent studies, transfer of classification performance occurred when training was not so extensive as in the studies just reviewed. After training with grammatical letter strings, significant classification performance was observed when the test items were constructed from a new letter set (Gomez & Schvaneveldt, 1994; Whittlesea & Dorken, 1993). Thus, participants appeared to learn abstract information about the grammatical rules. Even more compelling is the finding that participants can transfer grammatical knowledge across sensory modalities (Altmann, Dienes, & Goode, 1995; Manza & Reber, 1991). In these same studies, a significant advantage was often found when the same letters were used at study and test, as compared with when different letters were used. The latter finding suggests that, in addition to the influence of abstract information on grammaticality judgments, some specific information derived from the training exemplars is also important.

In the present study, amnesic patients and controls were tested both with the same and with different letter sets at study and test. Above-chance performance in the different letter-set condition would suggest that abstract, rule-based information does influence grammaticality judgments. Better performance for the same letter-set condition, in comparison to the different letter-set condition, would suggest that concrete information specific to the training letter strings also influences grammaticality judgments. Similar levels of performance in these two conditions would suggest that most of the information supporting classification judgments is abstract. Finally, the performance of amnesic patients in the two conditions would suggest whether concrete and abstract grammar knowledge can be learned implicitly.

Method

Participants

Amnesic patients. The same 9 amnesic patients who participated in Experiment 2 served as participants for Experiment 3. At least 3 weeks intervened between Experiments 2 and 3 ($M = 2.5$ months).

Controls. Fourteen individuals, who did not participate in either Experiment 1 or Experiment 2, served as a control group. These participants were either employees or volunteers at the University of California, San Diego, or at the Veterans Affairs Medical Center. They averaged 65.0 years of age and 14.5 years of education. Their mean score on the Information subscale of the WAIS–R was 23.2, and the mean score on the Vocabulary subscale was 57.1. The mean score for immediate and delayed recall of a short prose passage was 6.6 and 5.4 segments, respectively.

Materials

The artificial grammars from Experiment 2 (Grammars A and B) and two new artificial grammars (Grammars C and D; Figure 2) were used in Experiment 3. Two different letter sets were used for each grammar, resulting in a total of eight separate sets of materials. For Grammar A, the letters were *JTVX* and *HNPS*; for Grammar B, the letters were *BFLZ* and *DGKW*; for Grammar C, the letters were *BCJW* and *HNPS*; and for Grammar D, the letters were *FTVX* and *DGKL*. For each grammar, 23 grammatical training items, 23 grammatical test items, and 23 nongrammatical items with errors in one position were generated and also translated into the second letter set. The items were printed on individual index cards, and the grammatical and nongrammatical test items were intermixed in the test list. For each grammar, the order of the training and test items was the same for both letter sets.

Procedure

Each participant was tested four times in four separate sessions, once with each of the four grammars. In the first two sessions,

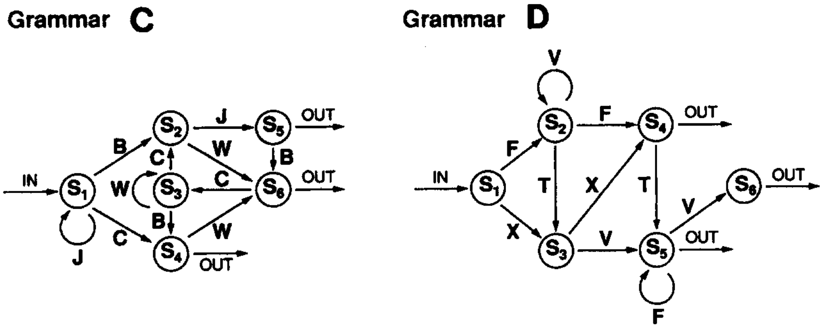

Figure 2. Artificial Grammars C and D used in Experiment 3. S_1–S_6 indicate the six possible states that could occur during generation of grammatical letter strings.

Grammars C and D were used. In one of these sessions, participants were tested on one of the two grammars (C or D), using the same letter set at study and test. In the other session, the other grammar was used, and different letter sets were used at study and test. These first two sessions were separated by at least 1 week. Three variables were counterbalanced across subjects as completely as possible: (a) which grammar (C or D) was used first, (b) whether the same letter-set or the changed letter-set condition was presented first, and (c) which of the two possible letter sets was used for training for each grammar. After an interval of at least 1 month (for amnesic patients, $M = 1.4$ months; for controls, $M = 10.2$ months), all participants were tested in the third and fourth sessions by using Grammars A and B. The procedure for these final two sessions was identical to that used in the first two sessions. In this way, the use of Grammars A and B provided an opportunity to replicate the results obtained with Grammars C and D.

The procedures for all four test sessions were identical to the procedure followed in Experiment 1. Thus, participants were presented with the grammatical letter strings one at a time and were allowed up to three attempts to reproduce the item from short-term memory. Across all four tests, the amnesic patients correctly reproduced 84.5% of the items in the first attempt and 96.1% of the items within three attempts, and the controls correctly reproduced 88.5% of the items in the first attempt and 98.6% of the items within three attempts. For sessions in which different study and test letter sets were used, participants were told that the test items would be made up of different letters than they had seen during training.

Results

In all four sessions, both groups exhibited above-chance classification performance for the same letter-set condition and also for the changed letter-set condition ($ts > 2.77$, $ps < .05$; Figure 3). Controls scored 59.9% ± 1.5% correct on Grammars C and D and 65.5% ± 2.6% correct on Grammars A and B when the same letters were used at study and test. When different letters were used at study and test, controls scored 56.1% ± 1.5% correct on Grammars C and D and 60.7% ± 1.4% correct on Grammars A and B. Amnesic patients scored 57.2% ± 2.6% correct on Grammars C and D and 60.9% ± 3.1% correct on Grammars A and B when the same letters were used at study and test. When different letters were used at study and test, amnesic patients scored 54.6% ± 1.3% correct for Grammars C and D and 57.3% ± 2.2% correct on Grammars A and B.

Percentage correct classification performance was analyzed with a 2 × 2 × 2 ANOVA (Group [amnesic patients vs. controls] × Session [first two vs. final two] × Letter set [same letters vs. different letters at study and test]). The analysis yielded a main effect of letter-set condition, with the same letter set at study and test resulting in better performance, $F(1, 22) = 6.83$, $MSE = 44.87$, $p < .05$. There was also a main effect of sessions, with performance in the final two sessions (Grammars A and B) better than in the first two sessions (Grammars C and D), $F(1, 21) = 7.02$, $MSE = 53.17$, $p < .05$. Finally, there was a trend for a main effect of group, $F(1, 21) = 4.02$, $MSE = 51.17$, $p = .06$, with the amnesic patients performing somewhat worse overall than the controls. There were no significant interactions between any of the variables ($Fs < 1$).

Discussion

In Experiment 3, both controls and amnesic patients exhibited excellent transfer of grammatical knowledge to a new letter set. For both groups, performance was better when the same letter sets were used at study and test, but performance was significantly above chance in the different letter-set condition. These results are consistent with the findings of Gomez and Schvaneveldt (1994), who obtained good letter-set transfer performance in normal individuals. The advantage of the same letter-set condition could be due to the influence of chunk strength on grammaticality judgments or other information specific to the training exemplars. In any case, in agreement with the findings of Experiment 1, the results of Experiment 3 demonstrate that abstract, rule-based knowledge can exert a measurable influence on grammaticality judgments.

In Experiment 3, there was also a trend for amnesic patients

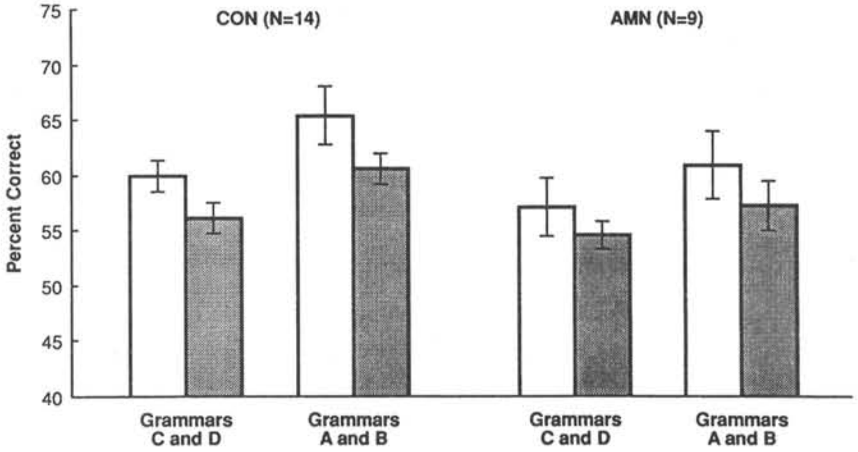

Figure 3. Percentage correct performance in Experiment 3 for the controls (CON) and the amnesic patients (AMN) on four different sessions. The open bars show performance when the same letter set was used to construct the study and test items, and the shaded bars show performance when a different letter set was used to construct the study and test items. Error bars indicate standard error.

to be impaired on the classification test ($p = .06$). The difference was small, with the amnesic patients performing only 3.1% lower than the controls across the four classification tests. It is also worth noting that this difference between groups stands in contrast with the results of Experiment 1 and also with the results of three previous experiments, in which amnesic patients performed as well as or even numerically better than controls on grammatical classification tasks, with no hint of a trend for impaired performance (Knowlton et al., 1992; Knowlton & Squire, 1994). One possibility is that the performance of the amnesic patients was adversely affected by interference from their earlier experience with the artificial grammars (in Experiment 2 and also in the first two sessions of Experiment 3). Interference could have occurred because some of the same letters appeared in Grammars A and B (which were used in Experiment 2 and in the final two sessions of Experiment 3) and in Grammars C and D (which were used in the first two sessions of Experiment 3). In addition, the possibility for interference in the amnesic patient group was greater than in the control group. For the amnesic patients in Experiment 3, the interval between the first two sessions and the final two sessions ($M = 1.4$ months) was shorter than for the controls (10.2 months). Also, the controls in Experiment 3 did not participate in Experiment 2 and would not be susceptible to interference; whereas the amnesic patients in Experiment 3 had participated in Experiment 2 2.5 months earlier. The possibility of interference seems a real one because individuals have been shown to retain grammatical knowledge for as long as 2 years (Allen & Reber, 1980).

It is important to note that, despite their slightly lower level of performance, the amnesic patients exhibited the same pattern of performance as the controls. Specifically, they performed better when the same letter-set condition was used at study and test than when the different letter-set condition was used. At the same time, performance in the different letter-set conditions was unmistakably above chance. Thus, to make their grammatical classification judgments, the amnesic patients relied on both abstract knowledge and concrete, exemplar-specific knowledge to the same extent as controls.

General Discussion

In this series of experiments, amnesic patients and controls demonstrated that both abstract and exemplar-specific information can contribute to classification judgments. In Experiment 1, both groups endorsed grammatical test items more than nongrammatical items, even though chunk strength was equated for the two types of items. In addition, the chunk strength of an item had a separate influence on the tendency to endorse an item as grammatical, though this influence was observed only for nongrammatical items. These results support the idea that rule-based information influences classification judgments and that exemplar-specific information can make an additional contribution. In Experiment 2, recognition memory for letter chunks was severely impaired in amnesic patients, demonstrating that the good classification performance exhibited by amnesic patients cannot be accounted for by their declarative knowledge about grammatically permissible chunks. Experiment 3 provided further evidence for both amnesic patients and controls that abstract knowledge contributes to classification judgments. Both groups exhibited above-chance classification performance when test items were constructed from a different letter set than the one used to construct training items. However, Experiment 3 also supported the idea that exemplar-specific information influences grammaticality judgments to some degree because the two groups performed better when the same letter set was used to construct training and test items than when different letter sets were used. Finally, the finding that amnesic patients performed like controls in all three experiments supports the idea that both abstract and exemplar-specific information can be learned implicitly.

It has sometimes been supposed that, if performance on classification tasks is exemplar-specific, such performance cannot be supported by implicit memory. However, several forms of implicit memory that are exemplar specific have been well studied in humans and experimental animals. One example of such a task in which exemplar-specific information is acquired is priming. In a priming task, a stimulus item is processed more rapidly or accurately after an earlier exposure to the stimulus. Priming is intact in amnesia and does not depend on the brain structures that are important for declarative memory (the hippocampal formation, adjacent medial temporal lobe cortices, and midline diencephalic structures; for reviews, see Schacter et al., 1993; Zola-Morgan & Squire, 1993). Artificial grammar learning may be similar to priming in the sense that a test item containing chunks that were repeated frequently during training might be processed more fluently, thus leading to the item being endorsed more readily as grammatical. Indeed, it is known that single stimulus presentations not only increase the facility with which a stimulus is processed but can also influence preferences and judgments involving that stimulus (Jacoby, Woloshyn, & Kelley, 1989; Kunst-Wilson & Zajonc, 1980; Mandler, Nakamura, & Van Zandt, 1987; Squire & McKee, 1992). Recently, normal individuals trained on an artificial grammar were found to perceive grammatical items more readily than nongrammatical items, as measured with a perceptual identification task (Buchner, 1994).

Another possible view of artificial grammar learning is that it is akin to habit learning. Thus, one might suppose that during training participants are implicitly accruing exemplar-specific information in the form of associations between chunks and the grammatical category. By this view, an individual learns gradually across multiple trials to associate two stimuli or a stimulus and an outcome. A single trial is not critical. Rather, individuals extract the invariant properties of stimulus items across many trials and in this way acquire information about the structure of the stimulus set. Studies demonstrating the independence of habit learning from hippocampal function and declarative memory have typically involved experimental animals (see Squire, 1992, for a review). Recently, however, an analogue of habit learning has been demonstrated in humans, and performance on this task was found to be intact in amnesic patients (Knowlton, Squire, & Gluck, 1994).

Studies with experimental animals indicate that habit learning is impaired by neostriatal damage (Packard, Hirsh, & White, 1989; Wang, Aigner, & Mishkin, 1990). In a preliminary study, patients with Huntington's disease, who have neural degeneration in the caudate nucleus, exhibited normal artificial grammar learning (Knowlton, Squire, & Butters, 1994), suggesting that the neostriatum may not be involved in such learning. This finding, together with the finding that patients with Huntington's disease also exhibit intact word stem completion priming and fragmented picture identification priming (Heindel, Salmon, & Butters, 1990; Heindel, Salmon, Shultz, Walicke, & Butters, 1989; Randolph, 1991), suggests that neither artificial grammar learning nor priming depends on the neostriatum and raises the possibility that artificial grammar learning is based, at least in part, on perceptual fluency.

In Experiment 3 and in previous studies, performance was better when the training and test letter sets were the same than when they were different. This finding is consistent with the finding that perceptual priming is sensitive to the physical features of the stimulus (Roediger & McDermott, 1993). However, the fact that letter-set transfer performance is quite robust suggests that artificial grammar learning differs from perceptual priming in that abstract representations make a substantial contribution to performance.

The present results show that classification performance on artificial grammar tests depends not only on exemplar-specific information but also on more abstract, rule-based knowledge. This conclusion was based on the findings that (a) the grammaticality of the test items influenced classification judgments, even when grammatical and nongrammatical test items were balanced for chunk strength (Experiment 1); (b) the similarity between whole test items and whole training items did not influence classification judgments when test items were balanced for chunk strength (Knowlton & Squire, 1994); and (c) participants were able to transfer grammatical knowledge to new letter sets (Experiment 3). The question arises, What kind of abstract, rule-based knowledge is being acquired during artificial grammar learning, which can then support transfer to new letter sets? One possibility is that individuals are forming explicit hypotheses about correspondences between the individual letters used at study and the letters used at test. This possibility seems unlikely, however, because amnesic patients transferred performance to new letter sets nearly as well as controls, even though they would have had difficulty testing hypotheses that were based on explicit memory for the training items.

Another possibility is that individuals are not learning grammatical rules but are forming specific, abstract analogies between training items and test items that are constructed from different letters (Brooks & Vokey, 1991; for example, *MXVVVM* might be analogous to *BDCCCD*). Although the similarity of test items to specific training items does not appear to influence judgments when congruent letter sets are used at study and test (Knowlton & Squire, 1994), one could suppose that individuals use specific-item knowledge to construct analogies when they are presented with a new letter set at test. In a study of letter-set transfer, Brooks and Vokey showed that participants were more likely to endorse test items that were analogous to specific training items than items that were not. However, the training procedures used in their study were likely to have resulted in good explicit memory for the training items, suggesting that analogies between test items and training items are based on explicit knowledge.

In the present study, in which much less study opportunity was given for individual training items, amnesic patients exhibited good letter-set transfer performance, so it is unlikely that participants depended on explicit analogies to accomplish letter-set transfer. Nevertheless, it is difficult to rule out the possibility that specific-item knowledge (e.g., some kind of analogy learning) does contribute to letter-set transfer performance. For example, in two earlier studies of artificial grammar learning (not letter-set transfer experiments), participants were presented with training exemplars from two artificial grammars under two different encoding conditions (Brooks, 1978; Whittlesea & Dorken, 1993). Subsequent classification performance was influenced by memory for which training items were associated with which encoding condition. At the same time, it is unclear whether amnesic patients would perform these tasks as well as normal individuals. Indeed, we would suppose that amnesic patients would not do well because declarative memory is likely involved in tasks that require individuals to discriminate between different artificial grammars. In any case, the good letter-set transfer performance exhibited by amnesic patients in the present study indicates that their knowledge is implicit in these conditions and independent of the explicit, specific-item knowledge used to make recognition judgments.

Perhaps the most likely possibility for the kind of abstract, rule-based knowledge that supports letter-set transfer is that individuals are implicitly learning some rules about permissible locations of letter repetitions, alternations, or dependencies between different parts of the letter strings (e.g., a doublet cannot be followed by another doublet or alternating letters often occur at the beginning of a string). Such rules would be abstract in the sense that they are not tied to the identity of specific letters. The present results support the idea that such rules can be learned implicitly.

In summary, both abstract, rule-based information and concrete, exemplar-specific information appear to contribute to classification judgments in an artificial grammar learning task. Both types of knowledge can be acquired independently of declarative memory. It would be interesting to determine the conditions that differentially affect these two kinds of implicit knowledge, as they could depend on distinct processes and on different neural substrates.

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Appendix

Training and Test Letter Strings Used in Experiment 1

Training items

XXVT
XXVXJJ
VXJJ
XVJTVJ
XXVXJ
XVX
VXJJJJ
XVT
XXXVT
VJ
XVXJJJ
VJTVTV
XXVJ
VTVJ
VJTVX
XXXVTV
XXVJ
VJTVX
XXXVTV
XVXJJ
VT
VJTVXJ
XXXVX
VJTXVJ
XVXJ
XXXXVX

Test items

Grammatical and high chunk strength	CS	Grammatical and low chunk strength	CS	Nongrammatical and high chunk strength	CS	Nongrammatical and low chunk strength	CS
XXVXJ	10.4	VJTVT	6.0	VJTV	7.0	XXJJ	6.8
XVTV	6.8	VTVJJ	5.1	XXV	12.3	VXJTJ	4.9
VXJ	9.3	VTVJ	5.6	XVXV	10.0	XXVVJJ	6.2
XXVTV	8.0	XVJTVT	6.7	XVXVJ	9.1	JXVT	5.0
XVJTVX	7.4	VTV	5.0	XXVJJJ	7.8	XXTX	2.8
XXVTVJ	7.7	XVTVJ	6.7	XJJ	7.0	TVJ	6.7
VJTXVX	6.8	XVTVJ	6.1	VXVJ	8.2	VXJJX	5.9
VX	12.0	VTVJJ	5.2	XVXT	7.0	VJJXVT	4.9
M	8.6	*M*	5.8	*M*	8.6	*M*	5.4

Note. CS = chunk strength.

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