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A Critical Reappraisal of the Evidence for Unconscious Abstraction of Deterministic Rules in Complex Experimental Situations

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In a recent experiment (Lewicki et al., 1988) subjects were submitted to a four-choice RT paradigm for 3600 trials. On each of the successive logical blocks of five trials, the first two locations of the target were randomly distributed, and the last three locations were determined by complex rules. Although subjects were unable to verbalize the actual nature of the manipulation, performance on the last trials of each block improved at a faster rate and was better overall than performance on the first trials. In addition, subsequent rules changes on 480 additional trials only affected performance on the last three trials of each block. The present paper demonstrates that contrary to Lewicki et al's assertions this performance pattern requires neither acquisition of tacit knowledge of the composition rules, nor partitioning by the subjects of the sequence into logical blocks of five trials. Rather, the results can be accounted for by the relative frequency of a few simple sequences of target locations. Moreover, this alternative explanation alone correctly anticipates some striking features of fine-grained performance (Lewicki et al., 1988). The discussion focuses on methodological implications of these findings for investigation of unconscious learning, and speculates on what and how people learn when they encounter a complex and structured situation. © 1990 Academic Press, Inc.

The recent literature reflects a growing interest in the distinction between two modes of learning (e.g., Berry & Broadbent, 1988; Hayes & Broadbent, 1988; Mathews, Buss, Chinn, & Stanley, 1988; Perruchet, 1988; Reber, 1989). Although authors differ in their use of terminology and minor features of theoretical assessment, most would adhere to the following general description. The first mode of learning is thought to be activated when the situation to be learned is a simple one. People perform controlled operations on the conscious representation of identified and isolated variables of the stimulus environment. Traditional concept learning and problem solving experiments deal primarily with this adaptive

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mode. It becomes inefficient however when a large number of variables are involved, and/or when the structure of the situation is not salient. In this case, subjects may adopt the second learning mode whose properties contrast the first: here, the representation of events is unavailable to conscious awareness, and processing of these representations is beyond attentional control. Both conscious and unconscious, or explicit and implicit, modes of learning are assumed to concur in the elaboration of a common corpus of knowledge which is mainly composed of the rules (or a subset of the rules) underlying the situation to which subjects are exposed.

The Implicit Learning of Synthetic Grammars

The most extensive empirical support for this general model comes from the field of artificial grammar learning, as explored over the last 20 years by Reber and his associates (e.g., Reber, 1967; Reber, Allen, & Regan, 1985). In a typical experiment, subjects first study a set of letter strings generated from a synthetic grammar which defines authorized letters and the permissible transitions between them. After studying some representative exemplars, subjects are asked to categorize new letter strings as grammatical or nongrammatical. Nongrammatical items are formed from the same subset of letters, but violate transition rules. When the underlying grammar is made salient and easy to discover, subjects categorize better when given explicit instructions (i.e., instructions engaging the subject in a search for the rules) than with implicit instructions (i.e., instructions which stress the need to pay attention to items, but divert subjects from the search for rules). This pattern is interpreted as showing that performance taps the first mode of learning (Reber, Kassin, Lewis, & Cantor, 1980).

When the structure of the stimulus is made very difficult to discover, subjects always perform better than chance. Nevertheless, implicit instructions are more efficient than explicit instructions (Reber, 1976; Reber et al., 1980). Since subjects in this condition are unable to verbalize the rules underlying their decision of well-formedness, their performance is thought to be the end-product of an unconscious abstraction process.

The evidence for this alternative mode of learning provided by synthetic grammar learning has been challenged by Dulany, Carlson, and Dewey (1984, 1985). According to these authors, subjects exposed to a set of strings generated by a complex synthetic grammar learn a multitude of simple rules rather than an integrated representation of the grammar. These microrules are thought to be limited in scope and imperfectly valid, in the sense that they cannot lead to correct decisions on the well-formedness of letter strings in all cases; however, they are sufficient to account for observed performance, which is only probabilistic in nature.

This hypothesis has obvious implications for the relationships between learning and consciousness; briefly, the observed inability to verbalize the abstract rules forming the grammar is clearly compatible with the claim that a large number of simple and approximate rules are available to conscious awareness.

Although Dulany et al. (1984) provide empirical confirmation for their view by showing that subjects are able to locate specific features of the letter strings motivating grammaticality judgments, their procedure does not provide an unambiguous means of determining the content of knowledge which underpins grammaticality assessment. In a recent series of experiments, Perruchet and Pacteau (1990) tested a specific hypothesis on the nature of rules extracted from representative examplars, namely that subjects acquire conscious fragmentary knowledge of permissible pairs of letters irrespective of the position of these pairs in the strings. The results can be summarized in four points. (a) Grammaticality judgments of subjects initially studying grammatical letter strings do not differ from judgments of subjects learning from a list of the different permissible pairs of letters, a condition which precludes the abstraction of complex rules. (b) Judgments are extremely poor when the test of grammaticality requires more than the knowledge of pairs of letters. (c) Subjects learning from the letter strings perform better than chance on a subsequent recognition test on the separate pairs of letters making up these strings. (d) A simulation of the strategy involving nongrammaticality judgment for any test string containing at least one unrecognized pair of letters yields performances which match nicely with the observed ones. These findings unambiguously refute the claim that the grammaticality judgments of subjects learning a complex artificial grammar necessarily involve unconscious abstraction of its composition rules.

The present paper addresses issues presented in a study recently published by Lewicki, Hill, and Bizot (1988). This study claims to provide evidence that subjects unconsciously abstract tacit knowledge about a complex pattern of events in a situation which departs from the artificial grammar learning paradigm. We intend to demonstrate that subjects' performance, as in grammaticality judgments in artificial grammar settings, can be explained by an alternative framework which does not assume nonconscious rule abstraction. A detailed account of the Lewicki et al. (1988) study is presented below, and is followed in the next section by our alternative interpretation of their data.

The Lewicki, Hill, and Bizot (1988) Study

After reading instructions, subjects are seated facing the screen of a microcomputer, which is divided by one vertical and one horizontal line into four quadrants of equal size. Subjects are exposed to a long sequence of 3600 frames divided into 15 segments of 240 frames with 10-s breaks between segments. Each frame consists of a target (letter X) presented in one of the four quadrants. Subjects are asked to react to the appearance of the target by pressing the key which spatially matches with the location of the target on the numeric keypad of the microcomputer (subjects were requested to use keys 4, 5, 1, 2, which formed a 2 × 2 square). Instructions stress both speed and accuracy of response.

The sequence of frames was structured as follows. The 240 frames of each segment consisted of 48 logical blocks of 5 frames each. The two first locations of the target in these blocks (hereafter A and B) were pseudorandomly distributed, except that the target was never displayed twice in the same location. In contrast, the last three locations (C, D, and E) were determined by second-order recurrent rules: they always depended on the two preceding locations of the target. However, the specific rules in use changed between presentations of C, D, and E. For example, if the target "moved" (in the Lewicki et al. study, a discrete transition between two targets is termed a "movement") horizontally from A to B, the movement from B to C was vertical. If the target moved horizontally from B to C, the movement from C to D was diagonal, and so on.

The subjects were not informed of the existence of any rules, or even that the series was segmented into logical blocks of five trials. Nevertheless, a sequence of five notes (timing note A, G, F, E, and D) accompanied the five trials in each block, in order to help subjects process the material in terms of chunks of five trials.

There was global improvement in performance over the 15 segments, attributed to unspecific training. However, the main result was a progressive differentiation between performance on trials A and B, and performance on trials C, D, and E: performance on trials C-D-E improved faster and was better overall than performance on trials A-B.

The pattern of the simulus material was modified for two final segments (16 and 17). Specifically, the rules determining the location of the target for trials C-D-E were "reordered." For example, the rule that was used for the first 15 segments to determine the location of trial C was now used to determine the location of trial E, and so on. As predicted, performance on trials C-D-E decreased drammatically, while performance on trials A-B was essentially unaffected by the change in pattern.

At first glance, these results provide convincing evidence that subjects acquire some knowledge of the composition rules relating the position of the target on trials C, D, and E to its two preceding locations. Furthermore, since none of the subjects, who were all faculty members of a University Psychology Department, could state anything even approximating the pattern of exposures when questioned in an extensive postexperimental interview, Lewicki et al. claim that their results "demonstrate that nonconsciously acquired knowledge can automatically be utilized to facilitate performance, without requiring conscious awareness or control over this knowledge.''

An Alternative Interpretation of the Lewicki et al. (1988) Results

This section is intended to show that the Lewicki et al. findings do not imply that subjects acquire knowledge about the rules determining the location of the last three targets (C-D-E) in each logical block of five trials, and moreover challenges the assumption that subjects partition the sequence into logical blocks. This obviously entails that the Lewicki et al. claims regarding nonconscious processing do not hold: the fact that subjects do not articulate any of the composition rules no longer applies if improvement in performance turns out to be unrelated to this kind of knowledge.

To begin with, a general outline of our argument will be presented. Close examination of the sequence of trials shows that the frequency of occurrence of particular events differs from a random distribution. The events of interest here are not the locations of the target per se, which Lewicki et al. were careful to equalize for each quadrant, but the nature of the ''movement'' of the target from one location to the next. Because RTs are highly sensitive to the frequency of events in a sequence, it is likely that the length of RTs will be directly proportional to the infrequency of the last movement of the target. The crucial point is that frequent and infrequent movements are not equally distributed over A-B and C-D-E trials: infrequent events occur mainly in A-B trials. This stems from the fact that the composition rules determine both the rarity of some events in the whole sequence, and the selective occurrence of these events in specific trials. As a consequence, RTs for A-B trials are longer than those for C-D-E trials.

Recall that the target was never displayed in the same location twice. If transitions had been distributed randomly, the probability of horizontal, vertical, and diagonal movement from one trial to the next would be .33. The actual distribution of the events in the Lewicki et al. arrangement[1] diverges substantially from this a priori value, in that there were only 20% horizontal movements in the whole session. Similarly, the probability for the target to return to the same location after being displayed in only one other location, i.e., to move back and forth between two quadrants,

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[1] The Lewicki et al. (1988) paradigm includes two orders of presentation: the sequence utilized for segments 1 to 15 for part of the subjects was used for segments 16 and 17 for the remaining subjects, and vice versa. As mentioned above, both sequences rely on closely related patterns, and empirically, order of presentation does not affect any of the dependent measures. Only the first order will be examined in the following development.

would also be .33. Instead, back and forth movements only amounted to 10.83% of the total number of trials in the session.

Turn now to the distribution of these events within each block of five trials. Infrequent movements tended to selectively precede trials A and B because they were partially or totally prohibited by the composition rules applying to trials C-D-E. Horizontal movements were excluded by the rules generating the location of the target for trials D and E. As a result, the proportion of horizontal movements was far higher for trials A-B (34.4%) than for C-D-E (11.1%). Selectivity was even more striking for the back and forth movements, which only appeared before trials A and B (where they represented 27.2% of the trials). Both causes may have cumulated to account for the fact that RTs on trials A-B were higher than the pooled RTs on trials C-D-E.

The same line of reasoning applies to the lengthening of RTs on trials C-D-E when the pattern of exposure was changed on segments 16 and 17. Analysis of the new pattern shows that horizontal movements now occur before C, D, and E trials ("reordering" of the rules now prevents vertical movement on trials D and E). Therefore, the mean RT for trials C-D-E computed on segments 16 and 17 includes a higher proportion of long RTs consecutive to horizontal movement than was previously the case (33.3 vs 11.1%).

Testing the Alternative Interpretation

We show above that our alternative interpretation accounts for all the experimental findings reported by Lewicki et al. (1988). However, it also predicts specific features in the fine-grained pattern of subjects' performance, which can not be anticipated from the Lewicki et al. framework. These predictions will be used to test the relevancy of each interpretation.

Table 1 categorizes trials according to three criteria: (1) whether they are the backward step of a back and forth movement, (2), the direction of the last movement (horizontal vs. diagonal and vertical), and (3) rank within blocks (A-B, C, and D-E). Certain theoretical combinations of these criteria never occur, since the rules prohibit back and forth movements for trials C-D-E, and horizontal movements for trials D-E. Presented and chance movement frequencies are reported in marginal rows and columns. The icons in the cells stand for the predicted pattern of results for both conceptual frames. The "plus" signs indicate the trials for which high RT values are expected if it is assumed that performance depends on the overall frequency of events in the sequence; they appear in the column labelled "horizontal movement" and the line marked "backward movement." The upper left-hand cell is indexed by two "plus" signs, because a horizontal/backward movement is especially rare. Likewise, an "asterisk" designates the trials for which longer RTs

TABLE 1
Predicted Results

			Frequency	
	Horizontal	Diagonal/vertical	Presented	Chance
Backward	A–B††*	A–B†*	10.8	33.3
Nonbackward	A–B†*	A–B*		
	C†	C	89.2	66.7
		D–E		
Presented frequency	20.0	80.0		
Chance frequency	33.3	67.7		

Note. The trials are classified according to (1) whether they involve a backward movement, (2) the direction of the last movement (horizontal vs. diagonal/vertical), and (3) their rank within blocks (A–B, C, D–E). As a consequence of composition rules, some movement patterns never occur in C, D, and E positions. Presented and chance movement frequencies are reported in marginal rows and columns. We predict long RTs for infrequent events, that is for the events appearing in the first row or the first column of the table (marked "†"). According to Lewicki et al., long RTs should occur on A–B trials (marked "*") because the location of the target is not determined by composition rules.

are expected on the basis of the knowledge of the composition rules structuring the logical blocks of five trials; it indexes the A-B trials (note that the consistent focus throughout the paper on conditions which lengthen RTs rather than on conditions improving performance has no intended empirical or theoretical relevance: only relative speed of reaction is of interest). The two sets of predictions differ on several points. For example, only the alternative model predicts that when considered separately, RTs on C trials are longer than RTs on D and E trials. Another striking difference concerns the RTs on trials A-B which do not involve a backward movement. We expect them to differ from other A-B trials, but not from the comparable C-D-E trials, while the Lewicki et al. framework predicts the opposite pattern.

These two sets of predictions concern the RTs obtained for segments 1 to 15. The RTs for segments 16 and 17 may also be used to test both interpretations. Our hypothesis is that lengthening of RTs on trials C-D-E in contrast to their values on segments 1 to 15 is due to the appearance of horizontal movements on trials D-E. This leads to the prediction that the lengthening of RTs selectively affects trials D and E, but not trial C where the proportion of horizontal movement remains unchanged. Recall that this configuration cannot be hypothesized in the Lewicki et al. framework, since the reordering of rules affects C as well as D and E trials.

Since Lewicki et al. pooled performances on C, D, and E trials, and did not provide separate data for backward and horizontal movements, none of the above predictions can be tested from their original article. Therefore, a replication of the Lewicki et al. experiment was carried out in order to collect the raw data needed for the re-analysis of results along the lines suggested above.

The replication used a larger sample of subjects than the original experiment because our re-analysis involves a more fine-grained analysis of data. In addition, a new procedure for the last two segments (16 and 17) was designed for a subset of the subjects: the same sequence of trials as for the first 15 segments was used, but the target was not displayed on some selected trials, and the subjects were asked to predict its more probable location by pressing the corresponding key on the numeric keypad. This manipulation was intended to confirm and extend chronometric analyses by a direct assessment of subjects' expectations regarding the location of the target. For the sake of clarity, the detailed objectives of this part of the experiment will be made explicit in the Results section.

METHOD

Subjects

Forty third-year university students (ages 22 to 29) majoring in psychology served as subjects, in partial fulfillment of a course requirement.

Material and Procedure

For the first 15 segments, the experiment was a replication of the Lewicki et al. procedure. The program was written for an ATARI Mega ST2 in a way that mimicked all the outputs of the original program, which was run on an IBM-PC computer. The instructions were verbatim French translations of the Engish version; the same sequence of trials was used, with the same timing. Each trial was accompanied by a tuning note as in the original arrangement, and so on. A detailed description of these common features can be found in Lewicki et al. (1988).

Only two minor changes were introduced, both of which were due to differences in recruitment of subjects. First, subjects were all tested in the same environment (a sound-attenuated experimental box) rather than in their own or in colleagues' offices. Second, subjects were informed at the beginning of the experiment that the session was structured in segments separated by short breaks. They were informed of the total number of segments, and a running count of the segments was displayed during each break. This change was introduced because it was found to minimize subjects' discouragement or irritation during pilot studies. Recall that subjects of Lewicki et al. (faculty members in a psychology department) were a priori more motivated and cooperative on this long and boring task.

Half of the subjects were presented with segments 16 and 17 that replicated the Lewicki et al. procedure: the rules relating the location of the target to the preceding two locations were re-ordered, but the task remained identical for the subject.

The other half of the subjects were run on a new procedure. The structuring rules were the same as those for the first 15 segments, and for most of the trials the subject's task remained unchanged, i.e., pressing the key in spatial correspondence with the location of the target. However, on a few trials (hereafter referred to as "guess trials") the target was replaced by a question mark which was displayed in the center of the screen. The guess trials were distributed as follows. As explained at length in Lewicki et al., the entire sequence was composed of a repetition of 12 different blocks of five trials. One guess trial occurred on each of the 12 * 5 = 60 different trials. They were distributed pseudorandomly through segments 16 and 17, so that there were never fewer than 4 targets and never more than 11 targets between two successive guess trials.

The normal course of the experiment was interrupted after segment 15. Subjects were then instructed about their additional task. They were asked to press the key matching the location of the target which seemed the more probable when a question mark was displayed in the center of the screen. They were encouraged to respond quickly, and to try not to think about the task. The microcomputer recorded both latency and nature of guessing.

Regardless of task on segments 16 and 17, none of the subjects was subsequently interviewed. This departure from Lewicki et al.'s original procedure stems primarily from the lack of reliability of verbal reports after a change in procedure on the last 480 trials. Furthermore, the issue of the availability of frequency related knowledge is somewhat marginal to our main focus, for reasons which will be discussed later at length.

RESULTS

Lewicki et al. (1988) used the number of accurate responses faster than 400 ms as the main dependent variable, rather than the more conventional latency data. We performed analyses on both these variables, and found the results to be comparable. In particular, there were no crucial changes regarding the statistical significance of effects. This article reports all the descriptive and inferential results on RTs, because this familiar indicator of performance provides a better general assessment of the magnitude of the effects. Analyses of the number of fast and accurate responses paralleling those of Lewicki et al. will be also presented, and the figures will be plotted against Lewicki's units in order to facilitate direct comparison between studies.

Comparison with the Lewicki et al. Results

The two groups of subjects in the present experiment differed only with respect to segments 16 and 17. An ANOVA performed on the first 15 segments with groups as a between-subjects factor, and segments and trials as repeated measures factors, revealed no main effect for groups ($F < 1$), and no significant interaction for groups with other factors (all Fs < 1.04). Therefore, the data collected for the first 15 segments were pooled over groups.

As in the Lewicki et al. report, RT means dropped sharply over the first 15 segments, presumably due in part to unspecific training, and increased significantly between segments 15 and 16 [($F(1,19) = 4.52, p = .047$]. The RTs on trials C-D-E for the first 15 segments were globally shorter than the RTs for trials A-B [$F(1,39) = 324, p < .0001$], and the former decreased more quickly than the latter across the segments, as shown by the interaction between trial (A-B vs C-D-E) and segment factors [$F(14,546) = 1.77, p = .039$]. In addition, the change of pattern on segment 16 had a selective detrimental effect on trials C-D-E: RTs on segment 16 were longer than RTs on segment 15 for trials C-D-E [$F(1,19) = 10.9, p =$

.004], but not for trials A-B ($F < 1$), thus generating a significant interaction between segments (15 vs 16) and trials (A-B vs C-D-E) [$F(1,19) = 12.28, p = .002$].

The same general outcome was observed for the number of fast (TR < 400 ms) and accurate responses. As shown in Fig. 1 (which corresponds to Fig. 4 in the Lewicki et al. report), this score was better overall [$F(1,39) = 376.17, p < .0001$], and increased faster [$F(14,156) = 14.4, p < .0001$] for trials C-D-E than for trials A-B. Performance deteriorated between segments 15 and 16 for C-D-E trials [$F(1,19) = 25.03, p < .0001$], while performances for trials A-B remained stable [$F(1,19) = 1.72, p = .21$]. The interaction between trials (A-B vs C-D-E) and segments was significant [$F(1,19) = 53.8, p < .0001$].

These results closely parallel those of Lewicki et al. The main difference which emerges from a graphical comparison of both sets of data concerns initial performance. In our experiment, differentiation of responses on trials A-B and C-D-E appears early in the session: planned comparisons revealed a significant difference between trials A-B and C-D-E as of the first segment, for both RTs [$F(1,39) = 69.03, p < .0001$] and

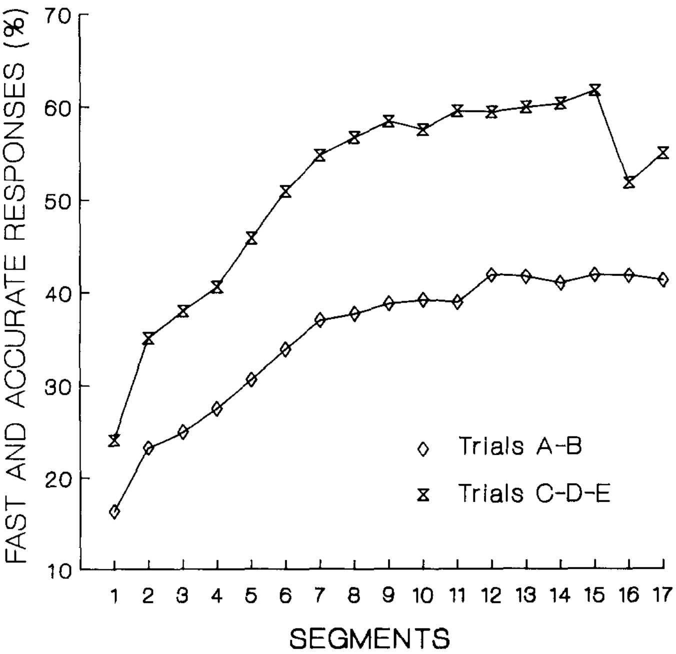

FIG. 1. Percentage of fast (RT < 400 ms) and accurate responses for trials A-B and C-D-E separately. For segments 1 to 15, percentages were computed from 1920 values for A-B trials, and 2880 values for C-E trials. These values must be divided by two for segments 16 and 17, since only half of the subjects were submitted to the reversal procedure.

fast and accurate responses [$F(1,39) = 35.27$, $p < .0001$]. Although Lewicki et al. did not provide analogous tests (which in any case would have been less powerful than ours, since they would be based on a substantially smaller number of observations), the differentiation in performances seems to occur later. It is worth noting that this putative difference in results has no substantive implications for the relevance of the following re-analysis.

Experimental Tests of Alternative Interpretations

Lewicki et al. (1988) did not anticipate any difference in performance between C trials and D-E trials, since the location of the target was determined in all cases by a similar set of rules. In contrast, we hypothesized that RTs obtained during the first 15 segments would be longer for C trials, which included horizontal movements, than for D-E trials, which did not. In addition, we expected no changes for the C trials during segments 16 and 17, since the number of horizontal movements remained unchanged.

Figure 2 shows the number of fast and accurate responses (to allow for

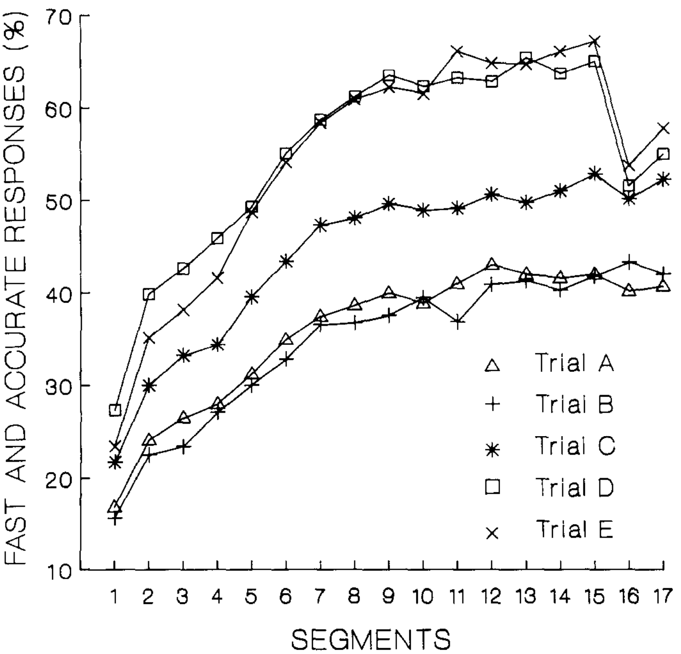

FIG. 2. Percentage of fast (RT < 400 ms) and accurate responses separately for A, B, C, D, and E trials. For each point, percentages were computed from 960 trials for segments 1 to 15, and from 480 trials for segments 16 and 17.

a direct comparison with Fig. 1) separately for trials A, B, C, D, and E. Figure 3 displays the corresponding RT data. Our predictions are clearly confirmed. On the first 15 segments, RTs on C trials differed significantly from RTs on D-E trials [$F(1,39) = 160$, $p < .0001$], and this difference increased over segments, as shown by the segments-ty-trials (C vs D-E) interaction [$F(14,546) = 2.81$, $p = .0005$]. The change in rules on segment 16 elicited a decrement in performance for trials D-E [$F(1,19) = 31.8$, $p < .0001$], but had no significant effect on C trials ($F < 1$). This pattern of results generated a reliable interaction between the nature of trials (C vs D-E) and segments (15 vs 16) [$F(1,19) = 23.88$, $p = .0001$].

Table 2 presents the joint influence of horizontal and backward movements on RT performance on trials A-B, C, and D-E over the first 15 segments. The values should be interpreted in terms of the predicted effects presented in Table 1. The empirical data exhibit a strikingly good fit with our hypotheses, while the predictions derived from the Lewicki et al. framework are clearly disconfirmed.

The trials involving horizontal movements induced longer RTs than their counterparts for other directions of movement, on both A-B trials with [$F(1,39) = 39.71$, $p < .0001$] and without [$F(1,39) = 75.69$, $p <$

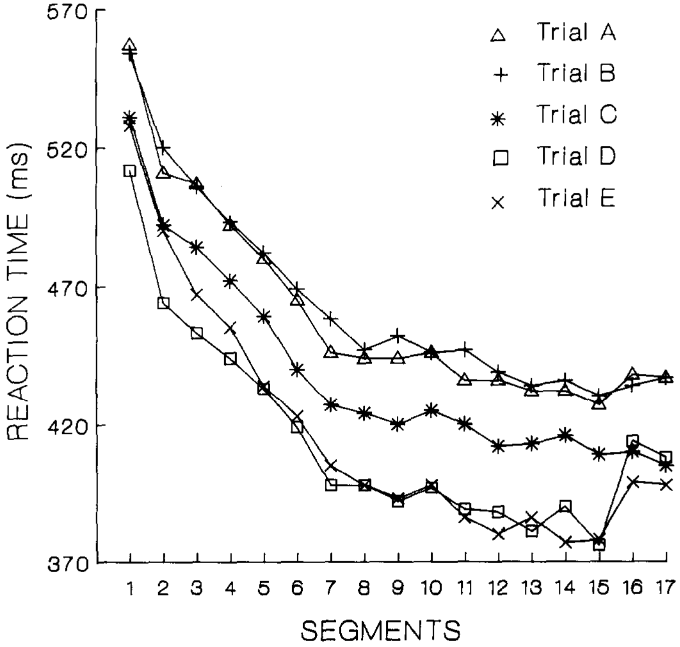

FIG. 3. Mean RTs separately for A, B, C, D, and E trials. Each point was averaged over 960 values for segments 1 to 15, and 480 values for segments 16 and 17.

TABLE 2

Observed Mean RTs for Trials Classified According to the Three Criteria in Table 1

	Horizontal		Diagonal/vertical		Mean RTs
Backward	A-B	546	A–B	511	528.5
Nonbackward	A–B	486	A–B	428	457.0
	C	479	C	433	456.0
			D–E	423	423
Mean RTs		503.7		448.7	

Note. Comparison with predicted results displayed in Table 1 shows that RTs fit much better with our predictions than with those of Lewicki et al.

.0001] backward movements, and C trials [$F(1,39) = 103.68, p < .0001$]. Backward movements also increased RTs, for both vertical/diagonal [$F(1,139) = 309, p < .0001$] and horizontal [$F(1,39) = 133.6, p < .0001$] movements. It must be emphasized that the occurrence of back and forth movements between two quadrants on A-B trials is sufficient to account for the difference between performance on trials A-B and C-D-E when the effect of the direction of movement is partialled out. RTs on trials A-B without backward movements did not differ from RTs on trials C-D-E when analyses were conditionalized upon vertical/diagonal movements ($F < 1$), or from RTs on C trials when analyses were conditionalized upon horizontal movements [$F(1,39) = 2.12, p = .15$].

To sum up, the differences in performance on trials A-B and C-D-E may be accounted for by the joint action of two factors: the presence of (infrequent) horizontal movements in trials A, B, and C, which lengthened the latencies by about 55 ms, and the presence of (infrequent) backward movements in trials A-B, which lengthened the latencies by more than 80 ms. Both factors seem to have additive effects, as shown by the fact that the highest mean RT was observed for horizontal backward movements.

Subjects' Explicit Predictions

The following analysis concerns the guessing task that half of the subjects performed on segments 16 and 17. The first objective of the procedure was to confirm results of the chronometric analyses, by showing that backward and horizontal movements are predicted less often than would be expected on a random basis. The relevant results are displayed in Table 3, extreme right-hand column. Out of a total of 1200 guessing trials, there were 68 repetition predictions. Of the residual 1132 responses, subjects predicted 174 (i.e., 15.4%) back and forth movements, and 234 (i.e., 20.7%) horizontal movements. It is worth noting that these observed values depart considerably from the theoretical 33.3%, and tend toward

TABLE 3
Results of the Guessing Phase

		TRIALS					
		A	B	C	D	E	Mean
Backward movement	Predicted	13.80	17.86	14.85	9.50	20.80	15.36
	Presented	31.25	22.92	0	0	0	10.83
	Chance	33.33	33.33	33.33	33.33	33.33	33.33
Horizontal movement	Predicted	17.24	22.77	17.90	20.36	25.22	20.70
	Presented	35.42	31.25	33.33	0	0	20.00
	Chance	33.33	33.33	33.33	33.33	33.33	33.33
Correct responses	Observed	21.98	37.50	50.65	62.00	54.00	45.23
	Chance	33.33	33.33	33.33	33.33	33.33	33.33

Note. All values are percentages. Predictions for repetition were eliminated from data before percentage computation.

the real percentages (10.83 and 20%, respectively). The fact that subjects' predictions matched the real frequency of events is not surprising, given the abundant literature on this point.

The second objective of the guessing task calls for preliminary comments on the intrinsic limits of chronometric exploration. In the introductory section, we posited that subjects would only be sensitive to the overall frequency of events across the entire sequence of trials. The foregoing analyses showed that this explanation readily accounts for the RT data. However, it is fair to acknowledge that RTs are ill-suited to reveal any knowledge about the structure of the sequence in logical blocks of five trials. This is because RT methodology can only measure expectations for events that occur at least a few times within a session. It provides no direct information on the degree of expectation for, say, a backward movement in trials C-D-E in the Lewicki et al. paradigm, since such an event never occurs. It is unfortunate not to have this information, since it is crucial for assessing whether subjects learn about the distribution of back and forth movements on A-B and C-D-E trials.

Analysis of subjects' predictions can overcome this limitation. Table 3 shows the percentage of predicted backward and horizontal movements for each kind of trial. The proportion of predicted backward movements for A-B trials did not differ significantly from the corresponding value on C-D-E trials [15.83 and 15.05%, respectively, $F(1,19) < 1$]. Moreover, there was a slight nonsignificant tendency toward predicting horizontal movements less often for trials A-B-C where they really occurred than for trials D-E [19.30 and 22.79%, respectively, $F(1,19) = 2.20$, $p = .15$]. These data run counter to the claim that subjects learn the frequency of events as a function of their location in the logical blocks of five trials.

TABLE 4
Results of the Guessing Phase for the Trials on which Eliminating Backward/Horizontal Movements Left Two Possibilities Open (Vertical and Diagonal)

		TRIALS	
		C	D
Backward and horizontal movements	Predicted	10.26	5.48
	Presented	0	0
	Chance	33.33	33.33
Vertical movement	Predicted	58.97	30.14
	Presented	100	0
	Chance	33.33	33.33
Diagonal movement	Predicted	30.77	64.38
	Presented	0	100
	Chance	33.33	33.33

Note. All values are percentages. Predictions for repetition were eliminated before percentage computation.

Table 3 also displays the proportion of correct predictions. As expected, subjects were more accurate on trials C-D-E than on trials A-B [$F(1,19) = 40.53, p < .0001$]. Predictions tended to be correct less often for C trials than for D-E, but the difference does not reach significance [$F(1,19) = 1.65, p = .21$].

The guessing task was subjected to an additional, unplanned analysis[2] aimed at assessing whether factors linked to frequency of backward and horizontal movements were sufficient to account for the high rate of correct predictions on C, D, and E trials. The whole sequence of trials was structured in such a way that eliminating simple repetitions and backward and horizontal movements from guesses led to correct prediction on all the E trials, and on two-thirds of C and D trials. The following analyses are conditionalized on the remaining C and D trials (corresponding to eight predictions per subject). Because predictions for backward and horizontal movements are confounded for this subset of trials, eliminating these predictions still left two possible options open, namely vertical and diagonal movements. According to our line of reasoning, choices between these options should be randomly distributed.

The relevant data are displayed in Table 4. The small number of predictions for repetition (5.6% of the guesses) was eliminated before percentage computation. For illustrative purposes, consider the C trials. Backward/horizontal movements were predicted on 10.26% of these trials. If predictions were randomly distributed on the other trials, the rate

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[2] This complementary analysis was suggested by D. Kahneman.

of correct responses (here: vertical movement) should be approximately (100 − 10.26)/2, i.e., 44.87%. The difference between this value and chance (33.33%) illustrates to what extent a low rate of predictions for backward/horizontal movements improves the rate of correct responding. However, the actual proportion of correct responses (58.97%) considerably exceeds the expected value (44.87%). As shown in Table 4, the same pattern emerges for trial D. On the pooled C and D trials, 15 subjects made more correct than incorrect predictions, while only three exhibited the reverse pattern, a result which has a binomial probability of .004 (in this subanalysis, the number of trials-by-subjects was too low to validate the use of t or F statistics). The fact that correct predictions were vertical movement for C trials and diagonal movement for D trials shows that the response pattern was not due to a general tendency to predict a particular direction of movement.

Thus analysis of explicit predictions reveals that subjects acquire more thorough knowledge than has been postulated throughout this paper. A plausible interpretation is that subjects either acquire knowledge of some of the constituting rules, or memorize a subset of the sequences of trials generated by the rules, as Lewicki et al. (1988) contend. By extending our line of reasoning a step further however, another alternative is possible. Up to now, only first-order dependency (the location of the target on trial n as a function of the direction of its displacement from trial $n - 1$), and second-order dependency rules (the location of the target as a function of whether the target goes back to its location on the trial $n - 2$) have been examined. A closer examination of the trials included in the present subanalysis revealed a striking regularity involving a third-order structure: the locations of the three targets preceding each guess are all different, and correct predictions always correspond to the remaining (fourth) quadrant. Hence, subjects respond correctly whenever they eliminate the three preceding locations of the target as possible positions.

Could a tendency to "cover" the four quadrants in the smallest possible number of trials be learned from exposure to the whole sequence? To assess this, we counted how many times the target covers the four quadrants on four successive trials in the Lewicki et al. arrangement, and found that this occurs in 48.33% of the cases. When repetitions on the same location on consecutive trials are eliminated from the possible options, the corresponding chance value is $4!/4*3^3$, i.e., 22.22%. In order to take into account the departures from chance shown previously, we generated a pseudorandom series of 240 trials without repetition, in which the frequencies of backward and horizontal movements matched the frequencies observed in the Lewicki et al. sequences; after averaging over 1000 program-generated sequences, the sets of four trials covering the four positions represented 39.62% (SD = 2.62) of all the four trials sets. This value is markedly lower than the observed percentage, which proves that, on the Lewicki et al. sequence, the target covers the four quadrants on consecutive trials more often than would be expected by chance, even when chance estimates integrates the low rate of backward and horizontal movements.

Thus the reliable tendency to correctly predict a vertical movement on the C trials and a diagonal movement on the D trials when the factors linked to backward and horizontal movements are not relevant may be reduced to an acquired propensity to predict the four quadrant after the target has been located in the three other ones, as a consequence of the observed high proportion of sets of four trials in which the target covers the four quadrants.

DISCUSSION

What Underpins RT Modifications in the Lewicki et al. Procedure?

The present study provides a straightforward demonstration that the reliable differences in RT on the (unpredictible) first two trials and the (predictible) last three trials of each logical block of five trials observed in the Lewicki et al. (1988) paradigm may be attributed to the relative frequency of particular target transitions throughout the session. Subjects react more slowly to infrequent events, which, as a consequence of composition rules, tend to be located in the first two trials of each block.

The crucial events whose frequency has been the primary concern of this paper are horizontal displacements and back and forth movements. We do not claim that these are relevant entities for the subjects. Take horizontal movements for instance; this category includes four physically different movements (from left to right and from right to left on the upper and lower rows). Subjects may deal with these movements as a single functional unit; but they may also handle each kind of movement separately, or abstract intermediary units (for instance, movements on upper rows). The fact that subjects behave similarly when given a set of physically different events does not imply that the category subtending these events is represented in subjects' minds. Our study provides no information on this point, which calls for further specially designed investigations.

Whatever the outcome of these future investigations, the present findings demonstrate that RT modifications are not indicative of acquisition of knowledge pertaining to the complex and specific rules determining the location of the predictible targets within blocks, and furthermore, do not imply that subjects partition the sequence of trials into a succession of logical blocks. This conclusion rules out the interpretation that Lewicki et al. (1988) advocated. The same authors make incidental mention of an alternative interpretation for their results which warrants consideration. They argue that subjects could have learned a subset of the concrete sequences of trials generated by the rules, rather than the rules themselves; in other words, they could have memorized at least some of the A-B-C-D-E sequences, rather than the rules generating C-D-E from A-B trials. A similar interpretation, which stems from the exemplar-based model of categorization (e.g., Medin & Smith, 1981), has been put forward in the context of artificial grammar learning, with an additional assumption enabling generalization: since test strings usually differ from study strings, subjects would ground their decision for the well-formedness of new test items on the degree of global ressemblance with specific remembered instances of grammatical items (see Brooks, 1978, 1987; McAndrews & Moscovitch, 1985; Reber & Allen, 1978). It is worth noting that the evidence as a whole presented in this paper against the rule-abstraction model also applies to the explanation based on the direct retention of concrete sequence exemplars. This kind of explanation assumes that subjects partition the sequence into a succession of logical blocks, and we found no empirical support for this assumption. Furthermore, an exemplar-based model turns out to predict exactly the same RT pattern as a rule-abstraction model; for instance, it anticipates no difference between C, D, and E trials, and hence is unable to account for the striking specificity of the C trials exhibited above in Figs. 2 and 3.

When Explicit Predictions Reveal More Knowledge

Explicit subjects' predictions support to a large extent the general interpretation put forward for RT data. Backward and horizontal movements were predicted less often than would be expected on a random basis, and these predictions were not linked to the rank of trials within the logical blocks of five trials. However, predictions on a subset of trials where knowledge pertaining to the rarity of backward and horizontal movements was not relevant were found to be reliably better than chance, thus testifying to additional knowledge.

Although the chronometric data could not be submitted to analyses paralleling those carried on guesses, the fact that frequency of backward and horizontal movements account for the pattern of RTs without significant residuals suggests that RTs are not sensitive to the additional knowledge revealed by the predictions. A first possible explanation for this discrepancy is related to differences pertaining to the mode of expression of knowledge. However, the fact that explicit prediction testifies to knowledge that motor performance fails to reveal is somewhat puzzling. The available experimental data show a striking correspondence between subjects' predictions and RTs. For instance, there is strong evidence that subjects react markedly faster to stimuli that are correctly predicted than to stimuli that are incorrectly predicted when they verbalize which stimuli they expect prior to each trial in a choice RT paradigm (e.g., Geller & Pitz, 1970; Richard-Simon & Craft, 1989; cf. also Perruchet, 1985, Exp. 1, for related evidence). A second, more suitable explanation for the observed discrepancy is connected to when both these measures were obtained over the course of training. RTs were collected throughout the first 15 segments, and most of our analyses bear on mean estimates. Predictions were collected during segments 16 and 17. The most plausible interpretation of the data is that the complementary knowledge revealed through guessing emerges only on the last segments of the learning session.

Correctness of predictions for cases where knowledge pertaining to the low frequency of backward and horizontal movements is irrelevant can readily be explained within the Lewicki et al. (1988) framework, and we have no empirical argument to rule out this account. However, the explanation developed for RT data can be generalized a step further to cover this result. Above chance performance may be imputed to subjects' tendency to align their predictions with the high observed proportion of sets of four trials in which the target moves over the four quadrants. The results on the whole are consistent with the contention that subjects first learn about the relative frequency of events involving two consecutive trials (absence of repetition, low proportion of horizontal displacements) and three consecutive trials (low proportion of back and forth movements), and finally four consecutive trials (high proportion of four-trials sets covering the four quadrants). This interpretation is parsimonious, inasmuch as it neither requires that subjects partition the sequence in logical block of five trials nor that they learn the numerous and specific rules generating each block. Note that except for horizontal displacement, the apparently heterogeneous pieces of knowledge we attribute to subjects possess a straightforward psychological unity: they illustrate increasingly integrative instantiations of the single general principle that the outcomes of successive trials tend to be more diversified than in a truly random sequence.

The Issue of Awareness

The Lewicki et al. (1988) claim that subjects relied on unconscious knowledge is based on the fact that none noticed anything even remotely similar to the actual nature of the pattern of events during an extensive postexperimental interview. Since improvement in performance turns out to be causally independent from knowledge of the stimulus pattern the authors have in mind, this argument no longer applies. For instance, the fact that subjects did not mention the organization of the sequences in logical blocks of five trials provides no evidence for unconscious abstraction, since performance can be accounted for without assuming that subjects acquire this specific knowledge. Conversely, it is likely that in the Lewicki et al. work, subjects' reports on the frequency of occurrence of particular target transitions would have been rejected as irrelevant to the actual manipulation.

This does not imply that conscious awareness is necessarily involved in the task. The effect of the frequency of events on RTs may be accounted for by at least two very different interpretations. The first is that subjects build up a conscious representation of the relative frequency of events; this declarative knowledge would elicit a different degree of expectancy for each event, which would in turn affect RTs. Even if the processing of frequency information is influenced more by intentionality (e.g., Kellog & Dowdy, 1986; Naveh-Benjamin & Jonides, 1986; Sanders, Gonzales, Murphy, Liddle, & Vitina, 1987) than was previously assumed (e.g., Zacks, Hasher, & Sanft, 1982), there is a general consensus that frequency encoding is a partially automatic process. Thus reliable knowledge of the frequency of events may have emerged in the Lewicki et al. experiment, even though subjects were not specifically oriented towards this type of learning.

Conscious representation of frequency information may, however, not be required to account for the effect of event frequency on performance. A second, more economical interpretation derives from a procedural view of cognitive processes (Kolers & Roediger, 1984), where the effect of frequency on performance is seen as the direct consequence of the repetition of the operations carried out in performing the task. Analogy with data in memory research may shed light on this point. Availability in memory of a particular item is highly dependent on the number of repetitions of this item during the learning session; by and large, greater frequency yields better retention. The relationships between this general outcome and explicit frequency knowledge subjects acquire are not well understood. Some authors claim that both phenomena reflect a single underlying process—presumably trace strength or multiple traces—while others suggest that somewhat different processes might be involved (see Hintzman, 1976, for a review). However, the powerful effect of frequency on memory enhancement is never viewed as a consequence of the verbal knowledge of item frequency. Likewise, it may be assumed that repetition of sensory and motor processing elicited by a particular target sequence induces a subsequent facilitation of this processing, hence modulating observed performance, whatever the possibilities for subjects to acquire explicit information on the number of repetitions.

To sum up, available data do not demonstrate subjects' ability to unconsciously abstract the complex rules used to produce the situation. However, the processes underlying improvement in performance, although very different from those Lewicki et al. put forward, may nevertheless be unconscious in nature.

Methodological and Theoretical Implications

Reference was made in the Introduction to a recent distinction between two modes of learning, which differ mainly with respect to their relation to conscious, controlled mental activities. The present results have closely interconnected methodological and theoretical implications regarding this distinction.

Our analysis had a primary methodological concern. Together with previous evidence on artificial grammar learning (Dulany et al., 1984; Perruchet & Pacteau, 1990) the findings point to a major bias likely to plague all studies aimed at investigating the implicit mode of learning. As soon as a situation becomes complex, subjects can tackle it successfully in a way which has no obvious relation to the manipulation introduced by the experimenter. Therefore, the fact that subjects are unable to articulate the manipulated pattern does not imply that they operate on an unconscious level.

A first step to ensure unconsciousness of processing consists in ensuring that observed performance resulting from subjects' hypotheses does not correlate with performance predicted when subjects possess knowledge of the actual pattern of events. This post hoc analysis may in itself be insufficient. Subjects may, for example, neglect to report the fragmentary pieces of knowledge they judge irrelevant to the task. For this and other reasons, it is now generally believed that a recognition-like procedure provides a better assessment of consciousness than simple introspective reports (e.g. Brody, 1989). However, the use of a recognition procedure means that the experimenter must anticipate the modes of processing that subjects may engage in when encountering the task. For most tasks, there is no canonical way to draw up an exhaustive catalog of the possible modes of processing, and this enterprise calls principally upon empirical, intuitive explorations. One of the conclusions our study reinforces is that any demonstration of unconscious complex learning will necessarily be limited by the researchers' ability to ask their subjects the right questions when assessing conscious knowledge.

Our results have more theoretical implications as well. It is highly plausible that the processing modes subjects develop when exposed to the Lewicki et al. (1988) paradigm are not specific to this particular situation; presumably, they apply equally as well to other laboratory settings and to real-world situations. This leads to speculations as to how people proceed when facing a complex and structured situation requiring immediate adaptation.

First of all, the present study suggests that people do not unconsciously abstract rules that could be discovered through effortful application of analytical and logical reasoning. This proposal seems intuitively valid. The reverse, namely that subjects can acquire identical, or even better knowledge about a complex situation by developing some kind of passive apprehension mode rather than when engaging in a controlled analysis of the situation, appears to tap a somewhat "magical" process, which makes high-level cognitive skills redundant and useless for adaptive purposes. However, this view is not commonly acknowledged in contemporary research on unconscious learning. It obviously runs against the Lewicki viewpoint (see Lewicki, 1986; Lewicki, Czyzewska, & Hoffman, 1987), but it also challenges other main theoretical accounts of implicit learning. In the Reber and associates' framework (e.g., Reber, 1989), people supposedly abstract the very same rules, or a subset of the rules, constitutive of the synthetic grammar that a tedious logical analysis of the letter strings would also bring out. In the Oxford laboratory research group (e.g., Berry & Broadbent, 1988; Hayes & Broadbent, 1988), people are thought to acquire the same basic knowledge under unselective and selective modes of learning, namely the contingencies between a set of variables, with differences only affecting the number of variables at hand.

Our analysis demonstrates that the simple and ubiquitous effect of frequency may elicit behavioral modifications mimicking those which result from elaborate and specific knowledge. Similar conclusions were previously drawn in the field of concept learning (e.g., Kellog, 1980). One value of this kind of contention is that the effect of frequency may be easily accounted for by models which do not require mediation of conscious thought. To what extent it may account for cases in which the acquisition of explicit knowledge is not sufficient to account for changes in performance remains a speculative issue which warrants further research.

REFERENCES

Berry, D. C., & Broadbent, D. E. (1988). Interactive tasks and the implicit-explicit distinction. *British Journal of Psychology,* **79,** 251–272.

Brody, N. (1989). Unconsious learning of rules: Comment on Reber's analysis of implicit learning. *Journal of Experimental Psychology: General,* **118,** 236–238.

Brooks, D. N. (1978). Nonanalytic concept formation and memory for instances. In E. Rosch & B. B. Lloyd (Eds.), *Cognition and categorization.* Hillsdale, NJ: Erlbaum.

Brooks, D. N. (1987). Decentralized control of categorization: the role of prior processing episodes. In U. Neisser (Ed.), *Concepts and conceptual development: Ecological and intellectual factors in categorization.* Cambridge: Cambridge University Press.

Dawson, M. E., & Reardon, P. (1973). The construct validity of recall and recognition postconditioning measures of awareness. *Journal of Experimental Psychology,* **98,** 308–315.

Dulany, D. E., Carlson, A., & Dewey, G. I. (1984). A case of syntactical learning and judgment: How conscious and how abstract? *Journal of Experimental Psychology: General,* **113,** 541–555.

Dulany, D. E., Carlson, A., & Dewey, G. I. (1985). On consciousness in syntactic learning and judgment: A reply to Reber, Allen, and Regan. *Journal of Experimental Psychology: General,* **114,** 25–32.

Geller, E. S., & Pitz, G. F. (1970). Effects of prediction, probability, and run length on choice reaction speed. *Journal of Experimental Psychology,* **84,** 361–367.

Hayes, N. A., & Broadbent, D. E. (1988). Two modes of learning for interactive tasks. *Cognition,* **28,** 249–276.

Hintzman, D. L. (1976). Repetition and memory. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol 10). New York: Academic Press.

Kellog, R. T. (1980). Feature frequency and hypothesis testing in the acquisition of rule-governed concepts. *Memory and Cognition,* **8,** 297–303.

Kellog, R. T., & Dowdy, J. C. (1986). Automatic learning of the frequency of occurrence of stimulus features. *American Journal of Psychology,* **99,** 111–126.

Kolers, P. A., & Roediger, H. L. (1984). Procedures of mind. *Journal of Verbal Learning and Verbal Behavior,* **23,** 425–449.

Lewicki, P. (1986). *Nonconscious social information processing.* New York: Academic Press.

Lewicki, P., Czyzewska, M., & Hoffman, H. (1987). Unconscious acquisition of complex procedural knowledge. *Journal of Experimental Psychology: Learning, Memory and Cognition,* **13,** 523–530.

Lewicki, P., Hill, T., & Bizot, E. (1988). Acquisition of procedural knowledge about a pattern of stimuli that cannot be articulated. *Cognitive Psychology,* **20,** 24–37.

Mathews, R. C., Buss, R. R., Chinn, R., & Stanley, W. B. (1988). The role of explicit and implicit learning processes in concept discovery. *The Quaterly Journal of Experimental Psychology,* **40A,** 135–165.

McAndrews, M. P., & Moscovitch, M. (1985). Rule-based and exemplar-based classification in artificial grammar learning. *Memory and Cognition,* **13,** 469–475.

Medin, D. L., & Smith, E. E. (1981). Strategies in classification learning. *Journal of Experimental Psychology: Human Learning and Memory,* **7,** 241–253.

Naveh-Benjamin, M., & Jonides, J. (1986). On the automaticity of frequency coding: effects of competing task load, encoding strategy, and intention. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **12,** 378–386.

Perruchet, P. (1985). Expectancy for airpuff and conditioned eyeblinks in humans. *Acta Psychologica,* **58,** 31–44.

Perruchet, P. (1988). L'apprentissage sans conscience: Données empiriques et implications théoriques. In P. Perruchet (Ed.), *Les automatismes cognitifs.* Liège: Mardaga.

Perruchet, P., & Pacteau, C. (1990). *Synthetical grammar learning: implicit rule abstraction or explicit fragmentary knowledge? Journal of Experimental Psychology: General,* **119,** 264–275.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior,* **6,** 855–863.

Reber, A. S. (1976). Implicit learning of synthetic languages: The role of instructional set. *Journal of Experimental Psychology: Human Learning and Memory,* **2,** 88–94.

Reber, A. S. (1989). Implicit learning and tacit knowledge. *Journal of Experimental Psychology: General,* **118,** 219–235.

Reber, A. S., & Allen, R. (1978). Analogy and abstraction strategies in synthetic grammar learning: A functional interpretation. *Cognition,* **6,** 189–221.

Reber, A. S., Allen, R., & Regan, S. (1985). Syntactical learning and judgment, still unconscious and still abstract: Comment on Dulany, Carlson, and Dewey. *Journal of Experimental Psychology: General,* **114,** 17–24.

Reber, A. S., Kassin, S. M., Lewis, S., & Cantor, G. (1980). On the relationship between implicit and explicit modes in the learning of a complex rule structure. *Journal of Experimental Psychology: Human Learning and Memory,* **6,** 492–502.

Richard-Simon, J., & Craft, J. L. (1989). The effect of prediction accuracy on choice reaction time. *Memory and Cognition,* **17,** 503–508.

Sanders, R. E., Gonzales, E. G., Murphy, M. D., Liddle, C. L., & Vitina, J. R. (1987). Frequency of occurrence and the criteria for automatic processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **13,** 241–250.

Zacks, R. T., Hasher, L., & Sanft, H. (1982). Automatic encoding of event frequency: Further findings. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **8,** 106–116.

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