Learning and Awareness in the Serial Reaction Time Task

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Abstract

This study examined evidence for implicit rule-based learning in the serial reaction time task and investigated the effect of explicit knowledge on performance. Participants responded to visual stimuli appearing in one of six locations. In each run, six stimuli were presented, with a stimulus appearing in each and every position exactly once in a random order. Participants implicitly learned the pattern as indicated by better performance on the sixth trials than on the first trials. Yet none of the three measures of explicit knowledge -- verbalization, free generation, and recognition -- were able to detect participants' awareness of the pattern. Explicit knowledge of the pattern improved performance, whereas active search for the pattern hurt performance if the pattern was not found. A possible learning mechanism is proposed to account for serial learning.

Introduction

In the serial reaction time task, participants have to respond as quickly and accurately as possible to the occurrence of a stimulus. The stimulus appears in one of several locations in a display, each of which requires a different response. Another stimulus appears shortly after the previous response is completed. The sequence of the location in which the stimulus appears either is random or follows a repeating pattern. Learning the sequence is evidenced by a decrease in reaction time while the repeating pattern is presented, as compared to a random sequence.

Studies have demonstrated that participants are able to learn the sequence, as indicated by reaction time decreasing more quickly when the same sequence is continuously repeated than when a random sequence is presented (Cohen, Ivry, & Keele, 1990; Curran & Keele, 1993; Hartman, Knopman, & Nissen, 1989; Lewicki, 1986; Lewicki, Czyzewska, & Hoffman, 1987; Lewicki, Hill, & Bizot, 1988; Nissen & Bullemer, 1987; Stadler, 1989; Willingham, Nissen, & Bullemer, 1989). These studies suggest that the regularity imposed by the sequence facilitates participants' performance on the task. More importantly, some researchers claim that learning occurs even though participants are not aware of the repeating sequence. In other words, there may be a dissociation between participants' performance on the serial reaction time task and their explicit knowledge about the sequence (Cohen, Ivry, & Keele, 1990; Nissen & Bullemer, 1987; Willingham, Nissen, & Bullemer, 1989). However, not all investigators agree that such a dissociation occurs.

Two important issues generate the debate over the relationship between performance and explicit knowledge on the serial reaction time task. The first issue is how explicit knowledge about the sequence should be measured. Different methods of measuring explicit knowledge have led to different conclusions about the relationship between explicit knowledge and performance. Studies using either a postexperimental interview or a standard generation task often conclude that participants are not aware of the sequence (e.g., Cohen & Curran, 1993; Willingham, Nissen, & Bullemer, 1989). In a postexperimental interview, participants are asked to report the sequence of stimuli after training on the task. With a standard generation task, participants are required to *generate* the next target rather than to *respond* to the present target as they would during training, and their responses are corrected trial-by-trial during testing. In addition, participants are not explicitly instructed to reproduce the prior sequence in a generation task, resulting in testing instructions being given only indirectly.

Due to the continuous distraction provided by corrective feedback as well as the indirect instruction in the standard generation task, Perruchet and his colleagues have questioned the adequacy of this task for measuring explicit knowledge (e.g., Perruchet & Amorim, 1992; Perruchet & Gallego, 1993). They have thus adopted a recognition test and a different version of the generation task to measure explicit knowledge (Perruchet & Amorim, 1992). In this revised generation task, participants are directly instructed to generate a sequence of trials that looks like the sequence they encountered in the training phase, and participants are not provided with any correction. Their results show a close parallel between explicit knowledge of fragments of the repeating sequence and performance. Participants revealed reliable explicit knowledge of the sequences after training. Willingham et al. (1993) also adopted a recognition test to measure explicit knowledge, but they found a dissociation between performance and explicit knowledge. However, this study has been criticized because it is based on only two no-knowledge participants (Shanks & St. John, 1994).

The second issue about the relationship between performance and explicit knowledge involves defining the nature of the knowledge that participants acquire in the serial reaction task. Researchers supporting parallelism usually suggest that learning *fragments* of the training sequences is sufficient to explain performance (e.g., Perruchet & Amorim, 1992; Perruchet, 1994). On the other hand, investigators demonstrating dissociation (Lewicki et al. 1987 ; Stadler, 1989, 1992) tend to propose that learning occurs because participants learn the *rule* that governs the sequence of the stimulus.

The first purpose of the present study is to provide more clear and convincing evidence about the nature of implicit rule-based learning in the serial reaction time task. Instead of arguing that the free generation and recognition tests do not necessarily measure explicit knowledge, the present study demonstrates that dissociation between performance and explicit knowledge is found, even if these two tests are used to detect participants' awareness of a sequence. Secondly, this study aims to investigate systematically the role of explicit knowledge in serial learning. Participants' explicit knowledge about the sequence was directly manipulated to examine the relationship between task performance and explicit knowledge.

The Pattern of Sequences

The present study differs from previous serial reaction time studies mainly in the rule determining the sequence of the stimuli. In the present study, the stimulus appears in one of six locations (from the first to the sixth position). Stimuli are presented in runs, with each run consisting of a series of 6 successive trials. Within each run, a stimulus appears in each and every position exactly once (i.e., in one trial). For example, 1, 2, 3, 4, 5, and 6 and 3, 5, 4, 6, 2, and 1 are two possible runs that follow this pattern. Sequences like 1, 2, 3, 2, 4, 6, do not follow the pattern because one of the locations (position 2) appears more than once, and thus another location (position 5) does not appear at all within this run of six trials. For the control sequence (the random sequence), the only constraint is that the stimulus cannot appear in the same location on any two consecutive trials. Within each training block, the frequency of the occurrence of each location is exactly the same for both the experimental and control sequences.

The pattern used in the present study is simple and can be easily verbalized, yet it is difficult for participants to figure out. Thus, the chance that participants will become aware of the pattern is minimized. More importantly, if learning occurs, participants must have acquired some knowledge about the pattern itself. Knowledge of either a fragment of instances or of any particular instances would not be useful for performing the task. There are two reasons for this. First, knowledge of an incomplete sequence (i.e., a fragment of the sequence, such as 2, 3, 4) is not useful, since the sequence is randomly determined within every run of six trials. Participants cannot make use of this knowledge because participants cannot know which sequence is being presented until all but the final stimulus is presented. Secondly, to make use of the knowledge of a particular instance that follows the pattern, participants would be required to remember all six positions of some instances. Since there are many instances (i.e., 6! = 720) that follow the pattern, the probability that any of the instances appear several times is very low. Therefore, the knowledge of particular instances is not useful either. In short, the improvement in the task performance can not be accounted for by participants' knowledge of any particular instances or fragment of instances.

The Explicit Measures

To demonstrate that participants were able to learn this task without corresponding explicit knowledge, three tests of explicit knowledge were used in the present study. There were a postexperimental interview, a recognition test and free generation. In all three explicit measures, participants were clearly asked to retrieve what they had learned in the training phase. In the postexperimental interview, if participants know the pattern, they should have no problem reporting it, since the pattern is easy to verbalize. As to the recognition and free generation tests, as mentioned before, most studies using these tests have found an association between task performance and explicit knowledge. Even though there are controversies over whether these two tests are appropriate measures of explicit knowledge (e.g., Lee, 1995; Mathews, 1990; Reber et al 1985; Willingham, Greeley & Bardone, 1993), to be conservative the present study adopted a stricter criterion for demonstrating implicit learning. The recognition and free generation tests were added to the verbalization to measure explicit knowledge.

Based on the nature of the pattern used in the present study, if learning occurs, participants' performance in terms of reaction time and improvement in reaction time should be in the following order, from the best to worst: the sixth, fifth, fourth, third, second, and first trials. Since each stimulus appears in each of the six locations exactly once within each run, the location of the first trial in each run is randomly determined. As the trial proceeds, the number of possible positions decreases. For example, if the first trials is in position 3, then there will be 5 positions left for the second trial. If the second position is 4, then the possible positions for the third trial will be the rest of the four positions (1, 2, 5, and 6). The same logic applies to the rest of the trials. The locations of the sixth trial thus is completely determined by the location of the previous 5 trials. If participants learn the pattern, they should respond fastest to the sixth trial, and improvement should also increase as training proceeds. On the other hand, for the first trial of each run, the decrease in reaction time should be similar to all trials in the random sequence. In addition, when a random sequence is presented, there should be no difference in performance between any trials of each run. The pattern of the sequence in the present study has the following statistical structure (Stadler, 1992): the sixth trial of each run has the highest level of statistical structure, and the statistical constraint decreases from the sixth to the first trial, in which the sequence is randomly determined.

The Purpose of This Study

The purpose this study was first to examine whether participants were able to learn the pattern used in the present study. Specifically, were there any differences in reaction time between the first and sixth trials, when participants were presented with the patterned sequence as opposed to a random sequence? Secondly, this study aimed to explore systematically the role of explicit knowledge in the serial reaction time task.

Method

Participants and Design

Participants in this study were students from introductory psychology courses at the Chinese University of Hong Kong, participating voluntarily to fulfill part of their course requirements. One hundred and four participants aged 19 to 22 took part in this experiment. They were randomly assigned to one of the following groups: the control group, the unaware group, the pattern-search group, or the pattern-told group.

Apparatus and Display

The experiment was run on an IBM 486 computer. The display consisted of six circles arranged in a horizontal line on the center of the computer screen and separated by a interval of 0.8 cm. Each circle was 3.5 cm in diameter. The viewing distance was 58 cm, and the distance between the centers of any two adjacent circles subtended a visual angle of 4o. Each circle corresponded to a key on the computer keyboard. The six corresponding keys were "s", "d", "f", "j", "k", and "l". The spatial configuration of the keys was entirely compatible with the screen position. Stimulus presentation consisted of one of the six circles becoming filled. Reaction time was measured as elapsed time between the onset of the stimulus and the participant's correct response.

Stimulus Sequence. In the experimental condition, the stimulus appeared in each of the six positions only once within each run of six trials. The sequence of these six stimuli appeared randomly. However, since repeated stimuli elicit shorter reaction times independently of their probability of presentation, the sequence did not use the same location on any two consecutive trials. For the control condition, the sequence of the stimuli was random, with the same constraint that there were no immediate repetitions of a particular location. For both experimental and control conditions, each participant received a different random order of stimuli.

Procedure

Participants first received instructions about the nature of the experiment. They were told that the purpose of the experiment was to discover more about how people learn typing skills and effects of practice on such learning. They were then instructed to place their fingers on the keyboard in a normal typing position. In other words, they were required to put four fingers of each hand on the "a", "s", "d", "f", "j", "k", "l", and ";" keys. The experiment was started when participants pressed the space bar. Participants then pressed the appropriate key in response to the filled circle as quickly and accurately as possible. Once participants pressed the correct key, the filled circle returned back to the original color. Otherwise, the filled circle stayed in the same location, and the timer kept running until the participants pressed the correct key. A warning tone sounded to alert participants when they had made a mistake by pressing an incorrect key.

All participants received a total of 7 training blocks, with two extra blocks as practice trials before training. For the experimental group, the sequence of the stimuli followed the pattern, while for the control group, the sequences of the stimuli were random. There were a total of 180 trials in each block. Thus, for the experimental condition, the pattern repeated 30 times. The frequency of occurrence of each location was the same (i.e., 30 times) for both experimental and control conditions. .

The unaware group was given the standard instructions. Participants in the pattern-search group were told that there was a pattern determining the sequence of the stimuli and that they should search for this pattern while performing the reaction time task. They were also told that after completing the training, they would be tested for the pattern. For the pattern-told group, before training, the experimenter explained the pattern to the participants and gave examples that followed the pattern and examples that did not follow the pattern. To ensure that participants understood the pattern, they were given 5 sequences on a piece of paper and were asked to choose those sequences that followed the pattern. The experimenter corrected them if they made mistakes.

As for the measures of explicit knowledge, first of all, all participants were asked to perform a recognition test. The only difference between the recognition test and the training task was that in the recognition test each time after participants made 6, 12, or 18 responses, they were asked to judge if the sequence of these stimuli followed the pattern appearing in training. No feedback was given. A question was completed after participants made a "yes" or "no" decision. There were a total of 18 questions in the recognition test.

After the recognition test, all participants were then instructed to generate six stimuli in the sequence that they thought followed the pattern appearing in training. Participants looked at the six circles in the computer screen while pressing the corresponding keys to indicate the sequence of the six stimuli. With each key that was pressed, the corresponding circle on the display became filled, and then the circle returned to its usual appearance when the next key was pressed. Once again, no feedback was given to participants. Finally, all participants except for the pattern-told group received a questionnaire containing questions regarding the rules. Since the pattern-told participants were told the pattern, they were not asked these three questions.

Results

Task Performance

One participant in the control group, three in the unaware group, and one in the pattern-told group were excluded from the data analysis, because they made too many errors (more than 10%). One participant in the pattern-search group was also excluded because he found the correct pattern. Both mean error rates and mean reaction times of correct responses were computed per participant and block. Figure 1 show reaction times of the first and sixth trials across blocks separately for the four groups of participants.

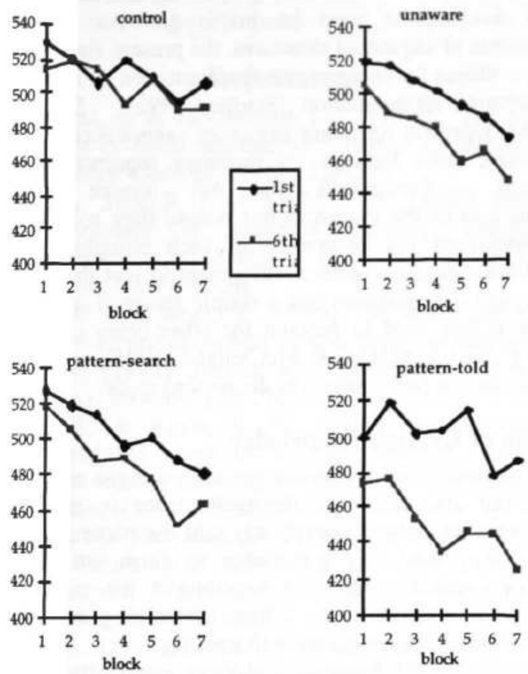

Figure 1: Mean reaction times in the first and sixth trials as a function of trial blocks for the control and three experimental groups.

A 4 (4 groups of participants) x 2 (first vs. sixth trials) x 7 (block 1 to block 7) mixed-design ANOVA was carried out. There were significant main effects of both trial, $\underline{F}(1, 90) = 48.81$, $\underline{MSe} = 4273.27$, $\underline{p} < .001$, and block, $\underline{F}(6, 540) = 25.28$, $\underline{MSe} = 1677.88$, $\underline{p} < .001$. More importantly, there was an interaction between trial and group, $\underline{F}(3, 90) = 6.12$, $\underline{MSe} = 4273.27$, $\underline{p} < .001$.

Post hoc comparisons (Tukey HSD test) showed that there was a significant decrease in reaction time from the first to the sixth trials for both the unaware and the pattern-told groups ($\underline{p}$'s < .001). No such difference was found in either the control or pattern-search group.

The average error rates were 4.00%, 4.34%, 4.40%, and 4.66% for the control, unaware, pattern-search, and pattern-told groups, respectively. A 2 (control vs. experimental groups) x 2 (first vs. sixth trials) x 7 (block 1 to block 7) mixed-design ANOVA revealed that there was a significant decrease in the error rate from the first trial to the sixth trial, $\underline{F}(1, 90) = 13.83$, $\underline{MSe} = 14.29$, $\underline{p} < .001$. More importantly, there was an interaction between trial and group, $\underline{F}(3, 90) = 5.75$, $\underline{MSe} = 14.29$, $\underline{p} < .001$. Post hoc comparisons (Tukey HSD test) showed that there were significant decreases in the error rate from the first to the sixth trials for both the unaware and the pattern-told groups ($\underline{p}$'s < .01). No such differences were found in either the control or the pattern-search groups. Along with the reaction time data, these results clearly indicate both unaware and pattern-told groups did better on the sixth trial than on the first trial.

Measures of Explicit knowledge

Mean percentages of correct generation and recognition are presented in Table 1. For correct generation, a one way ANOVA showed a significant between groups effect, $\underline{F}(3, 90) = 12.60$, $\underline{MSe} = .08$, $\underline{p} < .001$. A post hoc comparison indicated that the pattern-told group generated more correct responses than the other three groups (all $\underline{p}$'s < .001) and that no differences were found between the other three groups. As for correct recognition, a one way ANOVA also showed a significant between groups effect , $\underline{F}(3, 90) = 6.77$, $\underline{MSe} = .02$, $\underline{p} < .001$. A post hoc comparison indicated that the pattern-told group did better than the other three groups (all $\underline{p}$'s < .01). The correct percentages of recognition in the control, unaware, and pattern-search groups were at the chance level, while the pattern-told group performed significantly better than the chance level ($\underline{p}$ < .001). As for the questionnaire data, only one participant in the pattern-search group found the correct pattern.

In sum, the pattern-search participants' performance was similar to the control participants insofar as there was no difference between random trials (the first trials) and structural trials (the sixth trials), whereas the unaware and pattern-told groups learned the pattern. On the other hand, only participants in the pattern-told group were aware of the pattern, as measured by both free-generation and recognition. The unaware and pattern-search groups did not differ from the control group in these two measures of explicit knowledge.

Experimental Condition	Free Generation	Recognition
Control	47	48
Unaware	46	55
Pattern-search	54	56
Pattern-told	89	67

Table 1: Mean Percentages of the Correct Generation and Recognition as a Function of Experimental Conditions.

General Discussion

Participants learned the pattern without being aware that there was a pattern. Search for the pattern hurt performance, if the participant did not find the pattern. Secondly, explicit knowledge of the pattern did facilitate performance. Finally, both free-generation and recognition were valid measures of explicit knowledge. When participants were explicitly told the pattern, they did better than others on these two measures.

The percentage of correct recognition in the pattern-told group was only 66%, even though it was higher than the other three groups. This result can not be fully explained by the fact that participants did not understand the pattern, since at the beginning of the experiment, they were all tested on the pattern and corrected if they made errors. One possible explanation is that recognition is not an easy test for participants, even though they know the pattern. To determine if the sequence follows the pattern, participants needed to keep track of the beginning and the end of each run and remember the position of each trial within the run. This would place heavy demands on participants' short-term memory and attention. Thus, their performance was not as good as expected.

One of the criticisms about using verbalization to measure explicit knowledge is that the pattern may for some reason be difficult to verbalize. The fact that one participant in the pattern-search group reported the correct pattern indicates that it was possible to verbalize the pattern. This rules out the possibility that participants were aware of the pattern, but the pattern is too complex or difficult to be verbalized.

Dissociation between Explicit knowledge and Performance

This study indicated that participants learned the pattern in the serial reaction time task, yet without being aware of the pattern. In none of three measures of explicit knowledge did participants reveal awareness of the pattern. These results are significant because studies using free generation and recognition usually reveal an association between performance and explicit knowledge (e.g., Perruchet & Amorim, 1992; Perruchet & Gallego, 1993). According to Perruchet and colleagues, free generation with direct test instruction is a "genuine explicit memory test." In the free-recall test, participants were allowed to express spontaneously what they had learned. The present study did not find any difference in free generation between the control and experimental groups, indicating that even the free generation test could not detect participants' awareness of the pattern.

As for recognition, it was a more sensitive index of explicit knowledge than either free generation or verbalization (Perruchet & Amorim, 1992; Perruchet & Gallego, 1993). Once again, there was no difference between the control and experimental groups, with both performing at the chance level. Along with the fact that only one participant in the pattern-search group reported the pattern on the questionnaire, the present study provides clear evidence for the dissociation between performance and explicit knowledge.

The Nature of Learning

The present study also suggests that participants learned the pattern itself and not simply relative frequencies of stimulus locations or any particular instances of sequences. Learning the relative frequencies of each stimulus cannot explain participants' performance on the task, since the frequencies of each stimulus were exactly the same for both the experimental and control groups. Remembering any particular instances could not account for the performance in training either because the sequence within a run was randomly determined. Thus, the learning system must somehow detect the pattern determining the location of the last stimulus.

What is the nature of the system that underlies implicit serial learning? There were no unique pairwise associations within a cycle of six trials, thus a pure associative mechanism cannot account for learning the pattern. The learning mechanism must not only be able to recognize repetitions of the pattern, but also to register the responses of all six trials. In other words, both parsing and short-term memory mechanisms must be involved. As for the representation of sequential structures, the present study also provides evidence for an aggregate representation as opposed to a verbatim representation (Stadler, 1992). Systems designed to represent repeating sequences cannot account for the learning, since there is no repeating sequence to be represented. Participants did not acquire literal representations of the sequences but instead they acquired a representation of the occurrence of each stimulus. A computational model is under development to test this view formally, and it is predicted that a simple recurrent network, which is widely used to account for other types of serial learning (e.g., Cleeremans & McClelland, 1991), may not able to model the performance in the present study.

The Role of Explicit Knowledge

Explicit knowledge of the pattern not only was the result of training, but also facilitated the performance in training. When the participants were explicitly told the pattern of the sequence, they used this knowledge to form attentional expectancies regarding the next locations in the sequence. This effect is additive to the effects of training and thus increases overall improvement with training.

On the other hand, knowing that there was a pattern and actively searching for the pattern did not facilitate learning. This is in accord with several other studies that show that explicit strategies played only a negligible role during learning (Cleeremans & McClelland, 1991; Lee, 1995; Reber, 1976). These results suggest that serial learning is implicit not only in the sense that participants are not aware of the pattern, but also in the sense that learning is unaffected by intention. Furthermore, when participants did not find the pattern, an active search for the pattern actually impaired performance. Searching for the pattern was a task secondary to the original serial learning task, and it interfered with the training. This interference may result from the limits of short-term memory, as suggested by Frensch, Buchner & Lin (1994). Further studies are needed to specify how this kind of distracter task affects performance.

Even though some participants were told the pattern, their performance was not necessarily based entirely on their explicit knowledge of the pattern. If they relied only on the knowledge of the pattern during training, then they needed to keep track not only of the beginning and the end of each run, but also of the position of all six trials within a run. This would place many demands on attention and memory. A more plausible scenario is that performance was the result of both implicit and explicit learning.

In conclusion, the present study provides evidence for implicit rule-based learning in the serial reaction time task and clarifies the role of explicit knowledge on performance. Explicit knowledge of the pattern facilitated performance. On the other hand, the intentional search for the pattern hurt performance if the pattern was not found.

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