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Non-Declarative Sequence Learning does not Show Savings in Relearning

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Abstract

Researchers have utilized the savings in relearning paradigm in a variety of settings since Ebbinghaus developed the tool over a century ago. In spite of its widespread use, we do not yet understand what type(s) of memory are measurable by savings. Specifically, can savings measure both declarative and non-declarative memories? The lack of conscious recollection of the encoded material in some studies indicates that non-declarative memories may show savings effects, but as all studies to date have used declarative tasks, we cannot be certain. Here, we administer a non-declarative task and then measure savings in relearning the material declaratively. Our results show that while material outside of awareness may show savings effects, non-declarative sequence memory does not. These data highlight the important distinction between memory without awareness and non-declarative memory.

Keywords

motor skill; implicit learning; memory

1.0 Introduction

Several factors influence human movement: biological constraints, goals of the actor, and unconscious biases. The latter influence, unconscious biases, can result from conditioned associations, such as an instinctive movement away from a bee, or learned skills. Sequence learning is a prime example of an unconscious bias in movement that results from skill learning. In sequence learning, participants respond to a target that appears according to a repeating pattern. Even if participants do not realize that there is a pattern, they learn it nevertheless, as evidenced by lowered reaction times. Thus, learning the pattern allows participants to execute movements in response to the target more quickly. The current work examines how unconscious skills might influence later conscious learning. To do this, we employ Ebbinghaus' savings in relearning measure.

Ebbinghaus developed the savings in relearning measure over a century ago in order to measure memory independently of conscious recollection (Ebbinghaus, 1885/1964). In contrast, other commonly used memory measures, such as recognition and recall, rely on conscious recognition. The paradigm is still used in experimental psychology (Roediger, 1990) as well as in social psychology (Carlston & Skowronski, 1994; Carlston, Skowronski, & Sparks,

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1995; Crawford, Sherman, & Hamilton, 2002) and clinical research (Iverson, Slick, & Franzen, 2001; Lamberty, Kennedy, & Flashman, 1995; Weiskrantz & Warrington, 1970), largely because of the paradigm's high degree of sensitivity. To measure savings, participants first study a set of material until a learning criterion is met. Days, weeks, or even years later, participants relearn the same material to the same criterion. Savings is indicated by faster learning in the second learning session. An impressive feature of savings is that effects are seen even if the learned material is not detectable by recall or recognition; in other words, savings occurs even when the material is inaccessible to consciousness. This fact and recent conceptions of memory that emphasize neurally separable memory systems raise questions about the nature of savings, specifically, whether the paradigm measures declarative or non-declarative memory. (Whether memory is organized into separable systems, or whether memory is best described as a single system with a number of separable processes has been a contentious issue (see Foster & Jelicic, 1999, for a number of perspectives). That controversy is not relevant to our purpose here, and we refer to separate systems throughout the paper merely for brevity.)

Declarative memory is supported by the medial temporal lobe, diencephalon, and associated structures, whereas non-declarative memory represents a confederation of subsystems that are independent of these structures (Squire & Zola-Morgan, 1991). Declarative and non-declarative systems are typically (but not exclusively) tapped by explicit and implicit tasks, respectively. Explicit tasks (e.g., recall, recognition) make reference to the encoding episode at retrieval and participants are aware of the to-be-learned material. Implicit tasks (e.g., repetition priming, motor skills) do not make reference to the original encoding episode and the participant need not be aware of the to-be-learned material. Note that while the explicit/implicit distinction refers to features of the *task* (Schacter & Tulving, 1994; Willingham & Preuss, 1995), the declarative/non-declarative distinction refers to the *memory system* involved in the task. Thus, although most implicit tasks involve non-declarative memory and most explicit tasks involve declarative memory, nothing about explicit or implicit tasks necessitate reliance on one memory system or the other.

Does savings in relearning measure non-declarative as well as declarative memory? On one hand, the experimenter need not make reference to the original training session during the relearning phase (Parkin & Streete, 1988; Vakil & Oked, 2003) and savings effects are observed even if the original material is forgotten, as measured by recognition or recall (Groninger & Groninger, 1980; MacLeod, 1988; Nelson, 1978; Parkin & Streete, 1988). For instance, Nelson (1978) asked participants to memorize lists of word-number pairs. Four weeks later the participants were given recall and recognition tests on the pairs. Though participants had forgotten some pairs, they nevertheless learned the “forgotten” pairs more quickly than they learned new word-number pairs.

Both features listed above are characteristic of implicit tasks, indicating that savings in relearning is likely a measure of non-declarative memory. On the other hand, the lack of awareness in savings refers to the *relationship* between the encoding and retrieval episodes. Participants are typically well aware of the to-be-learned material, which is characteristic of explicit tasks; indeed the training and retraining episodes are classic explicit tasks: recall or recognition. Furthermore, a study that specifically measured savings of non-declarative memory failed to find a savings effect, though this study tested participants after a very long interval (one year; Willingham & Dumas, 1997).

We investigated whether the non-declarative memory system shows savings by training participants with an implicit task, and then administering a savings paradigm with an explicit version of the task. If savings is supported by non-declarative processes, then participants

should show savings when trained on an implicit version of a task and then retrained on an explicit version of the same task. We trained participants on a version of Serial Response Time task (SRT). In the original SRT task (Nissen & Bullemer, 1987), participants respond to a cue as it moves between four spatial locations on a screen by pressing a corresponding button on a respond board. Some trials follow a repeating sequence of locations whereas other trials are random, but participants are not told about the sequence. Even if participants are not aware of the presence of a sequence they respond faster to the sequenced trials than to random trials, and there is substantial evidence that this learning is non-declarative (Shanks & Johnstone, 1999; Willingham, Nissen, & Bullemer, 1989). We tested whether this non-declarative learning would lead to an advantage on a savings in relearning test of the sequence. If savings is supported by non-declarative memory, one would predict such an advantage.

In order to minimize the possibility of declarative contamination (e.g., that participants would notice the repeating pattern in the stimuli), we used the Alternating Serial Response Time task (ASRT; Howard & Howard, 1997). This task interleaves random trials with sequenced trials, so that it is extremely difficult for participants to notice the sequence. Participants do, however, respond reliably faster to sequenced trials than to random trials (Howard & Howard).

In the Explicit Test phase participants explicitly learned a sequence that either contained (experimental group) or did not contain (control group) the sequenced trials from the implicit phase. Participants observed the to-be-memorized sequence, and then were asked to reproduce it three times perfectly; if recall was not perfect they observed again and recalled again. The cycle continued until the criterion of three correct reproductions were met. The dependent measure was the number of recall trials necessary for the participant to correctly recall the sequence. A difference in the number of trials necessary to memorize a new versus old sequence reflects savings in learning. If participants in the experimental group show an advantage in relearning the sequence, we may conclude that savings can measure non-declarative memory.

2.0 Method

2.1. Participants

One hundred seventy-nine volunteers participated in exchange for class credit or monetary compensation (\$7.50). Participants were randomly assigned to the experimental ($n = 92$) or control ($n = 87$) group.

2.2. Procedure

2.2.1. Implicit Training—The ASRT is a straightforward 4-choice RT task. Participants saw a row of four boxes on a computer screen and four response keys of a computer keyboard. Stimulus and response locations were compatibly mapped (leftmost response key to leftmost box, and so on). A circle appeared in one box until the participant responded, whereupon the next stimulus appeared after a response to stimulus interval (RSI) of 250ms. Unbeknownst to participants, the stimuli were ordered so that a 4-unit sequence was interleaved with random stimuli. Random stimuli alternated with sequenced so that, given the sequence 4-2-1-3, a series of trials would be: 4-r-2-r-1-r-3-r, where 1-4 represent the four stimulus locations from left to right and 'r' denotes any one of the four stimulus locations chosen at random. Note that because the random stimuli might appear in any of the four stimulus locations, stimulus repetitions are allowed.

Participants practiced 5 ASRT blocks in the Implicit Training phase. Each 170-trial block consisted of 10 random trials followed by 20 repetitions of the 8-trial alternating sequence. Instructions emphasized speed and accuracy.

2.2.2. Explicit Test—In the *Explicit Test* phase participants observed an 8-unit sequence and then attempted to reproduce it. Participants in the experimental group observed a sequence that incorporated the alternating sequence they had practiced during Implicit Training; the stimuli that had changed randomly during Implicit Training were consistent during Explicit Test. For instance, if the Implicit Training sequence was 4-r-2-r-3-r-1-r, the Explicit Test sequence might be 4-1-2-4-3-2-1-3. Participants in the control group observed a novel Explicit Test sequence that did share two or more consecutive trials with the Implicit Training sequence (i.e., if the Implicit Training sequence was 4-r-2-r-..., the Explicit Test sequence could not include 4-1-2-3, because the trials 4-x-2 appear in each). Participants in both groups observed the 8-unit sequence appear on the screen twice without responding. Each stimulus appeared for 500ms and, as in previous studies of sequence learning via observation, the inter-stimulus interval was 500ms (Howard, Mutter, & Howard, 1992; Keisler, Ashe, & Willingham, submitted).

Immediately after observing the sequence, participants attempted to generate the sequence three times using the same keys as in training. A circle appeared in the corresponding box as soon as the participant pressed each key. If the participant made any errors, he or she observed the sequence twice more and then was asked again to generate the sequence three times; this cycle continued until the participant could correctly generate the sequence. The key dependent measure was trials-to-criterion.

2.2.3. Group membership—After the Explicit Test phase participants were told that there were two groups in the experiment: one group had seen part of the memorized pattern during the response time task, and the other group had not. Each participant rated their belief about their group membership on a 1-7 scale as follows: 1 = “I am SURE I was in the group that did NOT have the pattern in the first phase”, 7 = “I am SURE I was in the group that did have the pattern in the first phase”, and 4 = “I have no idea what group I was in”. This question measures whether participants were aware of the presence of the sequence in the implicit phase.

3.0 Results

3.1. Implicit Training

First, we verified that participants learned the sequence in the Implicit Training phase and there were no group differences in sequence learning. The ten random trials inserted between sequences were not analyzed. For each series of eight trials, we calculated the median RT of the four sequenced trials and of the four random trials. Then, we calculated the mean of the medians for each block for each trial type (sequence and random). RTs to random and sequenced trials are initially equal but sequenced trials are faster than random later in training (see Fig. 1). We calculated a difference score for each participant for each block by subtracting the sequence mean from the random mean. Learning scores were submitted to a repeated measures analysis of variance (ANOVA) in which group (experimental, control) and block (1-5) were factors. This analysis reveals a significant effect of block on difference scores, $F(4,708) = 12.7, p < .01$, indicating that sequence learning increased over trials. There is neither a significant effect of group nor a group $\times$ block interaction, F 's = 2.9 and 1.1, respectively, p 's $> .05$. We then conducted one-tailed t -tests with Bonferroni corrections ($\alpha = .005$) on each block to verify that participants showed significant sequence knowledge, or in other words, that learning scores differed from zero. Both groups show significant sequence learning on blocks 4 and 5, t 's = 5.6 and 4.9, respectively, for the experimental group and 2.8 and 3.5, respectively, for the control group. Taken together, Implicit Training RT data indicates that (1) both groups successfully learned the sequence and (2) the groups learned the sequence to the same degree.

We also analyzed accuracy scores from Implicit Training. These data are presented in Fig. 2. These data were submitted to a three-way repeated measures ANOVA in which group (experimental, control), block (1-5) and trial type (random, sequence) were factors. Surprising, this analysis reveals a significant main effect of group, $F(1,177) = 6.8, p = .01$; the experimental group made fewer errors than the control group. The size of this effect is small, $d = 0.19$. Group did not, however, interact with block or trial type, F 's = 0.69 and 1.49, respectively, p 's > .05, indicating that the group difference reflects greater overall accuracy during Implicit Test and not sequence learning. There was a main effect of trial type, $F(1,177) = 99.17, p < .01$ and block, $F(4,708) = 25.61, p < .01$, such that participants were more accurate on sequence trials than random trials, and accuracy decreased over blocks. Finally, there was a significant Block $\times$ Trial Type interaction, $F(4,708), p = .02$, such that the difference between trial types increased over blocks. Thus, accuracy data echoes RT data, in that participants acquire sequence-specific knowledge over the course of Implicit Training.

The significant main effect of group is puzzling given that the two groups are treated identically before and during training. A potential explanation for this finding is a speed-accuracy tradeoff. In other words, perhaps control participants placed greater emphasis on speed and accuracy suffered as a consequence. However, this theory is not supported by RT data. As described above, there is no corresponding RT difference between groups. Furthermore, correlation analysis reveals a reliable positive relationship between RT and accuracy, $r(177) = 0.36, p < .01$, rather than a negative relationship, as would be predicted if participants sacrificed accuracy for speed. Because the groups are treated identically before and during the training session, we must assume that the difference in accuracy is due to random variation between the groups. What does this accuracy difference mean for subsequent performance on Explicit Test and potential savings effects? Because there is no interaction between group and trial type, we can assume that participants in the two groups achieved equal levels of sequence knowledge. This finding echoes that of the RT data analysis. Since we are interested in savings in sequence knowledge, it is unlikely that higher accuracy in training will affect savings, *per se*. Furthermore, it is unclear how a greater accuracy might influence performance on the Explicit Test, since the test does not involve responses to stimuli. One possibility is that the experimental group simply attended more to the task and/or tried harder to perform well. If this is the case, we would expect the experimental group to perform better on the Explicit Test. However, as described in the next section, the experimental group performed no better in this phase than the control group. Thus, while this group may have been biased to do better on the test because of general performance superiority, the experimental group did not, in fact, show a benefit in Explicit Test. Importantly, all participants began Explicit Test with comparable levels of sequence knowledge, so we may accurately gauge whether implicit training confers a savings advantage to an explicit task.

3.2 Explicit Test

The dependent measure in the Explicit Test phase was the number of recall trials it took the participant to learn the sequence to criterion (three correct generations of the sequence). As shown in Fig. 3, the experimental and control groups required almost exactly the same number of trials to successfully complete the Explicit Test. On average, the control group required 3.8 ($SE = 0.27$) trials to reach criteria and the experimental group required 3.7 ($SE = 0.24$) trials. This difference was not reliable in a two-tailed t -test, $t(177) = 0.34, p > .20$. Thus, there was no difference in the rate at which the two groups explicitly learned the sequence, despite the fact that the experimental group had prior implicit practice.

We conducted two other tests of the influence of Implicit Training on the Explicit Test. Although both groups took, on average, an equivalent number of trials to reach criterion, it is

possible that the experimental group was more accurate during Explicit Test before the criterion was reached. For this analysis, we disregarded the last generation trial in which participants correctly produced the sequence three times; we therefore did not analyze data from the 15 participants who reached the criterion on the first try. Remaining participants in the experimental and control groups showed equivalent accuracy on the 24 trials (3 generations of the 8-unit sequence), $F(1,162) = 0.17, p > .20$. Next, we examined whether the experimental group better recalled the sequenced trials (i.e., the first, third, fifth and seventh trials) than the random trials (i.e., the second, fourth, sixth and eighth trials). Accuracy on sequenced trials was, in fact, better, $F(1,81) = 14.36, p < .01$, but this effect also held for the control participants, $F(1,81) = 15.34, p < .01$. The effect turned out to be one of serial position – all participants were very good at remembering the first trial of the sequence. The advantage of sequenced over random trials was no greater for experimental than control participants, $F(1,162) = 0.13, p > .20$, and thus there is no evidence for savings in relearning by this measure.

3.3. Group Membership

We wanted to be sure that participants in the experimental group were not aware that the sequence that they had learned explicitly had also appeared in the implicit phase. We asked all participants to guess their group membership. Table 1 summarizes the ratings. A Wilcoxon two-sample test showed that the groups did not differ in their mean response to the group membership question, $T_w = 8755, p > .20$, indicating that the group that was exposed to the same sequence in the implicit and explicit phases was no more confident that there were in the experimental group than the control group was. Thus, we conclude that participants were not aware of the presence of half the Explicit test sequence in the Implicit Training phase.

4. Discussion

Participants in the experimental group were no faster to learn a sequence than those in the control group, though the experimental group had learned half of the sequence implicitly. In other words, there was no savings in relearning a sequence explicitly if the first training session was implicit. Power to detect a difference is relatively good. The effect size of implicit learning on Block 5 is $d = 0.44$. The power to observe a difference of that size during Explicit Test is 0.85. Although savings may be observed for material that is outside of awareness as the savings task begins (Groninger & Groninger, 1980; MacLeod, 1988; Nelson, 1978; Parkin & Streeter, 1988), we conclude that savings in relearning is likely supported by declarative memory. Further research on a variety of tasks would confirm whether this conclusion generalizes to all non-declarative tasks and whether different types of test measures, such as cued recall, might reveal savings effects for non-declarative memory.

One might consider an alternative hypothesis- that we failed to observe savings because of task differences. In the implicit task participants were directed to respond rapidly, whereas in the explicit task they were to observe and learn a sequence. Also, stimulus repetitions were allowed in Implicit Training but not Explicit Test, since the alternating random trials in Training could be any of the four stimulus locations. Perhaps we would have observed savings if repetitions were allowed in the Explicit Test as well. In other words, perhaps savings only occurs if the tasks are similar or identical.

Past research shows, however, that test and retest conditions needn't be identical for savings to occur. For instance, MacLeod (1988) found savings in recall for words across modalities (i.e., learning pictures in test and words in retest, or vice versa) and for non-identical pictures of the same referent (for instance, two different pictures of chairs). Nelson et al. (1979) found savings for words in superordinate and subordinate categories relative to the original word list. For instance, the word "vehicle" was memorized more easily if the word "car" appeared in

training. It is possible, though, that similarity between test and retest conditions is more important for savings in non-declarative memory than for declarative memory.

Furthermore, learning other than sequence-specific learning might afford savings. For instance, participants might have learned the rule that a stimulus may appear in the same location up to three times in a row during Implicit Training. Conceivably this knowledge could afford saving in a subsequent test, but we could not test this possibility because the regularity was present for both the control and experimental groups. Thus, while we excluded the possibility that implicit sequence knowledge does not show savings, we cannot exclude the possibility that knowledge of stimulus *rules* may show savings. Because past studies concerned savings for specific items (i.e., words or pictures), we do not know how or whether savings occurs for other features of the task.

Our results should not be taken to mean, though, that savings does not occur in sequence learning. Sequence learning in most everyday skills and lab setting involves some degree of explicit (declarative) knowledge. In these cases, one would assume that savings in relearning would occur in a similar manner as in the various declarative learning studies reviewed here.

The current results are also relevant to research on the nature of implicit sequence learning. Researchers commonly employ generate tasks such as that used in Explicit Test to determine whether participants develop explicit knowledge during a purportedly implicit task. In these studies, participants are not told of the presence of a sequence during training. Later, they must try to generate the sequence presented in the training phase. If a participant successfully generates all or part of the training sequence, researchers may conclude that the sequence is consciously accessible to him or her (i.e., the participants has explicit sequence knowledge). Results are mixed as to whether sequence learning can be implicit, based on free-generation results (Destrebecqz & Cleeremans, 2001; Perruchet & Amorim, 1992; Wilkinson & Shanks, 2004). The current results, though, demonstrate that participants do not have sequence awareness, as measured by free generation, although they show robust sequence knowledge. We can be confident in the current results because savings is a more sensitive measure than recall or recognition. Thus, these data add to the body of literature supporting implicit sequence learning.

Finally, these findings inform us about the interaction of declarative and non-declarative memory. Past work in our lab has shown that non-declarative memory can be formed in parallel with declarative memory during a declarative task (Willingham & Goedert-Eschmann, 1999). However, the reverse relationship does not seem to be true: declarative memory is not formed during a non-declarative task. If it were, we would expect that participants could recruit this knowledge during the savings task.

The results also highlight the distinction between memory without awareness and non-declarative memory. As outlined by Schacter and Tulving (1994), the two forms of memory may overlap but are not synonymous. We conclude that while savings may occur with or without awareness, only declarative memory shows savings effects in an explicit task.

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Fig 1. Mean response times by trial type and block (error bars indicate standard error about the mean).

Fig 2.
Mean accuracy by trial type and block for the two groups (1 = perfect accuracy; error bars indicate standard error about the mean).

Fig 3.
Explicit Test trials-to-criterion by group.

Table 1
Response Frequency to Group Membership Question by Group.

Confidence Rating	Frequency	
	Control Group	Experimental Group
1	4	9
2	8	5
3	6	8
4	56	54
5	5	9
6	3	1
7	5	6