Interference produces different forgetting rates for implicit and explicit knowledge

Tamayo, Ricardo; Frensch, Peter A.

Experimental Psychology, Vol 54(4), 2007, 304-310.
http://dx.doi.org/10.1027/1618-3169.54.4.304

Interference Produces Different Forgetting Rates for Implicit and Explicit Knowledge

Ricardo Tamayo

&

Peter A. Frensch

Humboldt-University Berlin, Germany

Running Head: Interference and Forgetting

Abstract

Exposure to a repeating set of target strings generated by an artificial grammar in a speeded matching task generates both explicit and implicit knowledge. Previous research has shown that implicit knowledge (assessed via priming) is preserved after a retention interval of 1 week but explicit knowledge (assessed via recognition) is significantly reduced (Tunney, 2003). In two experiments, we replicated and extended Tunney's findings. Experiment 1 was a partial replication of the experiment conducted by Tunney (2003), and demonstrated that the decline in recognition shown by Tunney was not due to a repetition of test items at the pre and post times of assessment. In addition, Experiment 1 lends credibility to Tunney's assumption that recognition scores assess explicit rather than implicit knowledge. Experiment 2 extended Tunney's findings theoretically by demonstrating that interference can produce the pattern of findings demonstrated in the present Experiment 1 as well as in Tunney (2003).

Interference Produces Different Forgetting Rates for Implicit and Explicit Knowledge

In the past two decades, the contrast between “implicit” and “explicit” forms of knowledge has received its fair share of attention in cognitive psychology (for overviews, see, e.g., Frensch & Rünger, 2003; Shanks, 2005). From the outset, the theoretical focus of much of the research has been on confirming or disconfirming one of two general classes of theory that can both account for much of the reported results. On the one hand, proponents of the single-system view (e.g., Perruchet & Vinter, 2002; Shanks, Wilkinson, & Channon, 2003) argue that implicit and explicit forms of knowledge are based on the same underlying memory system. On the other hand, proponents of the multiple-systems view reason that implicit and explicit forms of knowledge reflect the operation of two or more distinct types of memory systems (e.g., Dienes & Perner, 1999, 2002; Frensch et al., 2002; Willingham, 1998). If anything, then the continuing debate has made it obvious that no single experiment or series of experiments is likely to tell us which of the two classes of theory is correct. Rather, what appears to be needed is a host of research aimed at different aspects of implicit and explicit forms of knowledge that, in the end and hopefully, will lead to a unifying theory.

One rather promising issue that may contribute toward settling the theoretical controversy surrounding implicit and explicit forms of knowledge concerns forgetting. If it can be shown, for example, that the forgetting rates of implicit and explicit knowledge are similar, then a unitary, single-system theory would gain in acceptance. Although not definitive, the single-system view would be supported even further if it could be shown that the similar rates of forgetting of implicit and explicit knowledge may be caused by the same underlying cognitive mechanisms.

The main goals of the present research were therefore to (a) examine forgetting of implicit and explicit knowledge over a period of time, and (b) to test if the obtained pattern of results can be explained by a single mechanism, namely interference.

In order to investigate the forgetting rates of implicit and explicit knowledge, we partly replicated a study conducted by Tunney (2003). Using an artificial grammar learning paradigm, Tunney had shown that after a retention interval of 1-2 weeks, the accuracy with which learned items are explicitly recognized decays but implicit reaction-time savings for the same items are preserved.

In Tunney's task participants had to depress a key that corresponded to a single letter presented at the center of the screen. The letters shown were generated by an artificial grammar (AG). An initial learning phase was followed by three tests, one immediately following the learning phase, one administered 1 week later, and one administered 2 weeks later. For each test, old (grammatical) strings were mixed with new (ungrammatical) strings. During the test phases, participants provided two measures, (a) response times to each letter of the strings, and (b) binary recognition judgments for every string. The implicit measure of knowledge was computed by subtracting RTs to old sequences from RTs to new sequences (hereafter, RT priming). The explicit measure of knowledge was computed by subtracting z-scores for the proportion of new sequences incorrectly recognized from z-scores for the proportion of old sequences correctly endorsed (hereafter, d'). Results showed that recognition d' had significantly decreased after a 1-week retention interval but RT priming prevailed.

This evidence provide constraints for any theory of implicit and explicit forms of knowledge. There are two aspects of the findings, however, that deserve critical investigation. First, Tunney had used the exact same strings twice at each time of testing. Because a close examination of the recognition scores at the initial and the 1-week assessments indicates that the observed decline in d's was almost exclusively carried by an increase in false alarm rates, it appears possible that the repetition of test items might have been at least partly responsible for Tunney's (2003) observed decline in recognition. More specifically, it is conceivable that participants when they were repeatedly tested on the same incorrect items might have (correctly) remembered that they had seen the (incorrect) items previously but might have committed a source confusion error. The source confusion would have increased the false alarm rate which, in turn, would have caused a decline of the d’. In our Experiment 1, we therefore replicated the main parts of Tunney’s (2003) earlier experiment but used different test items in the test phases.

Second, Tunney’s dissociation argument was based on the assumption that in his task recognition scores reflect explicit, rather than implicit, knowledge of the learned items. It is quite conceivable, however, that participants’ recognition might have been based, for instance, on fluency of responding to the strings, and that fluency was determined, at least in part, by implicit knowledge. Thus, participants’ recognition might have reflected both implicit and explicit knowledge of the items encountered in the learning phase.

In order to tackle this difficult issue, we asked participants to provide confidence ratings (e.g., Tunney & Shanks, 2003) of their recognition scores. Doing so allowed us to separately compute d’s for (a) items for which participants were certain that they had (or had not) seen them in the learning phase, and for (b) items for which they were merely guessing that they had or had not seen them previously. The d’s for case (a) more likely reflect “true” explicit knowledge than the d’s for case (b).

While the goal of Experiment 1 was to conceptually replicate the main results of Tunney (2003), the primary goal of Experiment 2 was to test if the specific pattern of results obtained in Experiment 1 might be due to interference. Therefore, in Experiment 2, we used the same materials of Experiment 1 but the 1-week retention interval was replaced by an additional phase in which participants responded to new random items.

Experiment 1

Experiment 1 was a conceptual and partial replication of Tunney (2003). As in Tunney’s experiment, participants were exposed to 16 grammatical strings in a learning phase. Implicit and explicit measures of learning were assessed both immediately upon completion of the learning phase and after 1-week retention period. In addition, after typing in their binary recognition scores, participants were asked to indicate the confidence of their recognition decision on a 3-point scale. In contrast to Tunney (2003), participants in our Experiment 1 received half of Tunney's original test items in the first test phase. After the retention interval of 1 week, they were presented with the remaining test items.

In addition to the two issues described, our conceptual replication differed from Tunney's original study in the following minor ways. First, we ran only the experimental group that learned grammatical strings and not the control group. Second, we did not include Tunney's 2-weeks retention interval because it did not show relevant changes.

Method

Participants

Participants were 14 female and 6 male undergraduates at Humboldt University, Berlin, who received 8 Euros for taking part in the Experiment. Ages ranged from 18 to 25. All were naive to the purpose of the study. One participant was removed from any further analyses because she rated all items of tests sessions as "old".

Apparatus

Sessions were conducted individually. Instructions and stimuli were presented via a computer's CRT monitor (17 inches) with a resolution of 1280 by 1024-pixel at 85 MHz. Responses consisted of pressing keys on a QWERTZ keyboard and manipulating the computer's mouse. RT was measured with ExacTicks software, and programming was done in Delphi™ 7.0.

Materials

Grammatical strings of letters were constructed according to a modified version of the AG originally used by Tunney (2003). We replaced the original surface letters V, T, X, M, and R with the letters S, D, F, J, and K, respectively. Altogether, 32 strings were used, 16 grammatical and 16 ungrammatical (see Appendix).

Procedure

The experiment was completed in two sessions. The first session, about 30 minutes in duration, was divided into a learning phase and a test phase that was administered immediately after learning. The second session, conducted 7 days later, involved only a test phase.

Learning Phase. The learning phase involved five training blocks. In each block, 16 grammatical strings were presented once in a different randomized order for every participant. Before and after every string, the words START and END were presented; at these prompts, participants were asked to depress the space bar with the thumb. Then, the first target letter of a randomly selected string appeared at the center of the screen and participants had to depress as soon and as accurately as possible the corresponding key on the keyboard. Any response erased the target immediately. When the key pressed did not match the stimulus, the computer emitted a tone (440 Hz, 85 ms). RT was recorded from target onset to key press. The next target letter was presented after a fixed response-stimulus interval (RSI) of 200 ms.

Participants were instructed to press keys S, D, and F with the ring, middle, and index fingers, respectively, of their left hand, and to press keys J and K with the index and middle fingers, respectively, of their right hand.

Test Phase. Testing involved one measure of RT, one measure of recognition, and one measure of confidence. For RTs, participants were required to respond to each string as they had done during the learning phase. For recognition, the following question appeared at the center of the screen after every END prompt: “Do you think this string of letters was…” then, two buttons marked “new” and “old” were displayed. Participants had to click one of them. For confidence ratings, the question “How sure are you?” was presented after every recognition judgment. Buttons labeled “very sure,” “relatively sure,” and “guess” appeared below the question in a horizontal line. Participants responded by clicking one of the buttons.

For every participant, a different subset of 16 new and 16 old items was randomly determined. Half of the items were presented during the first test. Remaining items were presented during the second test. Items were randomized in such a way that every target string was always accompanied in a test session by the corresponding lure (items of the same row in the Appendix). There were therefore four different sets of items randomly selected for every participant depending of its grammaticality and test-phase: (a) 8 ungrammatical-first test, (b) 8 grammatical-first test, (c) 8 ungrammatical-second test, and (d) 8 grammatical-second test. Importantly, none of the item sets overlapped. Consequently, every participant made 16 new-old judgments in each test phase (in contrast to 64 judgments in Tunney's original experiment).

Results and Discussion

Learning Phase

Error rates and RTs were determined separately for every participant and every block. Errors ranged from 2% to 3%, and did not significantly change over blocks, $F < 1$. In contrast, RTs decreased significantly during the learning phase. An ANOVA for RT with block (5 levels) as a within-subjects variable, revealed a significant main effect of block, $F(4, 72) = 17.69$, MSE = 1,721, $p < .001$. Thus, participants were able to speed up their responses as a consequence of training without increasing their error rates.

Test Phases

First, RTs to individual letters of the strings presented in the test phases were averaged separately for every participant, every test phase, and every type of string (new vs. old). The resulting mean RTs are displayed in Table 1. As can be seen, RTs to old items were faster than RTs to new items at both times of testing.

Table 1

A 2 (time of testing: pre vs. post) X 2 (type of string: new vs. old) repeated measures ANOVA revealed a significant main effect of time of testing, $F(1, 18) = 5.72$, MSe = 5636.37,

$p < .05$, and a significant main effect of type of string, $F(1, 18) = 11.02$, MSe = 1503.31, $p < .01$, but no significant interaction between time of testing and type of string, $F(1, 18) < 1$. These results indicate that RT priming did not change with time. Namely, the implicit knowledge measure was not affected by the retention interval. This particular finding replicates the results described by Tunney (2003).

Table 1 also contains the mean endorsement rates[1] for old and new items at the two times of testing. Close inspection of the table shows that the endorsement rates for old items were higher than the endorsement rates for new items, both at pre and at post. More importantly, however, the mean d' decreased from the first to the second time of testing.

A corresponding 2 (time of testing: pre vs. post) X 2 (type of string: new vs. old) repeated measures ANOVA on endorsement rates revealed a significant main effect of type of string, $F(1, 18) = 106.7$, MSe = 0.027, $p < .01$, and a significant interaction between time of testing and type of string, $F(1, 18) = 5.81$, MSe = 0.0349, $p <. 05$. The main effect of time of testing was not significant, $p > .30$. A direct comparison of participants' d's at pre and post revealed a significant effect of time of testing, $F(1, 18) = 6.06$, MSe = 0.819, $p < .05$, indicating that recognition performance was affected by the 1-week retention period.

Taken together, our findings replicate the empirical dissociation reported by Tunney (2003). The implicit measure of knowledge (RT priming) was not affected by the 1-week retention interval while the explicit measure of knowledge (d') was. The dissociation was observed although the items used in the testing phases were different at the pre and post times of assessment. Thus, the repetition of test items in the original replicated experiment did not cause the dissociation.

One might argue, of course, that the lack of an effect for RTs might have been due to a lack of statistical power. Although we acknowledge that such a lack-of-power argument is always very difficult to refute in the absolute, we believe that there are at least 3 good reasons that speak against the lack-of-power argument. First, the decline in RT was very small (14 ms) and was comparable in size to the standard errors observed at Days 0 and 7. In contrast, the decline in d's was much larger and was about 4-5 times the size of the respective standard errors.

Second, Experiment 1 is a replication of Tunney (2003). That is, the empirically observed dissociation in the time pattern of RTs and d's has been observed in at least two independent studies thus far; the obtained pattern is not unique to our study.

Third and perhaps even more convincing, in order to address this issue, we computed a dRT score that is analogous to d' (Poldrack & Logan, 1997). According to Poldrack and Logan: dRT = Mnew – Mold / (SDold/2 + SDnew/2), where dRT is the degree of discriminability for RTs (analogous to d'), Ms are the mean RTs, and SDs are the standard deviations for RTs. The resulting dRT scores were .07 (SE = .04) for the first test and .09 (SE = .05) for the second test. The scores did not differ for the two times of testing, $\underline{F} < 1$. Importantly, thus, even with the dRT measure, there still was no significant decline on RT priming over the 1-week retention interval.

Experiment 1 also aimed to assess whether recognition can be considered a measure of explicit, rather than implicit knowledge. Therefore, we asked participants to provide confidence ratings of their recognition scores on a 3-point scale. The confidence ratings allowed us to separately compute d's for (a) items for which participants were certain, and for (b) items for which participants were merely guessing. Our reasoning was that if recognition measures explicit knowledge, then the d's for case (a) should show a similar time trajectory as the overall d's. In addition, d's for case (b) should not be significantly different from zero, and should also not differ for the two times of assessment.

We therefore computed d' scores separately for cases (a – "very sure" and "relatively sure") and (b – "guess"). The d's for case (a) were 2.07 at the pre and 0.97 at the post time of assessment. The d's were significantly different from zero at the pre and post times of testing, $\underline{F}(1, 18) = 108.74$, MSe = 0.749, $\underline{p} < .01$, and $\underline{F}(1, 18) = 25.84$, MSe = 0.695, $\underline{p} < .01$, for the pre and post testing, respectively. In addition, the d's differed for the two times of testing, $F(1, 18) = 14.46$, MSe = 0.793, $p < .01$, thus mirroring the overall findings.

In contrast, the d's for case (b) were -0.16 at the pre and -0.22 at the post time of assessment. The d's were not significantly different from zero at the pre and post times of testing, both F's < 1. Even more importantly, the d's did not differ for the two times of testing, $F < 1$. Given these results, it appears that the overall recognition findings were carried primarily by scores that were accompanied by high confidence ratings. Thus the recognition measure used here and in Tunney (2003) thus appears to assess primarily explicit and not implicit knowledge.

Experiment 2

While the goal of Experiment 1 was to conceptually replicate the main results of Tunney (2003), albeit with two major methodological improvements, the primary goal of Experiment 2 was to test if the specific pattern of results obtained in Experiment 1 might be due to interference.

Why would interference affect forgetting of implicit and explicit knowledge in the specific task used here and in Tunney (2003) in the first place? If it is assumed, for instance, that learning in the artificial grammar learning task consists, at least in part, of acquiring associations between consecutively typed manual responses, then any newly typed sequences of manual responses that do not correspond to the artificial grammar will weaken - absolutely and/or relative to other representations - the strengths of the acquired associations. In the real world, this interference might be due to the typing of any text on a typewriter or computer, for instance, to playing a piano, and the like.

Why, however, might interference lead to different forgetting rates for explicit and implicit knowledge over a 1-week retention period? According to the simplest and most stringent version of the single-system view, interference decreases the strengths of memory representations and the strengths of memory representations determine both their implicit and explicit accessibility to the same extent (e.g., Perruchet, Bigand & Benoit-Gonin, 1997; Perruchet & Vinter, 2002). In its most simple version, the single-system view would not predict that interference would lead to different forgetting rates for explicit and implicit knowledge.

In some weaker versions of the single-system theory (e.g., Norman, 1969), however, different threshold values are introduced for implicit and explicit accessibility. If it is assumed that the threshold value is higher for explicit than for implicit accessibility, then the theory predicts that explicit knowledge is affected more by interference than is implicit knowledge (for a similar weak version of the single-system theory, see, e.g., Kinder & Shanks, 2003; Shanks & Perruchet, 2002; Shanks, Wilkinson & Channon, 2003; Wilkinson & Shanks, 2004).

According to the multiple-systems theory of implicit and explicit knowledge, on the other hand, implicit and explicit knowledge is supported by different memory systems. Thus, the theory can explain different interference results for explicit and implicit knowledge by arguing that the explicit memory system might be more susceptible to interference than the implicit memory system (e.g., Graf & Schacter, 1987).

Experiment 2 was similar to Experiment 1. Again, a learning phase was followed by two test phases. In this case, however, the two test phases were not separated by a 1-week retention interval but by an interference task where participants responded to series of random strings of letters.

If indeed the empirical dissociation in forgetting of implicit and explicit knowledge that we observed in Experiment 1 is due to different sensitivities to interference rather than merely decay, then we should obtain a pattern of results that closely mirrors the dissociation pattern observed in Experiment 1. If, on the other hand, the obtained dissociation is caused by differences in decay rates, then the results of Experiment 2 should not be comparable to the findings obtained in Experiment 1.

Method

Participants

Participants were 16 undergraduates at Humboldt-University, Berlin (11 women and 5 men) with ages ranging from 20 to 28. All were naive to the purpose of the study and received credit for taking part in the experiment. One participant had to be excluded from further analyses because she classified all items of the test phase as “old”.

Materials

The materials used in the learning phase were identical to those used in Experiment 1. In the testing phase, the original items from Tunney (2003) were used (including the block repetition), rather than the test items from Experiment 1, to optimize the comparison to Tunney’s data.

The items used in the interference phase were randomly generated strings that were composed of the letters S, D, F, J, and K. All letters had an equal probability (.2) of occurrence in each interference trial. The lengths of the interference strings varied randomly between 3 and 7 letters. For every participant, 5 blocks of 16 strings were presented in the interference phase.

Procedure

The learning and test phases were conducted in the same manner as in Experiment 1 but in a single session of approximately 40 minutes. The first and second tests phases were separated by an interference task. The interference task, except for the use of randomly generated strings as described above, closely resembled the learning phase. All instructions, prompts, feedback, blocks, and breaks between blocks used in the learning phase, were also used in the interference task.

Results and Discussion

Data were analyzed and aggregated in much the same manner as in Experiment 1.

Learning Phase

Error rates ranged from 1% to 3%, and did not significantly change over blocks, $F < 1$. In contrast, RTs decreased significantly during the learning phase. An ANOVA on RT with block (5 levels) as a within-subjects variable, revealed a significant main effect of block, $F(4, 56) = 9.12$, MSe = 1,911.3, $p < .001$. Clearly, participants were able to speed up their responses as a consequence of training without increasing the percentage of errors.

Test Phases

The resulting mean RTs are displayed in Table 2. As can be seen, response times to old items were faster than response times to new items at both testing times.

Table 2

A 2 (time of testing: pre interference vs. post interference) X 2 (type of string: new vs. old) repeated measures ANOVA revealed a significant main effect of time of testing, $F(1, 14) = 10.22$, MSe = 977.37, $p < .01$, and a significant main effect of type of string, $F(1, 14) = 16.27$, MSe = 499.92, $p < .01$, but no significant interaction between time of testing and type of string, $p > .26$. These results indicate that RT priming (implicit knowledge measure) did not change as a result of interference.

Table 2 also contains the mean endorsement rates for old and new items at the two times of testing. Close inspection of the table shows that the endorsement rates for old items were higher than the endorsement rates for new items, both before and after the interference task. More importantly, however, the mean d’ decreased from the first to the second time of testing.

A corresponding 2 (time of testing: pre interference vs. post interference) X 2 (type of string: new vs. old) repeated measures ANOVA on participants’ endorsement rates revealed a significant main effect of type of string, $F(1, 14) = 72.87$, MSe = 0.02, $p < .01$, and a significant interaction between time of testing and type of string, $F(1, 14) = 5.02$, MSe = 0.01,

$p < .05$. The main effect of time of testing was not significant, $p > .91$. A direct comparison of participants' d's before and after the interference task revealed a marginally significant effect of time of testing, $F(1, 14) = 3.82$, MSe = 0.208, $p < .08$, indicating that recognition was indeed affected by interference.

Taken together, our findings replicate the empirical dissociation observed by Tunney (2003) and in our Experiment 1 in an interference paradigm. The implicit measure of knowledge (RT priming) was not affected by interference while the explicit measure of knowledge (d') was.

General Discussion

The present research had both methodological and theoretical goals. Methodologically, we replicated important findings by Tunney (2003) after removing a possible shortcoming in Tunney's procedure. More precisely, we tested if the repeated use of the same items in testing phases separated by a 1-week retention interval may have caused the observed decline in recognition performance (Tunney, 2003). In addition, we examined an assumption inherent in Tunney's (2003) reasoning, namely that recognition predominantly measures explicit, rather than implicit, knowledge.

The results of Experiment 1 show that Tunney's results are (a) robust with respect to repetition of test items, and that there is (b) good reason to assume that, at least in the context of the artificial grammar learning task used by Tunney (2003), recognition is more likely to assess explicit knowledge than implicit knowledge. All in all, these findings are consistent with other findings of dissociations for recognition judgments (e.g., Gabrieli, 1998). In principle, it appears that the recollective or explicit component of recognition is more affected by a retention interval than is its familiarity-based counterpart.

The theoretical goal of the present research was to assess if the empirically observed dissociation in forgetting of implicit and explicit knowledge might, in principle, be caused by interference. The results of Experiment 2 clearly demonstrate that this is indeed the case.

As was explained in the Introduction section to Experiment 2, the observed effect of interference can, in principle, be explained by both the single-system as well as the multiple-systems theory of implicit and explicit knowledge. Thus, the results reported here do not, by themselves, resolve the theoretical debate between single-system and multiple-systems theories of implicit and explicit knowledge. However, the findings add an important empirical constraint to the existing literature and make clear that the most simple forms of the single-system theory cannot be correct because they cannot explain the present results. Whether or not the parameters that need to be included in single-system theory to explain the present dissociation in forgetting rate for implicit and explicit knowledge (e.g., different thresholds for explicit and implicit accessibility) are warranted is a question that needs to be addressed by future research.

References

Dienes, Z., & Perner, J. (1999). A theory of implicit and explicit knowledge. *Behavioral and Brain Sciences*, *22*, 735-808.

Dienes, Z., & Perner, J. (2002). A theory of the implicit nature of implicit learning. In R. M. French & A. Cleeremans (Eds.), *Implicit learning and consciousness: An empirical, computational and philosophical consensus in the making?* (pp. 68-92). Hove, UK: Psychology Press.

Frensch, P. A., Haider, H., Rünger, D., Neugebauer, U., Voigt, S., & Werg, J. (2002). The route from implicit learning to verbal expression of what has been learned: Verbal report of incidentally experienced environmental regularity. In L. Jimenez (Ed.), *Attention and implicit learning* (pp. 335-366). Amsterdam: John Benjamins Publishing Company.

Frensch, P. A., & Rünger, D. (2003). Implicit learning. *Current Directions in Psychological Science*, *12*, 13-18.

Gabrieli, J. D. E. (1998). Cognitive neuroscience of human memory. *Annual Review of Psychology*, *49*, 87-115.

Graf, P., & Schacter, D. L. (1987). Selective effects of interference on implicit and explicit memory for new associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 45-53.

Kinder, A., & Shanks, D. R. (2003). Neuropsychological dissociations between priming and recognition: A single-system connectionist account. *Psychological Review*, *110*, 728-744.

Macmillan, N.A. & Creelman, C.D. (1991). *Detection Theory: A user's guide*, New York: Cambridge University Press.

Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology*, *19*, 1-32.

Norman, D. A. (1969). Attention to action: Willed and automatic control of behavior. In R. J. Davidson, G. E. Schwarts & D. Shapiro (Eds.), *Consciousness and self-regulation.* (Vol.

4, pp. 1-18). New York: Plenum Press.

Poldrack, R. A., & Logan, G. D., (1997). Fluency and response speed in recognition judgments. *Memory and Cognition, 25*, 1-10.

Perruchet, P., Bigand, E., & Benoit-Gonin, F. (1997). The emergence of explicit knowledge during the early phase of learning in sequential reaction time tasks. *Psychological Research*, *60,* 4-13.

Perruchet, P., & Vinter, A. (2002). The self-organizing consciousness. *Behavioral and Brain Sciences*, *25*, 297-388.

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

Shanks, D. R. (2005). Implicit learning. In K. Lamberts & R. Goldstone (Eds.), *Handbook of cognition* (pp. 202-220). London: Sage.

Shanks, D. R., & Perruchet, P. (2002). Dissociation between priming and recognition in the expression of sequential knowledge. *Psychonomic Bulletin & Review*, *9,* 362-367.

Shanks, D. R., Wilkinson, L., & Channon, S. (2003). Relationship between priming and recognition in deterministic and probabilistic sequence learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29,* 248-261.

Shanks, D. R., (2003). Attention and awareness in 'implicit' sequence learning. In L. Jimenez (Ed.), *Attention and implicit learning* (pp. 11-42). Amsterdam: John Benjamins Publishing Company.

Tunney, R. J. (2003). Implicit and explicit knowledge decay at different rates: A dissociation between priming and recognition in artificial grammar learning. *Experimental Psychology*, *50,* 124-130.

Tunney, R. J., & Shanks, D. R. (2003). Subjective measures of awareness and implicit cognition. *Memory and Cognition*, *31,* 1060-1071.

Wilkinson, L., & Shanks, D. R. (2004). Intentional control and implicit sequence learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30,* 354-369.

Willingham, D. B. (1998). A neuropsychological theory of motor skill learning. *Psychological Review, 105,* 558-584.

Footnote

[1] In cases when a hit rate or false alarm rate was 1.0 or 0, values of 1 - 1/N and 1/N, respectively, were used in the calculation of d' instead (Macmillan & Creelman, 1991). This procedure was followed in Experiment 2 as well.

Table 1. Mean Reaction Times and Endorsement Rates for Grammatical and Ungrammatical Test Strings in Experiment 1 (Standard Errors in Parenthesis).

Interval (Days)	0	7
Response Times		
Grammatical	671.60 (23.14)	637.24 (26.37)
Ungrammatical	707.97 (24.88)	659.94 (28.49)
Priming	36.36 (12.25)	22.70 (10.58)
Endorsement Rates		
Grammatical	.70 (.05)	.57 (.03)
Ungrammatical	.20 (.03)	.29 (.04)
d’	1.56 (.23)	.84 (.14)

Table 2. Mean Reaction Times and Endorsement Rates for Grammatical and Ungrammatical Test Strings in Experiment 2 (Standard Errors in Parenthesis).

Interval (Days)	0	7
Response Times		
Grammatical	561.24 (18.63)	540.44 (19.50)
Ungrammatical	589.53 (20.95)	558.72 (21.07)
Priming	28.30 (8.85)	18.28 (5.06)
Endorsement Rates		
Grammatical	.68 (.04)	.62 (.05)
Ungrammatical	.31 (.04)	.37 (.05)
d’	1.04 (.14)	.71 (.12)

Appendix

Grammatical and Ungrammatical Strings Used in Experiments 1 and 2.

Grammatical	Ungrammatical
1 JFK	JDK
2 JSFDK	JSFDD
3 JSKSJ	JDKSJ
4 JFKSFD	JFKKFD
5 JFDKKK	DFDKKK
6 SFSKSJ	SFSKSD
7 SJDKKKK	SJDKKKD
8 SFSKJFD	SFSKDFD
9 SJKSSSS	SJKSSSK
10 JFKDJSK	JFKDJDK
11 SJKJFDK	SJKDFDK
12 SJKSFSK	SJKSFSF
13 SJKJSKS	SJKJDKS
14 SJKJSFK	SJKJSFF
15 JFKDSFD	JFKDKFD
16 JFKJSFK	JFKJSFF