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Multiple learning mechanisms within implicit learning

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Abstract

The experiment reported in this paper provides evidence that there are at least two independent implicit learning mechanisms in implicit learning: an efficiency mechanism, which underlies changes in reaction time to patterned stimuli, and a conceptual fluency mechanism, which underlies the ability to make judgments about stimuli based on implicit knowledge. Each of these implicit mechanisms is independent of explicit learning. Subjects performed a serial reaction time task under one of three learning conditions (nonattentional, attentional and observational) for one of three study lengths (2, 6 or 12 blocks). Subjects then completed five tests of their knowledge: attentional and nonattentional reaction time tasks (measuring two kinds of efficiency learning), awareness questionnaire (measuring explicit knowledge) , a generation task, and a conceptual fluency task. Correlation analyses and criterion analyses found no dependencies between the measures in low awareness subjects. In addition, the measures were influenced differently by the independent variables of learning condition and study length; these dissociations indicate separate underlying mechanisms. Implications of the existence of multiple implicit mechanisms for connectionist modeling of implicit learning are drawn.

Implicit learning, particularly implicit sequence learning such as that shown in the serial reaction time task (SRT), has recently been the subject of many connectionist models (Cleeremans, 1993a, 1993b; Cleeremans & McClelland, 1991; Keele & Jennings, 1992; Kushner, Cleeremans, & Reber, 1990). This is not surprising, because implicit learning is especially suited to being modeled by connectionist mechanisms: It is a process that learns from exemplars by inducing similarities and patterns in the input. However, models of implicit learning have tended to assume that implicit learning is a single process. This paper provides evidence that implicit learning may involve at least two independent learning mechanisms: an efficiency mechanism, which underlies changes in speed of response towards patterned stimuli, and a conceptual fluency mechanism, which underlies the ability to make judgments about stimuli based on implicit knowledge.

Implicit learning has been defined as incidental learning of complex patterns without accompanying verbalizable knowledge sufficient to account for performance; additionally, implicit learning is preserved in subjects with amnesia (Seger, 1994). There are many experimental tasks that meet this definition of implicit learning; in addition to SRT, the best known of these include artificial grammar learning and dynamic systems learning. In an analysis of implicit learning tasks, Seger (1994) found that they involve three very different dependent measures, or ***response modalities***. The first response modality is conceptual fluency: Subjects make judgments about stimuli (such as grammaticality judgments in artificial grammar learning), usually reporting that they rely on their intuition or feelings of knowing as the basis of their judgments. The second is efficiency: Subjects show that they have learned via their increased speed and/or accuracy in processing the stimuli. The third is prediction and control: Subjects demonstrate learning by accurately predicting or controlling some aspect of the stimuli, as in dynamic systems research. On the surface, these dependent measures are quite different, and seem to require quite different mental processing; however, it is possible that each measure taps the same implicit representation, and that any differences in the type of response elicited are irrelevant as far as learning is concerned. For the most part, each implicit learning task has utilized only one of the possible response modalities. The few studies that have tested learning via more than one response modality have yielded conflicting results concerning the independence of the mechanisms underlying the response modalities (Seger, 1994).

The experiment presented here has as its goal to examine learning via two response modalities, efficiency and conceptual fluency, in a single task, SRT. Prediction and control was not used as a response modality because, despite extensive pilot testing, it proved impossible to find a task on which subjects show the ability to predict stimuli without having explicit knowledge of the pattern. In SRT subjects view a series of identical stimuli that appear in different locations, and for each stimulus location press a corresponding key. The stimulus locations follow a set sequence; learning of the sequence is measured via the efficiency response modality as the difference in reaction time between sequence blocks and blocks in which the stimuli are presented randomly. Although some subjects do become aware of the sequence during learning, aware and unaware subjects both show a pattern of reaction time decrease (Willingham, Nissen, & Bullemer, 1989), indicating that implicit learning can occur independent of awareness. Curran and Keele (1993) argue that there are two independent mechanisms in SRT, an attentional mechanism and a nonattentional mechanism; both types of learning are measured via the efficiency response modality in their experiments. The experiment presented here investigates the independence of conceptual fluency and both of these types of efficiency learning.

There are several reasons to suspect that efficiency and conceptual fluency are subserved by different learning mechanisms. First, some research indicates that efficiency task performance is linked to motor responses made by subjects (Cunningham, Healy, & Williams, 1984; Miller, 1987; Stadler, 1989; Willingham et al., 1989; but see also Howard, Mutter and Howard, 1992), though at a level higher than that of the selection of particular motor effectors (Cohen, Ivry, & Keele, 1990). Conceptual fluency tasks, on the other hand, require no motor involvement and instead involve making judgments about purely perceptual stimuli.

Second, neuropsychological evidence implies that multiple brain areas, which may correspond to different mechanisms, underlie implicit learning. Implicit learning is preserved in subjects with amnesia, indicating that implicit learning is dependent on neural systems other than the hippocampal-diencephalic systems that underlie explicit memory (Squire, 1992). Candidate systems include corticostriatal systems (damaged in Huntington's disease, HD, and Parkinson's disease, PD) and cortical association areas (damaged in Alzheimer's disease, AD). Several studies (Knopman & Nissen, 1991; Ferraro, Balota, & Connor, 1993) have found that HD and PD subjects are impaired on the SRT; these patients are also impaired on motoric implicit memory tasks (Heindel et. al., 1989). This pattern is consistent with the efficiency mechanism being related to motor programming systems and reliant on corticostriatal systems. Cortical association areas, on the other hand, have been implicated in implicit memory tests involving perceptual and conceptual priming (Heindel et al., 1991; Keane et al., 1991),which are at least conceptually similar to implicit learning experiments using the conceptual fluency response modality. This association implies that subjects with AD may well be impaired on conceptual fluency measures, but should be unimpaired on efficiency measures. Studies on SRT with AD subjects to date have produced mixed results; Ferraro et al. (1993) found overall impairment, but Knopman and Nissen (1987) found that most AD subjects are not impaired on SRT. Interestingly, the subgroup that was impaired also tended to be impaired on other spatial tasks, implying that their inability to learn the sequence was due to impairments in spatial cognition.

Method

Subjects

Subjects were 180 male and female UCLA students who participated in partial fulfillment of a course requirement.

Design

A 3 x 3 between-subjects design was used. The first independent variable was the learning task performed, with three levels: nonattentional learning (under dual task conditions), attentional learning, and observational learning. The second independent variable was the length of the learning task: short (2 blocks), medium (6 blocks) and long (12 blocks).

Materials

All of the experimental tasks and instructions (with the exception of the awareness questionnaire) were presented to subjects on a Macintosh II computer running MacProbe software. The display consisted of a blank screen with four open circles of 1 cm diameter, evenly spaced horizontally; the two end circles were separated by approximately 7 degrees of visual angle. On each trial, one of the four circles was filled in to be a solid black dot and was returned to being an open circle before the next trial began. Stimuli were presented in blocks of 50 trials, with rest breaks between them. There were two kinds of blocks, random and sequence blocks. In random blocks, the dots appeared at any of the four positions randomly, subject to the constraints that the same location was never repeated on adjacent trials, and that the overall frequency with which each location was chosen matched the frequency with which it appeared in the sequence blocks. In the sequence blocks, the dots appeared in a set sequence of length 10, which was the same for all subjects: BDBCABCDBC. Each block started at a randomly determined position within the sequence. There were 5 different sequence position to screen location assignments, counterbalanced across subjects, so that, for example, for some subjects the position "A" was the rightmost circle, whereas for other subjects "A" was the middle-left circle.

The tasks that subjects performed are each outlined below, along with the response modality each was designed to be a measure of. It should be noted that the same stimulus sequence was used in all of the tasks; the only difference was in how the subject was asked to respond to it.

Reaction time task (efficiency): Subjects were instructed to press the key corresponding to each dot; the keys v, b, n, and m on the bottom row of the computer keyboard were used. There were two forms of this task. In the *nonattentional* form of the task, subjects were given a tone counting task to perform in parallel with the button pressing task. After each key press, one of two tones was played to the subject over headphones. The subject was told to keep in mind a running total of the number of high tones, and was asked to report that number at the end of each block. In the *attentional* form of the task, subjects are not given a dual task to perform. These tasks were used in both the learning and testing phases of the experiment. Two measures were elicited from each subject: Eff-att and Eff-non. Each measure is calculated by taking the difference between the mean of median reaction times for each repetition of the sequence in the sequence blocks and the average of the mean of median reaction times for each group of 10 stimuli in the two surrounding random blocks.

Observation task (learning task appropriate to conceptual fluency): In this task subjects were asked to watch the screen without making any overt response as the dots were presented. This task was developed to be a neutral non-response learning condition similar to that used in implicit learning studies investigating conceptual fluency knowledge, and was used in the learning phase only.

Recognition task (conceptual fluency): In this task subjects were shown a series of sequences of dots of length 4, 5, or 6 and were asked to indicate for each sequence whether it is correct or not. Subjects made judgments about 60 different sequences, each of which were presented twice. Half of the sequences were correct (i.e., a subsequence of the sequence the subject was trained on) and half were incorrect. This task was intended to be similar to the grammaticality tests used in artificial grammar experiments (Reber, 1989); therefore, subjects were given instructions in which they were encouraged to rely on their intuition and feelings of knowing, not on conscious, explicit recognition. Seger (1994) argued that recognition can be carried out via conceptual fluency if subjects are willing to make recognition judgments through a process of attribution of their subjective feelings of fluency rather than using explicit memory processes. Two measures were derived from this task. The first (CF-all) is an overall measure of how well subjects discriminate correct from incorrect sequence segments. The second (CF-HO) is a measure of the amount of knowledge that subjects have about the higher-order properties of the string. The second measure is calculated by comparing how well subjects discriminate between correct sequence segments and incorrect sequence segments in which the pairs of adjacent elements are correct (i.e., all of the pairs in the sequence segment appear in the actual sequence), but the higher-order pattern is incorrect. D-prime scores were calculated for both CF-all and CF-HO to control for response biases.

Generation task: In this task subjects were asked to attempt to recreate the sequence that they were exposed to by pressing the same buttons that they used in the learning phase. Each subject was asked to try to generate the sequence twice, and was given the starting dot to begin with each time. Three measures of generation ability were used: Gen-1 (1 stands for first order), a measure reflecting how well the generated sequence matched the base frequencies of the elements in the actual sequence; Gen-2 (2 stands for second order), the number of correct pairs of elements used in the generated sequence; and Gen-HO (HO stands for higher order), the total length of runs of length three or more present in the generated sequence. It is unclear whether this task should be considered to reflect explicit knowledge, or whether it can be performed by implicit processes. If it is performed by implicit processes, it is similarly unclear whether it is related to conceptual fluency or efficiency or if it is independent. The task was included for purposes of comparison to other experiments that use generation tasks.

Awareness task (explicit learning): Subjects were given a questionnaire from which three measures of their awareness of the sequence were derived. One measure, Aware-Non Specific (A-NS), was provided by the subjects' rating on a 7-point Likert scale of how aware they were of the presence of any pattern. A second measure, Aware-Specific (A-S) was provided by the subject's rating on a 7-point Likert scale of how likely it was that the pattern was a set sequence of approximately length 10 (subjects also rated other possible but incorrect patterns so as not to reveal to them the actual type of pattern). Subjects were also asked to describe any pattern they had noticed in a free report question; the measure Aware-Free Report (A-FR) was a judge's rating on a 6 point scale of how well the subject's response to the question matched the actual pattern.

Procedure

Each subject was randomly assigned to one of the nine experimental conditions and performed one of three learning tasks (nonattentional, attentional or observational) for one of three numbers of blocks (2, 6, or 12). After completing the learning task, all subjects performed the following tasks in the following order: the attentional efficiency task (3 blocks -- random, pattern, random -- under single task conditions), the nonattentional efficiency task (4 blocks -- random, random, pattern, random -- under dual task conditions), the awareness questionnaire, the generation task, and the conceptual fluency test. In the instructions for each task, subjects were told as little as possible about the presence of a pattern. For example, in the efficiency conditions, a pattern was not mentioned at all. In the conceptual fluency conditions it was necessary to mention that there was some sort of pattern; however, subjects were not told about its nature.

Table 1: Order of tasks and their associated measures of learning.

Test	Measures
Learning task	
Attentional efficiency	Eff-att
Nonattentional efficiency	Eff-non
Awareness	A-NS
	A-S
	A-FR
Generation	Gen-1
	Gen-2
	Gen-HO
Conceptual Fluency	CF-all
	CF-HO

Results

The first evidence that there are separate learning systems involved in the serial reaction time task comes from findings indicating that the response modalities are affected differently by the independent variables. The learning task had a significant effect on the awareness measures as shown by one-way ANOVAs: A-NS: $F(2,177) = 22.75$, $p < .0001$; A-FR: $F(2,177) = 8.17$, $p < .0005$; A-S: $F(2,177) = 5.76$, $p < .005$; post-hoc tests indicated that the nonattentional group in each case showed lower awareness than the attentional and observational groups. The type of learning task also had an effect on conceptual fluency knowledge (CF-all: $F(2,175) = 3.59$, $p < .05$; CF-HO: $F(2,174) = 6.8$, $p < .005$); post hoc tests indicated that nonattentional learning led to worse performance than the other two conditions. Type of learning task did not have an effect on either efficiency measure (both Fs < 1.0). The latter result is somewhat surprising in light of research by Cohen et al. (1990) and Curran and Keele (1993) showing differences between attentional and nonattentional learning. However, in the present experiment the sequence used was a hybrid sequence (one in which some of the pairwise associations between sequence elements were unique and some were ambiguous), which has been shown to be learnable in both attentional and nonattentional conditions. Learning task also did not have an effect on generation, except for Gen-2 $F(2,174) = 3.46$, $p < .05$, in which post hoc tests indicated that the nonattentional group was significantly worse than the attentional group. Further ANOVAs on subjects with low degrees of awareness only (defined as answering 4 or less on A-NS) yielded no significant effects of learning condition, indicating that the differences between groups in the conceptual fluency and generation measures may be due to higher degrees of explicit knowledge in the attentional and observe conditions (only 19/60 attentional and 15/60 observe subjects qualified as low awareness, compared to 43/60 subjects in the nonattentional condition).

A different pattern of results was found when length of study was examined. Length of study had no effect on awareness, but did have an effect on generation (Gen-HO: $F(2,170) = 9.54$, $p < .0001$; Gen-1: $F(2,174) = 3.25$, $p < .05$; Gen-2: $F(2,174) = 4.69$, $p < .05$). As was the case for learning type, there was no effect of length of study on nonattentional efficiency, though there was a trend towards length of study influencing attentional learning (Eff-att: $F(2,177) = 2.8$, $p = .06$; the difference between the short and medium group was significant; $p = .02$). Like type of study, study length had an effect on both measures of conceptual fluency (CF-all: $F(2,175) = 6.82$, $p < .005$; CF-HO: $F(2,174) = 6.58$, $p < .005$); in both cases, the short and medium length conditions are significantly worse than the long condition.

To further investigate the independence of the different measures of learning, correlation analyses were performed on the ten measures. To control for the effects of explicit knowledge on the implicit tasks, results from high awareness and low awareness subjects were analyzed separately. For both high and low awareness subjects, measures elicited from the same task correlated with each other (e.g., the three Gen measures all correlated with each other). For low awareness subjects, the only significant cross-task correlations were between CF-all and Gen-2 and between A-S and CF - HO; these correlations, though significant, were low. For high awareness subjects, the tasks correlated to a much higher degree: The CF measures significantly correlated with all three Generation measures and all of the awareness measures (except for A-S). Gen-HO correlated with A-S and A-NS, though the other generation scores did not correlate with the awareness scores. The efficiency scores correlated highly with each other, but were less highly correlated with the other scores, though Eff-att correlated with CF-all and G-2, whereas Eff-non correlated with A-S. These results indicate that the tasks were independent in low awareness subjects, but in high awareness subjects they were all are performed using explicit knowledge. These results appear to be inconsistent with Perruchet and Amorim's (1992) finding that recognition and generation task performance correlates with efficiency test performance; however, those investigators did not control for explicit knowledge, and the correlations they observed could be due to high awareness subjects using their explicit knowledge of the sequence on the tests.

Table 2: Correlation matrixes for low and high awareness subjects.

low awareness	Eff-att	Eff-non	CF-all	CF-HO	Gen-1	Gen-2	Gen-HO	A-NS	A-S
Eff-att									
Eff-non	.04								
CF-all	.05	-.04							
CF-HO	-.02	.02	.67@						
Gen-1	-.02	-.05	.19	.15					
Gen-2	.09	.03	.22*	.08	.57@				
Gen-HO	.05	.08	.15	.08	.51@	.75@			
A-NS	.00	-.10	.18	.04	.16	.10	.04		
A-S	-.02	-.02	-.07	-.25*	-.03	.05	.05	.12	
A-FR	.21	-.20	.17	-.03	.09	.15	.10	.53@	.02

high awareness	Eff-att	Eff-non	CF-all	CF-HO	Gen-1	Gen-2	Gen-HO	A-NS	A-S
Eff-att									
Eff-non	.31@								
CF-all	.20*	.04							
CF-HO	.18	.04	.81@						
Gen-1	-.09	-.11	.26@	.14					
Gen-2	.21*	-.03	.27@	.23*	.41@				
Gen-HO	.13	-.08	.50@	.45@	.47@	.68@			
A-NS	.10	.21*	.28@	.22*	.06	.11	.26*		
A-S	.11	.07	.16	.12	.19	.15	.33@	.30@	
A-FR	.04	.06	.32@	.31@	.03	-.04	.12	.17	.03

*: p < .05; @: p < .01

A criterion analysis, similar to one performed by Willingham et al. (1989) to show that implicit and explicit knowledge were developed separately in SRT, was performed to investigate whether the types of knowledge tapped by the different measures develop independently over time. The logic is that if two measures are dependent, subjects should not meet criterion on one measure without also meeting it on the other measure, and that meeting criterion on one measure should routinely precede meeting criterion on another. For each of four of the variables, A-NS, Gen-HO, CF-all, and Eff-att, a criterion for learning was set and each subject was classified by that criterion as having either learned or not learned. There was no evidence that learning on any measure typically preceded learning on any other measure; subjects were evenly distributed into groups showing learning on only one of each pair of measures in each length of study condition.

Discussion

The research presented here indicates that the processes underlying implicit learning in the efficiency and conceptual fluency response modalities are independent of each other, and independent of explicit learning. An interesting pattern of dissociations was found in the effects of the two independent variables on the different response modalities: only learning condition affects awareness, and only length of study affects generation, whereas both variables affect conceptual fluency knowledge, and neither variable affects nonattentional efficiency. In addition, correlation analyses and criterion analysis indicated that the measures were independent. These results are consistent with evidence from neuropsychological experiments indicating that implicit motor learning and memory is dependent on different brain areas than perceptual forms of implicit memory (Heindel et al., 1989). Future research could profitably study the different modalities examined in this experiment in brain-damaged subjects to gain further evidence as to whether the modalities reflect the working of independent mechanisms. It is logical to predict that subjects with HD or PD (who have damage to the corticostriatal systems involved in motor implicit memory) would be impaired on efficiency measures of learning of the sequence, but preserved on conceptual fluency measures, whereas subjects with AD (who have damage to the cortical association areas involved in perceptual implicit memory) would show the opposite pattern of impairment.

The results from this experiment also have implications for modeling implicit sequence learning. Since there are at least two independent response modalities involved, modelers should be clear as to which response modality they are modeling. It is perhaps reasonable to take overall activation in the nodes as a measure of conceptual fluency knowledge, as conceptual fluency may be due to priming in high-level mental systems dealing with covariation calculation; but it is less justifiable as a measure of efficiency. In the latter case, it may be more reasonable to assign specific nodes to be the output node for each move, and have the individual node with the highest activation value be the selected action. Learning should be modeled as taking place within a response modality, and care should be taken not to mix different tasks that tap different modalities.

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