

Implicit Learning of New Verbal Associations

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Implicit learning of a series of new verbal associations was studied in four experiments. The first two experiments demonstrated that learning of a repeating sequence of verbal stimuli may occur without awareness, but only when the stimulus-response mapping requires an attention-demanding activity: Subjects who were unaware of the sequence learned when instructed to categorize the stimuli, but not when instructed simply to read them. However, in both situations, unaware subjects performed no better than untrained control subjects in expressing their knowledge of the sequence explicitly. In Experiments 3 and 4, subjects showed implicit learning when the task involved either motor responses to verbal stimuli or verbal responses to spatially arranged stimuli. These findings are discussed in terms of the conditions under which implicit learning can be obtained. First, they demonstrate implicit learning of a set of new associations in the verbal domain. Second, the data suggest that attention is important in implicit learning. Finally, the degree of interitem organization that is familiar preexperimentally seems to partially determine the amount of implicit learning.

This article is concerned with elucidating the circumstances under which learning can take place in the absence of conscious awareness of learning on the part of the subject. Under these conditions, knowledge is acquired without intentional instructions and is assessed through performance measures that require no explicit recollection of the knowledge. This type of learning has been termed *implicit* memory (Schacter, 1987) and stands in contrast to *explicit* memory, which is assessed directly through tests of recall and recollection and depends on the subjective recollection of having learned.

At the present time it is unclear whether learning without awareness is a unitary phenomenon. Numerous tasks have been used in this area of research (Richardson-Klavehn & Bjork, 1988; Schacter, 1987), and implicit memory remains a descriptive label rather than a theoretical construct. The necessary and sufficient conditions to produce implicit learning are not yet known, nor are the differences between implicit and explicit memory well defined (Richardson-Klavehn & Bjork, 1988; Roediger & Blaxton, 1987; Schacter, 1987). In order to clarify these issues, an important first step is to delineate this phenomenon more precisely by establishing the nature of the stimulus materials and the types of responses that can elicit learning without awareness.

Previous experiments in our laboratory have demonstrated learning in a nonverbal serial reaction time (SRT) task by young and old healthy adults (Knopman & Nissen, 1987; Nissen & Bullemer, 1987; Willingham, Nissen, & Bullemer, 1989), even though a proportion of the subjects report no explicit awareness of the learning. Patients with amnesia due to Korsakoff's Syndrome (Nissen & Bullemer, 1987; Nissen, Willingham, & Hartman, 1989), some patients with probable Alzheimer's Disease (Knopman & Nissen, 1987), and healthy adults injected with scopolamine (Nissen, Knopman, & Schacter, 1987) also demonstrate learning, although the patients report no awareness of the presence of a sequence. Patients with Korsakoff's syndrome retain the sequence normally for at least 1 week (Nissen et al., 1989. See also Lewicki, Czyzewska, & Hoffman, 1987, for a demonstration of implicit serial learning of a sequence of spatial positions in the context of a different task.)

The SRT paradigm used in the experiments from our laboratory involved a four-choice reaction time task in which a repeating sequence of spatial positions was embedded. On each trial a light appeared in one of four positions arranged horizontally on a video monitor. Responses were made on a board that had a button located directly below each light position. The subject's task was to press the corresponding button on each trial as quickly as possible. The testing was divided into blocks of 100 trials. A fixed sequence of light positions was repeated 10 times within each block. The sequence was 10 trials in length but contained only four unique elements (i.e., the four light positions). Neither the beginning nor the end of the repeating sequence was marked, and subjects were not told of the presence of a pattern. In the final block of trials, a random sequence was presented instead of the repeating sequence. Learning was measured by the presence of both a decrease in response latencies over the blocks in which the repeating sequence appeared and by a subsequent increase in response latencies in the final, random sequence block of trials. This paradigm employs a sensitive, chronometric measure of learning through performance in which

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small increments of learning can be detected. Learning can be construed as the learning of the specific sequence of spatial locations and/or their corresponding responses. Because learning can occur in the absence of awareness, it is clear that associations between successive items need not be consciously sought by subjects.

All of our previous research with this task involved learning a repeating spatial sequence. In the present experiments this paradigm was adapted in order to determine whether the implicit acquisition of a new series of associations could be demonstrated with visually presented verbal stimuli and vocal responses and whether that learning could take place in the absence of explicit knowledge of the information learned. These experiments were intended to test the generalizability to the verbal domain of our previous findings.

Although little work has been done with implicit learning of sequences of verbal stimuli, there is a substantial and rapidly growing body of literature examining other types of implicit verbal learning. Research with amnesic patients has demonstrated that verbal stimuli and responses can produce learning without awareness in a variety of tasks. Amnesic patients demonstrate normal acquisition and retention of the ability to read transformed script (Beatty et al., 1987) and mirror-reversed words (Beatty et al., 1987; Cohen & Squire, 1980). They also show repetition priming effects: Like individuals with normal memory, they are better able to complete a word fragment, make a lexical decision, or read a mirror-reversed word if the word appeared earlier in the experiment than if it did not (see Shimamura, 1986, for a review). In each case, amnesic patients show learning without conscious awareness of what they learned.

In addition to their verbal content, implicit memory paradigms such as stem completion differ from the learning in the SRT task in several ways. First, learning in the former case involves memory for single items or pairs of items after only one or two exposures to the stimuli, whereas the sequence in the SRT task is a 10-trial, supraspan sequence that is usually presented at least 40 times. Furthermore, the effect seems to depend upon preexisting knowledge of lexical items and semantic relations among words. Only mild amnesics show repetition priming of novel associations (Schacter & Graf, 1986; Shimamura, 1986; but see Moscovitch, Winocur, & McLachlan, 1986), and amnesics, unlike healthy adults, do not show repetition priming of nonwords (Cermak, Talbot, Chandler, & Wolbarst, 1985; Diamond & Rozin, 1984). In contrast, learning in an SRT task involves sequences that are novel and unique to the experiment.

An early study of implicit learning in the verbal domain is represented by an experiment by Hebb, in which subjects showed improved digit span performance on repeated nine-digit sequences (Hebb, 1961). More recently, the work of Reber and colleagues has demonstrated that healthy adults are able to learn artificial grammars without developing awareness of the underlying rules (Reber, 1976; Reber & Allen, 1978; Reber, Allen, & Regan, 1985; but see Dulany, Carlson, & Dewey, 1984, for an interpretation involving the conscious use of rules). The stimuli consisted of sequences of letters, and the task required discriminating "grammatical" from "nongrammatical" sequences. This procedure differed

from the SRT paradigm in that learning involved implicit abstraction of rules rather than sequences of stimuli; therefore, these findings do not suggest a clear prediction regarding implicit learning of a verbal analogue of the SRT task.

An important question both in our work with the nonverbal SRT task and in the area of implicit verbal learning concerns the presence of subjects' awareness. The designation of a task as implicit suggests that performance is not based on explicit recall or recognition. In studies of implicit verbal learning, the determination that learning actually occurred without awareness is straightforward in the case of severely amnesic patients, who report no conscious memory of even having performed the task in which the stimuli are presented. However, when testing mildly amnesic patients or healthy adults, it is difficult to establish with certainty that subjects are not using explicit memory strategies to carry out the implicit memory tasks. In studies of repetition priming effects, this problem is rarely addressed directly, although the interpretation of the results rests on the assumption that fragment completions, stem completions, and perceptual identification performance are pure measures of implicit memory. Dissociations between implicit and explicit memory tests suggests that there are at least some features unique to each but do not prove conclusively that awareness is not involved in the former.

In experiments with the spatial SRT task (Willingham et al., 1989), we have used two different measures of conscious awareness. The first is verbal report. After several blocks of trials, subjects were asked whether they noticed a pattern. This is a leading question with high demand characteristics that is likely to result in an overreporting of awareness. However, all subjects who stated that they noticed a pattern were asked also to specify the pattern. This report is, of course, susceptible to guessing on the one hand and to forgetting on the other. Because of these potential problems, a second measure of awareness was also obtained in some experiments. This measure was structured in such a way that awareness was assessed through performance rather than verbal report, and in the context of a task identical in all ways to the serial reaction time task except for the requirement of explicit knowledge. In other words, the stimulus and response modalities remained unchanged; only the instructions differed. In this "generate" version of the task, subjects were told that instead of pressing the key below the stimulus, they were to press the key corresponding to where they thought the next stimulus would appear. In one experiment (Willingham et al., 1989), 60 subjects were questioned about their awareness and knowledge of the sequence after four blocks of 100 trials of the repeating sequence. For the 12 subjects who reported no awareness of the repeating sequence, responding on the "generate" task was virtually identical to that of a group of subjects who said they noticed a pattern but indicated knowledge of fewer than 4 of the 10 positions in the sequence and to that of the control group who had received four blocks of the random sequence. The combined performance of the completely unaware subjects and those able to report fewer than four positions on the generate task demonstrated that these subjects had virtually no conscious access to the knowledge they had obtained implicitly. They also showed no savings in

learning across the two blocks of the generate task. Subjects with knowledge of between 4 and 9 positions performed similarly to the group with full awareness of the entire 10 trial sequence and significantly better than the unaware and control groups.

These results suggested that explicit knowledge is necessary for transferring learning from an implicit to an explicit task. In addition, we concluded that subjects who correctly reported fewer than 4 trials of the 10-trial sequence had minimal conscious access to information necessary for explicit memory. Although they may have had some sense that a pattern was present, they were unable to make use of that knowledge consciously. Subsequently, in that study and those reported here, we classified those subjects as unaware. In Experiments 2 and 3 of the present set of experiments, by using the generate version of the task, we again validate this distinction between subjects who claim to be aware and those who do not. In Experiments 1 and 4, we have relied on verbal report alone. Because the verbal report of no awareness corresponded closely to performance on the generate task, whenever tested, we felt that the verbal report was also a satisfactory measure of conscious awareness.

In summary, the present set of experiments tests the hypothesis that a repeating sequence of verbal associations can be learned in the context of an implicit learning paradigm. In addition to measuring the degree of learning by means of response latencies, subjects' awareness of the presence and nature of the sequence was assessed. The performance of aware and unaware subjects was compared; of particular interest was whether subjects who had minimal explicit knowledge of the pattern demonstrated any learning. Experiments 1 and 2 employed a verbal analogue of the original SRT task used in previous studies. These two experiments differed from each other only in the relation between the stimuli and the responses: In Experiment 1, subjects read the stimulus words aloud, whereas in Experiment 2, subjects were required to categorize them (e.g., to respond *tool* to the stimulus *hammer*). In Experiments 3 and 4, learning was examined with procedures modified to produce combinations of verbal and nonverbal stimuli and responses.

Experiment 1

The task in this experiment consisted of a serial reaction time procedure with four visually presented words. Subjects were asked to read the words aloud as quickly as possible. One group of subjects was given extensive training on a 10-trial repeating sequence consisting of four unique words and then switched to a random sequence of these same words. A second, control group was given the same amount of practice with a random sequence. All subjects were then asked about their awareness of a pattern. Learning was measured by the decrease in naming latency with practice by the subjects receiving the repeating sequence as compared with those receiving a random sequence and by the subsequent increase in latency when the experimental subjects were switched to the random sequence.

Method

Subjects. All subjects were undergraduate students at the University of Minnesota and received either \$5 or extra credit in an introductory psychology course. A total of 30 students (20 female and 10 male) with a mean age of 20.5 years (range: 18–30) were included in the experiment. Subjects were assigned randomly to the experimental and control conditions.

Stimuli and apparatus. The task was presented on a video monitor controlled by a microcomputer interfaced with a Grason-Stadler Voice Activated Relay (VAR). The stimuli consisted of four common two-syllable words: RULER, MUSIC, OCEAN, and LADY. Each stimulus was 1.1 cm in height, presented in the center of the screen, with a viewing distance of 58 cm. The display subtended a visual angle of approximately 6.7°. The stimuli were clearly suprathreshold in luminance.

On each trial, the stimulus appeared on the screen and remained present until the subject made a verbal response, at which time that stimulus was extinguished. The next stimulus appeared after a delay of 850 ms. Reaction time (RT) was measured in milliseconds from the onset of the stimulus presentation to the onset of the vocal response. Invalid trials, in which subjects made errors or in which the VAR was not activated properly, comprised 0.6% of the trials and were not included in the analyses.

Procedure. All subjects received nine blocks of 100 trials. There were two types of blocks: repeating sequence and random sequence. In repeating sequence blocks, the order of words followed a particular 10-trial sequence that was repeated 10 times: MUSIC, RULER, LADY, OCEAN, LADY, RULER, MUSIC, LADY, RULER, OCEAN. The end of one 10-trial sequence and the beginning of the next were not marked in any way. In random sequence blocks, the 100 trials were arranged pseudorandomly, with the constraints that the relative frequency of occurrence of each word in the sequence was preserved (e.g., MUSIC occurred twice in every 10 trials, whereas RULER occurred three times) and that no word occurred twice consecutively.

Subjects were assigned randomly to the experimental or control group. For subjects assigned to the experimental group, the first eight blocks were repeating sequence blocks; the ninth block was random. The control subjects received nine blocks of a random sequence.

Subjects were seated facing the video monitor and microphone in a moderately lit room. They were instructed to read each word aloud as quickly as possible without making errors. The presence or absence of a repeating sequence was not mentioned to subjects before or during this task. Each block was initiated by the experimenter and was followed by a short rest period of approximately 1.5 min. After the ninth block of trials, experimental subjects were asked whether they had noticed a pattern at any point, and if so, to indicate what it was.

Results

Verbal reports. The verbal reports obtained from the 15 experimental subjects provided two types of information: whether subjects noticed a pattern and, for those who said that they had, their accuracy in indicating what the sequence was. Eight subjects were unaware that there was a pattern. Seven subjects stated that they were aware of a pattern; of these only 5 were able to indicate more than three consecutive words accurately. For reasons explained in the introduction, the 2 subjects who reported sequences of fewer than four consecutive were grouped together with the unaware subjects. Subsequent analyses were conducted on results from three

groups of subjects: the *aware* group, who reported knowledge of at least four consecutive trials in the sequence ($n = 5$), the *unaware* group ($n = 10$), and the *control* group ($n = 15$).

Reaction times. For each subject the median RT of valid responses in each set of 10 trials within a block was determined, and the mean of these 10 medians was computed for each block.

The first 3 sets of 10 trials in the first block were examined to determine whether the experimental and control groups differed in their initial reaction times. The mean RT was 541 ms for the experimental group and 555 ms for the control group. This difference was not statistically significant, $t(28) = 1.08, p > .10$.

Figure 1 shows the group means and standard errors for each block of trials for the aware, unaware, and control groups. Visual examination of the data indicates that response times for all groups decreased slightly from the first to the second block. Beyond this, performance of the control and unaware groups was similar, in contrast to that of the aware subjects. The aware group responded considerably faster by the eighth block, and yet, on the final, random sequence block, performed identically to the other subjects.

These data were examined by means of a two-way analysis of variance (ANOVA) with subject group as a between-subjects factor and block as a within-subjects factor. There were significant main effects of group, $F(2, 27) = 4.24, p = .02$; block, $F(8, 216) = 71.90, p < .0001$, and a significant interaction between group and block, $F(16, 216) = 25.46, p < .0001$.

In order to investigate the nature of the interaction, two-way ANOVAs with each pair of groups were carried out. In comparing the aware and the control subjects, all effects were significant: group, $F(1, 18) = 9.37, p = .007$; block, $F(8, 144) = 59.72, p < .0001$; Group \times Block, $F(8, 144) = 27.77, p < .0001$. The only significant finding in the analysis of the unaware and control groups was a main effect of block, $F(8, 184) = 27.96, p < .0001$. There was no significant effect of group in the analysis of the aware and unaware subjects, but the effect of block and the interaction between group and

block were significant, $F(8, 104) = 45.94, p < .0001$, and $F(8, 104) = 23.08, p < .0001$, respectively. It appears then that the aware but not the unaware subjects learned the sequence. This conclusion is further supported by comparisons of RTs on the final block of the repeating sequence and the following block of random trials. Aware subjects showed a significant difference in response time on these two blocks, $F(1, 4) = 21.34, p = .01$, but the unaware subjects did not, $F(1, 9) = 3.27, p = .10$.

Discussion

The absence of learning without awareness in this experiment was somewhat surprising in light of our previous studies in which light positions and button presses were the stimuli and response modes. We had hypothesized that giving subjects extensive training, as was done in the previous studies, would be sufficient to produce unaware learning. However, after considerable practice on the present verbal task, subjects in the unaware group showed no improvement beyond the general learning attained by subjects exposed only to the random word sequence.

There are several possible explanations for these results. One is that there actually was learning in the unaware subjects, but the small sample size prevented detection of that difference. Although it is true that a difference occurred between Blocks 8 and 9, this difference was small (8 ms vs. a corresponding difference of 5 ms for control subjects), and variability was low (6%–7% of the mean). In addition, pilot testing on this task with other sets of verbal stimuli produced similar results and increased our confidence in the findings reported here.

A second possible explanation of these findings involves differences between the original task and this experiment. The stimuli and responses in this experiment and previous ones differed substantially—spatial versus verbal stimuli and button pushing versus verbalization. These differences in materials and test modality might have accounted for the absence of unaware learning. Before accepting this conclusion, however, we sought to develop a paradigm that involved verbal stimuli and verbal responses in which implicit learning would occur.

Experiment 2

One clue as to what form the stimulus–response dyad should take came from previous experiments with the non-verbal SRT task performed under dual task conditions (Nissen & Bullemer, 1987). In that situation, no learning occurred, demonstrating that attention may play an important role, at least for this task. A second observation was that word naming is exceedingly easy and virtually automatic for native speakers (Posner & Snyder, 1975; Stroop, 1935). If attention is an important prerequisite for implicit learning and was used only minimally in the reading of words in Experiment 1, then it follows that we should seek conditions that demand a higher level of effort, and hence attention, than reading. In Experi-

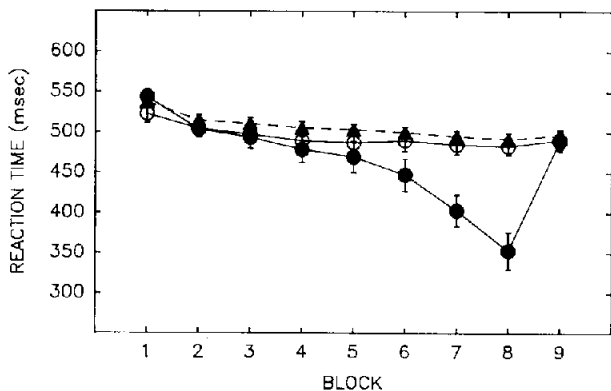


Figure 1. Experiment 1: Mean reaction times in milliseconds for naming latency. (Filled circles = aware subjects [$n = 5$]; open circles = unaware subjects [$n = 10$]; filled triangles = control subjects [$n = 15$]. Bars indicate one standard error above and below the mean.)

ment 2, the task used in Experiment 1 was modified. In this new task, subjects were required to respond by saying the semantic category to which each of the stimulus words belonged. It was predicted that because generating category names is less automatic a response than reading, this task would require more attention, and subjects would be more likely to learn the sequence.¹ The generate version of the task was also introduced in this experiment in order to obtain a more quantitative assessment of subjects' explicit knowledge of the sequence following training on the RT task.

Method

Subjects

All subjects were undergraduate students at the University of Minnesota and received either \$5 or extra credit in an introductory psychology course. The 75 students (36 female and 39 male) had a mean age of 20.5 years (range: 18–30). Subjects were assigned randomly to the experimental ($n = 44$) and control ($n = 31$) conditions. A greater number of experimental than control subjects was used in order to obtain subgroups of aware and unaware subjects of sufficient size.

Stimuli and Apparatus

The method of presentation of stimuli and collection of responses for the RT task used in this experiment was the same as in Experiment 1. The stimuli consisted of the following words: ROBIN, HAMMER, SALMON, and MAPLE. The corresponding responses were BIRD, TOOL, FISH, and TREE, respectively.

The presentation of stimuli and collection of responses differed somewhat for the generate task. The VAR was not employed; in its place was a response board with four keys, controlled by the experimenter. The keys were labeled with the four category names. Subjects made each response aloud, and the experimenter pressed the corresponding key on the response board. If the subject's response was incorrect, the stimulus remained on the screen. If the response was correct, the stimulus was extinguished and, after a delay of 850 ms, the next one appeared.

Procedure

RT task. All subjects received five blocks of trials with the categorization task. These blocks were identical in structure to those in Experiment 1. Each block consisted of either a repeating 10-trial sequence or a random sequence. The repeating sequence was similar to that used in Experiment 1: MAPLE, HAMMER, SALMON, ROBIN, SALMON, HAMMER, MAPLE, SALMON, HAMMER, ROBIN.

The experimental group was administered four blocks of the repeating sequence and one block of a random sequence, and the control group was given five blocks of a random sequence. Subjects were instructed to categorize each word as quickly and accurately as possible. Trials were considered invalid if the subject gave an incorrect response or if the voice key either failed to respond or responded to extraneous noise. Invalid trials comprised 1.6% of the trials and were eliminated from all data analyses.

Each block was initiated by the experimenter. Following the fifth block of trials, experimental subjects were asked whether they had noticed a pattern, and if so, to indicate what it was.

Generate task. The last 15 subjects tested in each group next received one additional block of the RT task. Subjects in the experimental group received one block of the repeating sequence; the control group was given a block of the random sequence. This additional block of trials was then followed by one block of the generate version of this task. The purpose of the block of RT trials was to ensure that the experimental subjects would not carry out the generate task on the basis of their most recent experience with a random sequence. Data from this block were not included in any of the statistical analyses.

Before subjects performed the generate task, they were told that the procedure would change in such a way that instead of naming the semantic category of the word present on the screen, they were to give the category response for the word they thought would appear next. Subjects were also told that we were more concerned with the actual responses than with speed. The instructions were designed to lead subjects to believe that a pattern was present, although the wording did not specifically mention the presence of the sequence or the relation between the generate and SRT versions of the task.

Results

For each subject the median RT of correct responses in each set of 10 trials within a block was determined, and the mean of these 10 medians was computed for each block.

Experimental and control groups were matched on the mean of the median reaction times for the first 3 sets of 10 trials in the first block. This resulted in the elimination of the 3 slowest subjects from the experimental group. When these subjects were removed, the initial reaction times were 795 ms for the experimental subjects and 796 ms for the control subjects.

Verbal Reports

The verbal reports obtained were used to divide the subjects who received the repeating sequence into aware and unaware groups. This was carried out in the same way as in Experiment 1. The resulting groups included the aware group ($n = 12$), the unaware group ($n = 29$), and the control group ($n = 31$). Of the 30 subjects who were given the generate task, 4 were in the aware group, 11 were in the unaware group, and 15 were in the control group.

¹ We have used the construct *attention* to suggest the active processing of a stimulus in order to map a stimulus onto its correct response. This term stands in contrast to the concept of *automaticity*, in which familiarity, practice, and the effortlessness of a cognitive process permit adequate performance as long as the individual is oriented to the stimulus. In skilled readers, the identification of words occurs automatically: The mapping of the visual display onto a vocal response requires little effort or attention. One reviewer suggested that the concept of overlearning may provide a better explanation. However, although it is equally descriptive of the phenomenon, we prefer the term *attention* because it directs one's thinking toward the cognitive mechanisms involved in carrying out the task.

Reaction Times

Figure 2 shows the means and standard errors for each block of trials for the aware, unaware, and control groups. Visual examination of the data indicates that the aware group had the largest decrease in RT during the first four blocks but performed similarly to the other two groups on the final block. The RTs of the unaware subjects were more similar to those of the control subjects, although they showed a divergence of 37 ms by the fourth block. The difference between the fourth and fifth blocks was 130 ms for the aware group, 25 ms for the unaware group, and 3 ms for the control group.

These data were analyzed by means of a two-way ANOVA, with subject group as a between-subjects factor and block as a within-subjects factor. There were significant main effects of subject group, $F(2, 69) = 4.30, p = .02$; and block, $F(4, 276) = 32.71, p < .0001$; and a significant interaction between group and block, $F(8, 276) = 9.80, p < .0001$.

In order to investigate the nature of the interaction, ANOVAS with each pair of subject groups were carried out. A comparison between the aware and control groups revealed significant main effects of group, $F(1, 41) = 4.64, p = .04$; block, $F(4, 164) = 16.92, p < .0001$; and an interaction between block and group, $F(4, 164) = 11.01, p < .0001$. Similar results were obtained in the comparison between the aware and unaware groups: group, $F(1, 39) = 7.60, p = .009$; block, $F(4, 156) = 31.69, p < .0001$; Block \times Group, $F(4, 156) = 7.96, p < .0001$. No main effect of group was obtained in comparing the unaware and control groups ($F < 1$), but the effect of block, $F(4, 232) = 17.25, p < .0001$, and the Group \times Block interaction, $F(4, 232) = 4.25, p = .003$, were significant.

Although these analyses indicate that the aware subjects learned more than the unaware subjects, who in turn learned more than the control subjects, a further check was made to verify that each of the experimental groups actually showed a significant amount of learning. Comparisons of performance on Block 4, the final block of the repeating sequence, and Block 5, the block of the random sequence, were carried out for aware and unaware subjects separately. Both the aware subjects and the unaware subjects were significantly faster on Block 4 than on Block 5, $F(1, 11) = 14.48, p = .003$, and $F(1, 28) = 11.16, p = .003$, respectively. In summary, the aware group benefitted to a greater extent than the unaware group from practice on the repeating sequence, but the latter nevertheless showed evidence of a significant, albeit small, amount of learning.

Generate Task

The percentage of correct responses on each set of 10 trials was computed for each subject. Means of these values appear in Figure 3. Overall, the aware subjects showed the highest accuracy at all times, with smaller and inconsistent differences between the unaware and the control groups. An analysis of variance was conducted with group as a between-subjects factor and set of trials as a within-subjects factor. This revealed a significant main effect of group, $F(2, 27) = 10.79, p = .0006$. No other main effects or interactions were significant. Follow-

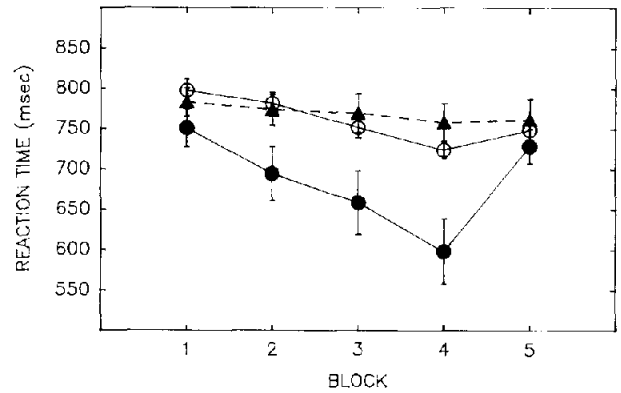


Figure 2. Experiment 2: Mean reaction times in milliseconds for the categorization task. (Filled circles = aware subjects [$n = 12$]; open circles = unaware subjects [$n = 29$]; filled triangles = control subjects [$n = 31$]. Bars indicate one standard error above and below the mean.)

up comparisons indicated that there were no significant differences between the unaware and control groups (49% and 43% correct, respectively), but that the aware subjects (72% correct) were significantly different from each of the other two ($p < .05$).

As a further test of the relation between awareness and learning, the correlation between performance on the reaction time task and the generate task was calculated. More specifically, the increase in reaction time from the fourth block of the repeating sequence to the subsequent random sequence block was correlated with the mean proportion correct on the generate task. When all experimental subjects (aware and unaware) were included in this calculation, the resulting Pearson product correlation was .60, thus confirming the relation between awareness and learning. For the unaware subjects alone, however, the correlation was $-.01$. This supports our claim that there is no transfer of learning between tasks for the unaware subjects.

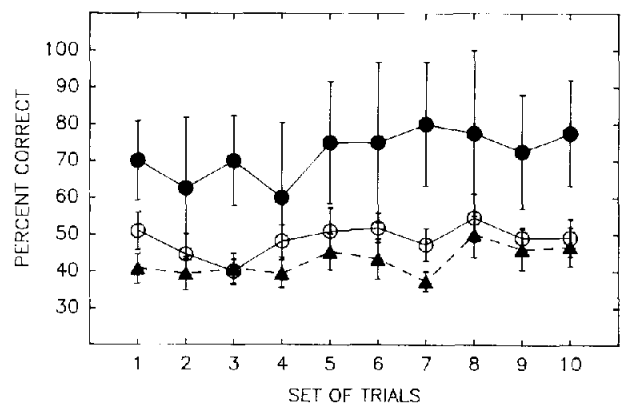


Figure 3. Experiment 2: Mean percent correct for each set of 10 trials in the generate version of the categorization task. (Filled circles = aware subjects [$n = 4$]; open circles = unaware subjects [$n = 11$]; filled triangles = control subjects [$n = 15$].)

Discussion

The results of this experiment indicate that implicit learning of new associations can occur in the context of an entirely verbal task. Training on the sequence resulted in at least some learning in both groups of experimental subjects, including those who did not develop explicit knowledge of the pattern. This learning was characterized by an increase in speed during blocks in which the repeating sequence was present and by slowed performance when a random sequence was subsequently presented.

In addition to the demonstration of implicit learning, the results also suggest that explicit knowledge of the sequence conferred an advantage. Although aware and unaware subjects both showed faster response times in comparison with the control subjects following four blocks of training trials, the explicit knowledge of the aware group was associated with greater improvement. In addition, subjects who developed explicit learning of the sequence under implicit acquisition conditions were more accurate than control subjects in the generate task. In contrast, unaware subjects showed no significant advantage on the generate task relative to the control group. These results provide substantiation of the claim that the unaware subjects indeed had little conscious access to the information they had acquired. More important, they also suggest that when learning occurs outside of awareness, it is unavailable for subsequent cognitive processing that is predominantly conscious in nature.

The contrast between the results of Experiments 1 and 2 supports the hypothesis that task demands that are more effortful and less automatic lead to implicit learning of the stimulus-response sequence. In Experiment 1, there was no evidence of learning in the absence of explicit knowledge, in spite of the fact that subjects in that study received twice the number of training trials as subjects in Experiment 2. This difference in outcome was produced by a simple change in the relation between stimulus and response, from reading to categorization. It is also possible that the nature of the semantic categorization task, independent of its effortfulness, enabled learning to occur. Perhaps the fact that the subjects had to inhibit an automatic response in the course of producing the semantic category name was a critical determinant of sequence learning. Regardless of what the specific critical feature was, it occurred within the performance of individual items, yet led to learning across items. Presumably, whatever occurred during the processing of the stimuli and the execution of a response in this task facilitated learning intertrial associations.

Experiment 3

Although learning of the sequence under implicit conditions was demonstrated in Experiment 2, the degree of learning was much less robust than in the original, spatial version of the task (Nissen & Bullemer, 1987). As a first step towards trying to understand these results better, and more specifically to isolate the important differences between the two versions of the task, similarities and differences between components of the two tasks were identified.

The two versions of the task were similar in many respects: Both consisted of a sequence of identical length; responses were made without explicit reference to previous trials; and there were no overt instructions or cues regarding the presence or nature of the pattern. The tasks differed primarily along two dimensions: the type of response and the nature of the stimuli. In one task, responses were verbal; in the other they consisted of button presses. A second difference was that the sequence consisted of words in one task and of a spatial pattern in the other.

The combination of verbal and spatial stimuli and responses was manipulated in Experiments 3 and 4. In Experiment 3, the stimuli and their presentation were the same as in Experiment 2, but responding was by means of button presses, as in the original, nonverbal version of the task. In Experiment 4, the stimuli were nonverbal and appeared in a spatial arrangement on the screen, but responding was verbal.

Method

Subjects. All subjects were undergraduate students at the University of Minnesota and received either \$5 or extra credit in an introductory psychology course. They comprised 30 students (15 female and 15 male) and had a mean age of 20.6 years (range: 18–30). Subjects were assigned randomly to experimental ($n = 15$) and control ($n = 15$) groups.

Stimuli and apparatus. Both the reaction time and the generate versions of the task were employed. In the former, the stimuli and their method of presentation were the same as in Experiment 2. However, responses were made by pressing one of four keys arranged horizontally on a board placed below and in front of the video monitor. The keys had center-to-center distances of 4 cm and were clearly labeled from left to right: ROBIN, HAMMER, SALMON, and MAPLE. Each stimulus remained on the screen until the subject made the correct response.

In this experiment a variable response-stimulus interval (RSI) was used to prevent subjects from predicting the time of onset of the following stimulus. Five intervals were used, ranging from 400 ms to 1,000 ms, with a mean of 700 ms. A variable response interval was introduced for button pressing responses in order to minimize anticipatory responses—that is, responses occurring before or within 100 ms of the onset of the stimulus. We have found that by deleting anticipatory responses in the original spatial version of the SRT task we minimized the advantage of explicit knowledge of the sequence (Willingham et al., 1989). However, this had no effect on performance in unaware subjects. The variable RSI was used to provide a strong test of the presence of unaware learning.

Reaction times and accuracy data were recorded. The generate version of this task was identical to the generate task employed in Experiment 2, with the exception that subjects made responses by pressing keys on the response board rather than verbally. As in the reaction time task, the keys were labeled ROBIN, HAMMER, SALMON, and MAPLE. On each trial, the stimulus remained on the screen until the correct response was made.

Procedure. Subjects first completed four blocks of pretraining trials in order to allow them to learn the correct word-to-response mapping. In these blocks, a random sequence of stimuli was presented. Pretraining was necessary in this experiment because the pairing of stimuli and responses was unfamiliar to the subjects, in contrast to the conditions of the other experiments. We wished to provide sufficient pretraining in order to separate the learning of stimulus-response mapping from the learning of the sequence.

Following this pretraining, all subjects completed a set of five blocks of trials. In the experimental condition, subjects completed four blocks of the repeating sequence and a fifth block of a random sequence. The repeating sequence was identical to that used in Experiment 2. Subjects in the control condition completed five blocks of a random sequence.

Subjects rested the middle and index fingers of both hands on the four keys and initiated each block of trials with a key press. They were instructed to press the button corresponding to each stimulus as quickly and accurately as possible. Successive blocks of trials were separated by a short rest period of 1.5 to 2 min.

After the final block of trials, experimental subjects were asked whether they had noticed a pattern. If they had, they were asked to indicate what it was. Following this inquiry, subjects received one additional block of trials. The repeating sequence was again given to the experimental group, and a random sequence block was given to the control group. Finally, one block of the generate version of this task was given. On the generate block, instructions stressed accuracy rather than speed.

Results

Verbal reports. As in previous experiments, the 15 experimental subjects were divided into aware ($n = 8$) and unaware ($n = 7$) groups on the basis of their reported awareness of the repeating sequence.

Accuracy. The overall level of accuracy on the RT task was high across groups in the four pretraining blocks (91.6% for aware subjects, 91.8% for unaware subjects, and 92.8% for the control group). Analysis of variance of these pretraining blocks revealed no significant group differences, effect of block, or any interaction between group and block.

In the five blocks of trials following pretraining, aware, unaware, and control subjects had overall accuracy levels of 92.3%, 91.6%, and 93.7%, respectively. A two-way ANOVA of these data revealed no significant effects of group or block nor any interaction between group and block.

Reaction times. Median and mean RTs of correct responses were calculated in the same way as in Experiments 1 and 2. Two methods were used to verify that the three groups of subjects did not differ initially in their response times. The first was a comparison of RTs averaged across the first three sets of 10 trials in the first block following pretraining, similar to the procedure used in Experiments 1 and 2. An ANOVA yielded a nonsignificant effect of group ($F < 1$). The RTs for the three groups were 485 ms for aware subjects, 479 ms for unaware subjects, and 508 ms for control subjects. Reaction times on the four pretraining blocks that used a random sequence were also analyzed to determine whether aware, unaware, and control groups differed initially in their response latencies. An analysis of variance with group as a between-subjects factor and block as a within-subjects factor revealed a main effect of block, $F(3, 81) = 39.00, p < .0001$, indicating that subjects improved during the course of pretraining (Block 1 $M = 599$ ms and Block 4 $M = 523$ ms). More important, however, there was no significant main effect of group (aware = 548 ms; unaware = 574 ms; control = 535 ms) nor any interaction between group and block. In addition, by the fourth block of training, the unaware subjects were slightly faster than the aware subjects.

Figure 4 shows the means and standard errors for the reaction times for the five blocks of trials following initial pretraining. Visual inspection of the data indicates that both experimental groups became faster than the control group over the course of training, although the effect was larger and occurred earlier for the aware than the unaware group. The unaware subjects had faster reaction times than the control group beginning with the second block. All groups performed similarly on the final block.

A two-way analysis of variance was carried out, with subject group as a between-subjects factor and block as a within-subjects factor. There were significant main effects of group, $F(2, 27) = 6.93, p = .004$; block, $F(4, 108) = 21.20, p < .0001$; and a significant interaction between group and block, $F(8, 108) = 9.39, p < .0001$.

In order to investigate the nature of the interaction, two-way ANOVAs with each pair of subject groups were carried out. All effects were significant in the analysis involving the aware and the control groups: group, $F(1, 21) = 13.88, p = .002$; block, $F(4, 84) = 15.86, p < .0001$; Group \times Block, $F(4, 84) = 18.21, p < .0001$. The aware group also differed from the unaware group, as revealed in a significant interaction between group and block, $F(4, 52) = 3.76, p = .009$, although the overall effect of group did not reach significance, $F(1, 13) = 3.14, p = .10$. The effect of block was also significant, $F(4, 52) = 19.95, p < .0001$. A comparison of the unaware and control groups showed a nearly significant effect of group, $F(1, 20) = 3.32, p = .08$; a significant effect of block, $F(4, 80) = 4.67, p = .002$; and a significant interaction between group and block, $F(4, 80) = 6.88, p = .0002$.

Performance on the final block of the repeating sequence and the following block of the random sequence was also compared for aware and unaware subjects separately. Both the aware and unaware subjects were significantly faster on the repeating than the random sequence, $F(1, 7) = 43.26, p = .0006$, and $F(1, 6) = 26.85, p = .003$, respectively. Overall, these results indicate that learning took place in both groups of experimental subjects, although the group with no explicit

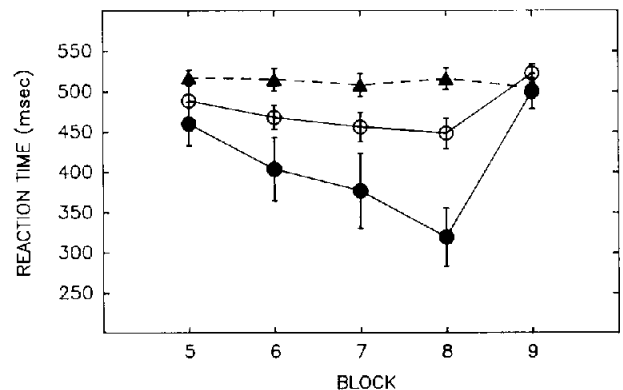


Figure 4. Experiment 3: Mean reaction times in milliseconds. (Filled circles = aware subjects [$n = 8$]; open circles = unaware subjects [$n = 7$]; filled triangles = control subjects [$n = 15$]. Bars indicate one standard error above and below the mean.)

knowledge of the sequence learned more slowly than those who developed awareness of the sequence.

Generate task. The percentage of correct responses on each set of 10 trials was computed for each subject. Means of these values appear in Figure 5. Examination of the data suggests that the aware group was consistently more accurate than the control group. The results of the unaware subjects were less consistent: Although they began at the same level of accuracy as the aware subjects, by the middle of the block, they were performing at the level of the subjects with no prior exposure to the repeating sequence.

As in the previous experiment, correlations between the amount of learning on the reaction time task and performance on the generate task were calculated. For all experimental subjects, the correlation was .08; for the unaware subjects alone, the correlation was $-.58$. Although this pattern of correlations is difficult to interpret, there are several possible explanations. First, the lack of an overall relation between awareness and learning is probably due to the small number of observations available for these calculations. This would be particularly true for the correlation for the unaware group ($n = 7$). In addition, the use of the variable RSI may have reduced the advantage of explicit knowledge on the reaction time task. Because subjects could not predict the onset of the stimulus, they were less able to plan their responses.

A two-way analysis of variance revealed main effects of group, $F(2, 27) = 7.62, p = .003$, and block, $F(9, 243) = 8.43, p < .0001$. The interaction between group and block was not significant. Follow-up comparisons revealed that the aware group was significantly more accurate than the unaware and control groups (79%, 63%, and 57% correct, respectively) and that the performance of the unaware group was not significantly different from that of the control group.

Discussion

The results of this experiment were similar to those of Experiment 2: Subjects with and without explicit knowledge of the 10-trial sequence showed learning of the pattern. Again,

only subjects who could report substantial knowledge of the sequence showed a clear advantage over the control group on a task requiring explicit use of that knowledge. The accuracy of the unaware group on the generate task was not significantly different from that of the control group. Thus, when information was acquired and assessed implicitly, all subjects showed an improvement in their performance; when the information was tested explicitly, only subjects who were considered aware were able to use their learning.

The implication of Experiment 3 is that subjects can learn a stimulus-response sequence with or without explicit knowledge of the sequence when responding involves the mapping of verbal stimuli to spatial locations and when the subject employs a motor response. In this situation, as in Experiment 2, subjects were required to identify each stimulus and carry out a mapping operation. Responding was not highly automatic, and the stimulus-response mapping was entirely arbitrary. The following experiment investigated the hypothesis that subjects would also show a combination of explicit and implicit learning when the responses were verbal and the stimuli spatially arranged.

Experiment 4

The task in this experiment used the words representing the four directions—north, south, west, and east—as members of the response set. The 10-trial sequence comprised a pattern analogous to that used in Experiments 1 and 2 but included this new set of words. Although the subjects responded verbally in this new task, the stimuli were nonverbal and consisted of white Xs. On each trial an X was placed on the video monitor in a spatial location representing one of the directions, and subjects were instructed to provide the appropriate label. Consequently, responding involved mapping from a spatial symbol onto a verbal response. Although this mapping was familiar to subjects, it was unlikely to have been a highly practiced and therefore automatic skill prior to the experiments.

Method

Subjects. All subjects were undergraduate students at the University of Minnesota and received either \$5 or extra credit in an introductory psychology course for their participation. They comprised 39 students (26 female and 13 male), with a mean age of 23.9 years (range: 18–30). This number of subjects was considered sufficient to produce sizeable subgroups of both aware and unaware subjects.

Stimuli and apparatus. The presentation of stimuli and collection of responses were controlled by a microcomputer interfaced with a VAR as in Experiments 1 and 2. Each stimulus consisted of an X that was 1 cm in height and 1 cm in width. Stimuli were generated on the video monitor and were clearly suprathreshold in luminance. On each trial the stimulus appeared at one of four locations: 4.5 cm above, below, left, or right of the center of the screen. These positions were designed to spatially represent the directions north, south, west, and east. At a viewing distance of approximately 58 cm, the four locations were separated by a maximum of 9.8° of visual angle. Each stimulus remained on the screen until the subject made a verbal response, at which time that stimulus was extinguished. The next one appeared after a delay of 850 ms. An experimenter recorded trials as

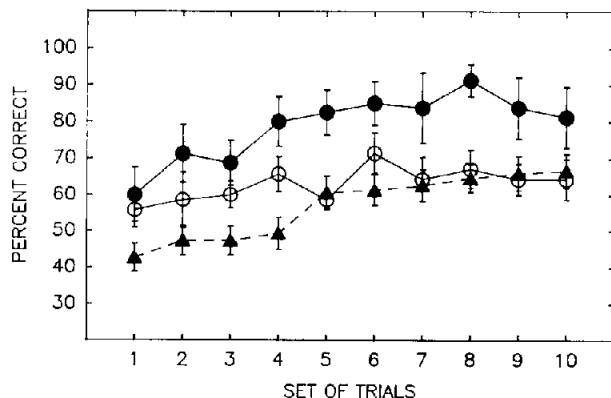


Figure 5. Experiment 3: Mean percent correct for each set of 10 trials in the generate version of the task. (Filled circles = aware subjects [$n = 8$]; open circles = unaware subjects [$n = 7$]; filled triangles = control subjects [$n = 15$].)

invalid if the subject made an error or if the VAR was not activated correctly. This resulted in the elimination of 1.7% of the trials; invalid trials were not included in the data analyses.

Procedure. All subjects were given four blocks of a repeating sequence and one block of a random sequence. No control group was used because extensive experience with this procedure indicated that control subjects were always identical to experimental subjects on the final block of random trials (Nissen & Bullemer, 1987; Willingham et al., 1989). The critical comparison was a within-subjects comparison between the last block of the repeating sequence and the final random sequence block.

The structure of each block of trials was identical to that used in Experiments 1–3, and the 10-trial repeating sequence consisted of the following pattern of direction words corresponding to the four spatial locations used in the presentation of the stimuli: WEST–SOUTH–EAST–NORTH–EAST–SOUTH–WEST–EAST–SOUTH–NORTH. After the fifth block, subjects were asked whether they had noticed a pattern, and, if so, to indicate what it was. The generate task was not included because of the consistent findings in Experiments 2 and 3, suggesting that verbal report was an adequate assessment of subjects' awareness.

Subjects were instructed to say aloud the direction corresponding to the displayed *X* as quickly and accurately as possible on each trial. Each block was initiated by a key press and was followed by a short rest period of approximately 1.5 min.

Results

Verbal reports. The subjects' awareness and knowledge of the repeating sequence were determined as in Experiments 1–3. This resulted in the division of the subjects into aware (*n* = 21) and unaware groups (*n* = 18).

Reaction times. Median and mean reaction times for valid responses were calculated in the same way as in Experiments 1–3. Figure 6 shows the means and standard errors for the reaction times for the five blocks of trials. Reaction times for both groups of subjects decreased from Blocks 1 to 4 and increased again in Block 5.

A two-way ANOVA was carried out with group as a between-subjects factor and block as a within-subjects factor. There was no significant group effect or any interaction between group and block. The main effect of block was significant, $F(4, 148) = 36.31, p < .0001$. To make sure this lack of

difference in the degree of learning between the aware and unaware groups did not mask an overall lack of learning in either of the two groups, one-way repeated measures ANOVAs were carried out for each group separately with the data from Blocks 4 and 5. These analyses revealed significant slowing on Block 5 as compared to Block 4 for each group: (aware, $F[1, 20] = 46.73, p < .0001$; unaware, $F[1, 17] = 39.64, p < .0001$).

Discussion

In this experiment both aware and unaware subjects gave clear evidence of learning across four blocks of trials. In fact, although the aware group showed a more marked decrease in response times than the unaware group, statistical analyses suggested no significant differences in the performance of the two groups.

The primary conclusion of this experiment is that the conditions for implicit learning can be met when responding is verbal and when the task involves a mapping of spatial locations onto words. This complements the findings of the preceding experiment in which verbal stimuli were mapped onto spatial locations.

General Discussion

The main results of the four experiments are summarized in Table 1. In all except the first, subjects who were given training on the repeating sequence demonstrated some learning of the sequence, even when they had no conscious knowledge of it. This pattern of results was obtained across a variety of experimental conditions. There were differences among Experiments 2, 3, and 4 in both the stimuli and responses. For instance, the stimulus words that were used varied in the degree of relatedness. The words in Experiments 2 and 3 were unrelated nouns, whereas those in Experiment 4 were highly related and comprised a complete category. The response requirements also differed, with Experiments 2 and 4 requiring spoken responses and Experiment 3 involving button presses. In all three experiments, however, verbal elements existed in one or all components of the task, suggesting that verbal materials and verbal responses may be part of an implicitly acquired skill.

Awareness of the sequence produced a benefit for subjects in Experiments 2 and 3, in that those who reported explicit knowledge of the sequence were able to respond more quickly than those who did not. Explicit knowledge of the sequence also allowed the aware subjects to perform at an advantage on the generate version of the task. In contrast, subjects who showed by their response latencies that they learned the sequence, but whose learning was outside of awareness, performed no better on the generate task than subjects who had no previous experience with the sequence.

Thus, the cumulative evidence of Experiments 2, 3, and 4 demonstrates implicit learning of 10-trial verbal sequences. It is clear from this set of experiments that when subjects learned, they acquired a sequence of stimuli and responses, rather than an unordered set of stimulus–response pairs. This

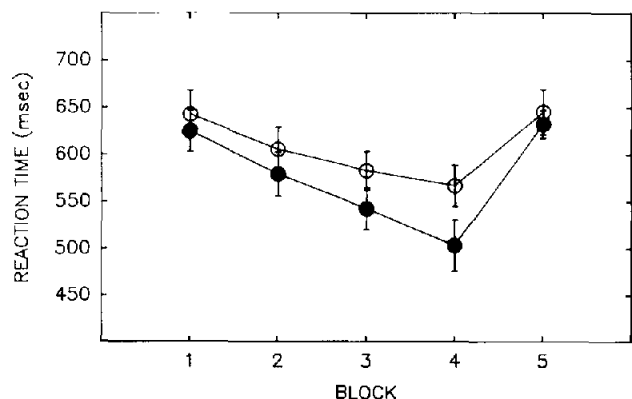


Figure 6. Experiment 4: Mean reaction times in milliseconds. (Filled circles = aware subjects [*n* = 21]; open circles = unaware subjects [*n* = 18]. Bars indicate one standard error above and below the mean.)

Table 1
Summary of Experiments 1-4

Task	Stimuli	Response	Did unaware subjects learn?
Naming	Verbal	Verbal	No
Categorization	Verbal	Verbal	Yes
Identification	Verbal	Spatial	Yes
Directions	Spatial	Verbal	Yes

aspect of the tasks differentiates them in a critical respect from repetition priming studies of implicit verbal learning. In the latter paradigm, learning is always assessed for individual words or pairs of words, whereas in the current studies, interitem relations within a sequence were important. Because the overt cognitive activity—that is the subjects' responding—involved individual words without reference to subsequent or preceding words, we must postulate that this cognitive activity facilitated the linkage of the entire context in which the activity occurred.

In addition to establishing that implicit learning of sequence can occur within the verbal domain, this set of studies also provides data concerning the conditions under which this learning takes place. The first point to consider is the contrast between the results of Experiment 1, in which subjects who were unaware of the sequence did not learn, and the other three experiments. The absence of implicit learning in the first experiment implies that the nature of the stimulus-response relation is a powerful factor in determining whether implicit learning will occur. When subjects were given a highly automatic and overlearned task such as word naming, little implicit learning occurred. However, when the task required a further mapping of the stimulus, as in the categorization task of Experiment 2, acquisition was facilitated. In Experiment 3, when the response was an arbitrarily defined motor response to each word, and in Experiment 4, when a verbal response was given to spatial symbols, implicit learning appeared even more robust. In both of these spatial-verbal tasks, responding involved a nonautomatic mapping of stimulus to response. Similarly, the original spatial task involved a non-automatic process of pressing buttons in response to light positions.

In asserting that only Experiment 1 involved a task that is highly automatized (Posner & Snyder, 1975), we are also suggesting that only in that experiment could subjects carry out the task with minimal attentional demands. Presumably, the other tasks were not automatic. As the Stroop task has underscored, even a skill that is well learned from childhood, such as color naming, may be less automatic than reading of words. Recently, MacLeod and Dunbar (1988) have argued that automaticity is likely to form a continuum based on practice and the salience of the mapping process. Where the tasks in Experiments 2 through 4 lie on this continuum is unclear, although one might speculate that the mapping of a word to an arbitrary button press is the least familiar and least automatic task because it was the only one on which subjects had no prior experience. Nevertheless, practice may affect the automaticity of these tasks differentially, and it would be premature to make this type of comparison.

On the basis of this reasoning, we suggest that the manipulations of the relation between stimuli and responses affected the amount of attentional resources that the subjects devoted to each stimulus-response pair. It is reasonable to hypothesize, on the basis of results of these experiments, that attention, mediated through effortfulness, plays a critical role in facilitating implicit learning. This finding is consistent with data from an earlier study (Nissen & Bullemer, 1987), which demonstrated that implicit learning of a nonverbal sequence does not occur under divided attention conditions. In that experiment, subjects who received training on a repeating spatial sequence under dual-task conditions subsequently performed similarly to naive subjects in responding to the sequence under single-task conditions. The present set of experiments thus provides converging evidence concerning the importance of attention in implicit learning. However, because we did not manipulate attention directly in these experiments, we cannot establish with certainty that it was specifically attention that produced the differences between Experiments 1 and 2.

Although we found evidence of implicit learning in Experiments 2, 3, and 4, the question still remains whether there were any differences in the amount of learning and whether certain conditions are more likely to produce such learning. A comparison of the size of the learning effects, summarized in Table 2, may be instructive.

The difference in reaction time in the last block of a repeating sequence and the immediately following block of a random sequence can be taken as a measure of the extent to which subjects learned the repeating sequence. This measure is not inflated by nonspecific learning but instead reflects the acquisition of the sequence itself. Using this measure, it appears from Table 2 that learning of the sequence was more robust when the task included a spatial component, as in Experiments 3 and 4, than when it did not, as in Experiment 2 (and, of course, Experiment 1).

Post hoc statistical analyses of the data from Experiments 2, 3, and 4 corroborate this impression. A one-way ANOVA examining the difference between Block 4 and Block 5 across these three experiments showed a significant difference in the degree of learning, $F(2, 51) = 5.55, p = .007$. Follow-up Newman-Keuls tests indicated that unaware learning on the

Table 2
Degree of Learning in Experiments 1-4: Learning Effect Size and Awareness

Experiment ^a	Subject group			Proportion aware (%)
	Aware	Unaware	Control	
1	136	12	5	33
2	130	25	-3	29
3	181	74	-12	53
4	129	79		54

Note. Values represent the difference in milliseconds between the reaction time in the final random block and the reaction time in the immediately preceding repeating sequence block.

^a Subjects received eight blocks of training in Experiment 1 and four blocks in all others.

categorization task (Experiment 2) was significantly less than in the other two experiments, which did not differ from each other ($p < .05$). In contrast, no significant differences were found in the amount of learning for aware subjects as a function of the task performed, $F(2, 38) = 1.13$. Although these analyses can be criticized for the lack of entirely equivalent conditions and sample sizes across the experiments, they are at least suggestive of differences among the tasks.

In addition to the differences in the amount of implicit learning between the purely verbal task and the other two tasks, almost twice as many subjects developed explicit knowledge of the sequence in Experiments 3 and 4 as in Experiment 2 (See Table 2). This trend is consistent with results from an earlier study that used the original, spatial task (Willingham et al., 1989). In that study, an even larger proportion of subjects—68%—reported knowledge of the sequence after four blocks of practice. Overall, the introduction of spatial components into the task appears to enhance the degree of implicit learning and simultaneously to increase the probability of the development of explicit knowledge of the sequence.

Why should the existence of a spatial relation either among the stimuli that are presented (as in Experiment 4) or the responses that are generated (as in Experiment 3) facilitate learning without (and with) awareness? Although verbal and spatial sequences could potentially be executed in similar fashion, such as through the hierarchical implementation of higher level programs (Rosenbaum, Kenny, & Derr, 1983), it is possible that subjects were able to organize the spatial sequences used in these experiments into natural subparts. Restle (1970) has suggested that subjects separate spatial sequences into their salient components, such as runs and trills. Each subpart can be generated by the application of a particular rule. A subpart of the motor sequence included in Experiment 3 involved pressing each button from right to left; another part involved transposing a segment one position to the right. Similarly, the sequence of stimuli used in Experiment 4 involved three counterclockwise changes followed by three clockwise changes. We are not suggesting that the particular spatial sequences in these experiments were unusually easy to learn; any spatial sequence will have subparts that can be defined by the application of a spatial transformation rule. What we are suggesting is that spatial sequences differ from sequences of nouns in the availability of salient rules of transformation for specifying and encoding the sequence. In the case of verbal sequences such as those used in the current experiments or the sequences of letters used by Reber (1976), there are, of course, always rules that can be specified to derive the sequence. However, they do not take advantage of simple patterns, such as spatial runs and trills that are familiar preexperimentally.

In summary, the findings presented in this article provide clear evidence that implicit learning can occur in the verbal domain. They extend previous research by using tasks that involve learning a series of associations among verbal stimuli, associations that were unique to the experimental context and which were not familiar to the subjects ahead of time. In addition, it has been argued that a minimal level of attention, i.e., performance of a nonautomatic mapping of a stimulus onto a response, is necessary for such learning to take place.

The admittedly speculative comments on the apparent difficulty in learning implicitly a set of verbal associations (as compared with a set of spatial associations) point to the need for further research. If the apparent advantage for unaware learning of spatial sequences (of either responses or stimuli) is truly a function of the ease with which the sequence can be organized or chunked, then further studies are needed to unconfound the roles of organization and the verbal versus nonverbal nature of the tasks. For example, an implicit learning task using verbal sequences that can be more easily subdivided into meaningful parts could be used. If ease of organization is the crucial factor, then such verbal patterns should show more robust implicit learning than an otherwise equivalent but difficult-to-subdivide sequence. This would be analogous to the differences in repetition priming obtained with easy and hard paired associates. Research with amnesic patients has shown that implicit learning of unrelated word pairs is obtained only with mildly impaired patients, whereas even severely amnesic patients show consistent repetition priming of highly related pairs (Schacter & Graf, 1986). A further direction for this work is with neurological populations who have disorders of memory and are known to have spatial and/or motor difficulties as well. The performance of such patients, including those with Huntington's disease and other dementing illnesses, would add to our knowledge of the kinds of learning that are preserved in amnesic patients and contribute to our understanding of the phenomenon of implicit learning.

References

- Beatty, W. W., Salmon, S. P., Bernstein, N., Martone, M., Lyon, L., & Butters, N. (1987). Procedural learning in a patient with amnesia due to hypoxia. *Brain and Cognition*, *6*, 386-402.
- Cermak, L. S., Talbot, N., Chandler, K., & Wolbarst, L. R. (1985). The perceptual priming phenomenon in amnesia. *Neuropsychologia*, *23*, 615-622.
- Cohen, N. J., & Squire, L. R. (1980). Preserved learning and retention of pattern-analyzing skill in amnesia: Dissociation of knowing how and knowing that. *Science*, *210*, 207-210.
- Diamond, R., & Rozin, P. (1984). Activation of existing memories in amnesic syndrome. *Journal of Abnormal Psychology*, *93*, 98-105.
- Dulany, D. E., Carlson, R. A., & Dewey, G. I. (1984). A case of syntactical learning and judgment: How conscious and how abstract? *Journal of Experimental Psychology*, *113*, 541-555.
- Hebb, D. O. (1961). Distinctive features of learning in the higher animal. In A. Fessard, R. W. Gerard, J. Konorski, & J. F. Delafresnaye (Eds.), *Brain mechanisms and learning* (pp. 37-51). Oxford: Blackwell.
- Knopman, D. S., & Nissen, M. J. (1987). Implicit learning in patients with probable Alzheimer's Disease. *Neurology*, *37*, 784-788.
- Lewicki, P., Czyżewska, M., & Hoffman, H. (1987). Unconscious acquisition of complex procedural knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 523-530.
- MacLeod, C. M., & Dunbar, K. (1988). Training and Stroop-like interference: Evidence for a continuum of automaticity. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*, 126-135.
- Moscovitch, M., Winocur, G., & McLachlan, D. (1986). Memory as assessed by recognition and reading time in normal and memory-

- impaired people with Alzheimer's disease and other neurological disorders. *Journal of Experimental Psychology: General*, *115*, 331–347.
- Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology*, *19*, 1–32.
- Nissen, M. J., Knopman, D. S., & Schacter, D. L. (1987). Neurochemical dissociation of memory systems. *Neurology*, *37*, 789–794.
- Nissen, M. J., Willingham, D., & Hartman, M. (1989). Explicit and implicit remembering: When is learning preserved in amnesia? *Neuropsychologia*, *27*, 341–352.
- Posner, M. I., & Snyder, C. R. R. (1975). Facilitation and inhibition in the processing of signals. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and performance V* (pp. 669–682). New York: Academic Press.
- 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., & Allen, R. (1978). Analogy and abstraction schemes in synthetic grammar learning: A functional interpretation. *Cognition*, *6*, 189–221.
- Reber, A. S., Allen, R., & Regan, S. (1985). Syntactic learning and judgments: Still unconscious and still abstract. *Journal of Experimental Psychology: General*, *114*, 17–24.
- Restle, F. (1970). Theory of serial pattern learning: Structural trees. *Psychological Review*, *77*, 481–495.
- Richardson-Klavehn, A., & Bjork, R. A. (1988). Measures of memory. *Annual Review of Psychology*, *39*, 475–543.
- Roediger, H. L., & Blaxton, T. A. (1987). Retrieval modes produce dissociations in memory for surface information. In D. S. Gorfein, & R. R. Hoffman (Eds.), *Memory and cognitive processes: The Ebbinghaus Centennial Conference* (pp. 349–379). Hillsdale, NJ: Erlbaum.
- Rosenbaum, D. A., Kenny, S. B., & Derr, M. A. (1983). Hierarchical control of rapid movement sequences. *Journal of Experimental Psychology: Human Perception and Performance*, *9*, 86–102.
- Schacter, D. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 501–518.
- Schacter, D. L., & Graf, P. (1986). Preserved learning in amnesic patients: Perspectives from research on direct priming. *Journal of Clinical and Experimental Neuropsychology*, *8*, 727–743.
- Shimamura, A. P. (1986). Priming effects in amnesia: Evidence for a dissociable memory function. *Quarterly Journal of Experimental Psychology*, *38A*, 619–644.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–661.
- Willingham, D. B., Nissen, M. J., & Bullemer, P. (1989). On the development of procedural knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*, 1047–1060.

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