Research Report

THE RELATION BETWEEN IMPLICIT AND EXPLICIT LEARNING: Evidence for Parallel Development

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Abstract—*Much research has focused on the separability of implicit and explicit learning, but less has focused on how they might interact. A recent model suggests that in the motor-skill domain, explicit knowledge can guide movement, and the implicit system learns in parallel, based on these movements. Functional imaging studies do not support that contention, however; they indicate that learning is exclusively implicit or explicit. In the experiment reported here, participants learned a motor sequencing task either implicitly or explicitly. At transfer, most of the stimuli were random, but the sequence occasionally appeared; thus, it was not obvious that explicit knowledge could be applied to the task. Nevertheless, participants with explicit training showed sequence knowledge equivalent to those with implicit training, implying that implicit knowledge had been acquired in parallel with explicit knowledge. This result has implications for the development of automaticity and of motor-skill learning.*

Much of the research on learning and memory over the past two decades has focused on the neural and cognitive separability of implicit and explicit learning (for a number of perspectives, see Schacter & Tulving, 1994). Less research has examined the relationship between implicit and explicit learning. Their relationship is of particular interest in motor-skill learning because it holds stark examples of the importance of both implicit and explicit learning. At advanced levels of skill, explicit access to the knowledge supporting the skill becomes unnecessary or even difficult (Fitts, 1964); an advanced tennis player need not consciously direct the movements of a serve, and in fact may be unable to describe the movement components. Indeed, some components of motor skills remain completely implicit throughout training. For example, in the serial response time (SRT) task, participants perform a four-choice response time task in which the stimuli appear in a repeating 12-unit sequence. Participants may demonstrate implicit learning of the sequence through faster response times even though they never learn it explicitly (Willingham, Nissen, & Bullemer, 1989). Nevertheless, conscious explicit processes are also important in motor-skill learning. Participants can use explicit knowledge of the sequence to support skilled performance in the SRT task (Curran & Keele, 1993).

Thus, there is evidence that both implicit and explicit knowledge are useful in producing skilled behavior. Do they interact, and if so, how? One of us (Willingham, 1998) recently proposed a model, COBALT, that posits that implicit motor-skill learning takes place in parallel with explicit learning, so long as physical responses to the stimuli are made. For example, in the SRT task, if participants were pushing buttons while they learned the sequence explicitly, they should simultaneously learn the sequence implicitly. However, studies using positron emission tomography (PET; Grafton, Hazeltine, & Ivry, 1995; Hazeltine, Grafton, & Ivry, 1997; Rauch et al., 1995) support separate, not parallel, implicit and explicit learning. Grafton and colleagues reported implicit learning was associated with metabolic changes in primary and supplementary motor cortices and the putamen, whereas explicit learning caused changes in prefrontal and premotor cortices (there was not simultaneous activity in the areas associated with implicit learning). Rauch and colleagues also reported separate sites supporting implicit learning (premotor cortex, caudate, and thalamus) and explicit learning (primary visual cortex, perisylvian cortex, and cerebellar vermis).

In the experiment reported here, we sought to test whether implicit knowledge is acquired in parallel with explicit knowledge in a motor-skill task. We trained participants to explicitly learn the sequence in the SRT task. We then administered an implicit test of the sequence to see if implicit knowledge had been acquired in parallel.

METHOD

Participants

One hundred twenty undergraduates from the University of Virginia completed the experiment as fulfillment of a course requirement or for a payment of $5.

Procedure

SRT task

Participants responded to a black circle that appeared in the center of one of four boxes arranged horizontally on a computer screen by pressing one of four keys on the computer keyboard ("z," "c," "b," or "m"). The response-to-stimulus interval was 250 ms, and errors were signaled by a brief tone. The experiment began with a 72-trial practice block in which the stimuli appeared randomly to familiarize participants with the task.

During the subsequent training, each participant saw a different repeating 12-unit sequence of stimulus positions, selected from a corpus of 563 such sequences. Each stimulus sequence met the following constraints (with the four positions designated 1 through 4 from left to right): A stimulus position could not repeat (e.g., 1223), each stimulus position appeared an equal number of times, and the sequence could not contain runs (e.g., 1234) or trills (e.g., 1313) of 4 units. A block consisted of the 12-unit sequence repeated six times, and participants saw four of these blocks.

Participants were given implicit- or explicit-learning instructions. For the explicit condition, participants were told that the stimuli would appear in a 12-unit sequence, which they were to learn. Numbers corresponding to the stimulus positions in the sequence were continuous-

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ly visible at the top of the screen. On the first sequenced block, numbers corresponding to the entire sequence appeared. On each consecutive block, three of the numbers disappeared, working from left to right, to encourage participants to memorize the sequence. In the implicit condition, participants did not see the numbers signifying the sequence, the sequence was not mentioned, and participants were simply told to respond as quickly as possible without making too many errors.

After training, participants completed a 72-trial transfer block constructed so that a repeating sequence was embedded within other random trials as follows: 24 random trials, 12 sequenced trials, 24 more random trials, and 12 more sequenced trials. For half of the participants, the sequence was the same one used during training. For the other half of the participants, it was a novel sequence. The intervening random trials were selected from the corpus of sequences.

It is known that participants will apply explicit knowledge to an ostensibly implicit task (Willingham et al., 1989). We used two methods to try to prevent this from happening: First, the transfer task employed mostly random trials. Second, participants with explicit sequence knowledge were misled about the purpose of the transfer task. They were told that the purpose of the training task was to evaluate how quickly they could respond when they memorized a sequence, and they were then told that the purpose of the transfer task was to obtain a measure of how quickly they could respond when the stimuli appeared randomly, as a baseline.

Confidence rating

After the transfer phase, all participants were told that the final block of the SRT task (i.e., the transfer block) had consisted mostly of random stimuli, but that a repeating sequence might or might not have been slipped in several times. Participants were asked to rate their confidence regarding which condition they were in, with a rating of 1 indicating they were confident that they were in the all-random group and a rating of 7 indicating they were confident they were in the some-sequence group.

Recall task

A free recall task was administered to assess explicit knowledge of the sequence. Participants were told that during training the stimuli had appeared in a repeating sequence, and they were asked to recall the sequence by using the same keys that they had used to respond to the stimuli. Their responses were echoed on the screen, and they could recall a maximum of 13 positions.

RESULTS

SRT Task

Response times were summarized by taking the median of each group of 12 trials, and then finding the mean of the six medians for each block, yielding a single summary response time per trial block for each subject. One subject in the explicit-learning group showed response times that tripled in the last trial block and was excluded from further analyses. The response times of the implicit- and explicit-learning groups across training blocks are shown in Figure 1. Response times decreased with training, $F(3, 351) = 43.8$, $MSE = 5{,}530$, $p < .001$. Participants receiving explicit instructions responded marginally more slowly than those receiving implicit instructions, $F(1, 117) = 3.6$, $MSE = 44{,}721$, $p = .06$, but that effect must be interpreted in light of the interaction of the two effects, which is also reliable, $F(3, 351) = 17.6$, $MSE = 5{,}530$, $p < .001$. It is likely that the explicit-learning participants initially responded slowly as they attempted to explicitly learn the sequence. Both the implicit- and the explicit-learning groups showed a significant decrease in response times if analyzed alone (Fs > 29).

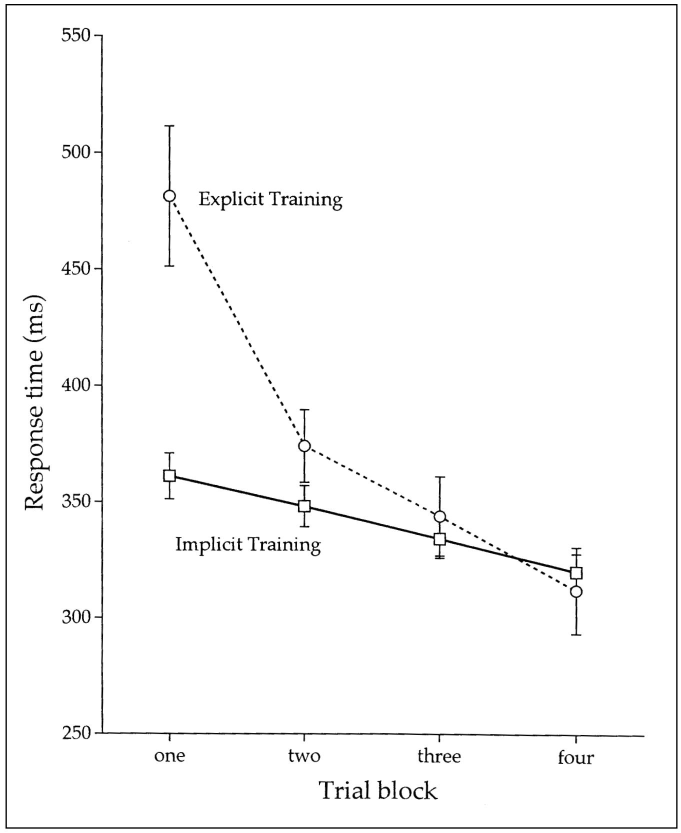

Fig. 1. Response times during training, shown separately for the implicit- and explicit-learning groups. Error bars are standard errors.

The critical data are those for the transfer block. These data were summarized into a single learning measure. To begin, we determined the median reaction time for the sequence each time it appeared. This median was computed using only the last nine trials of each sequence because it might happen by chance that the first few units of the sequence would appear during the random part of the block. Clearly, if the first unit of the sequence were the fourth position on the screen, there would be no reason to expect that response time would be particularly speedy every time the circle appeared in that position, even though it was part of the sequence. The median of each set of random trials was also taken, and then we calculated the mean of the sequence medians and of the random medians. The learning score for the transfer block was the difference between the sequence mean and the random mean.

These learning scores are shown in Figure 2. There was a reliable effect of transfer sequence, $F(1, 115) = 7.0$, $MSE = 518$, $p < .05$, showing that participants who saw the same sequence at training and transfer had larger learning scores than participants who saw a new sequence at transfer. Whether participants had received implicit or explicit instructions during training did not affect their learning scores

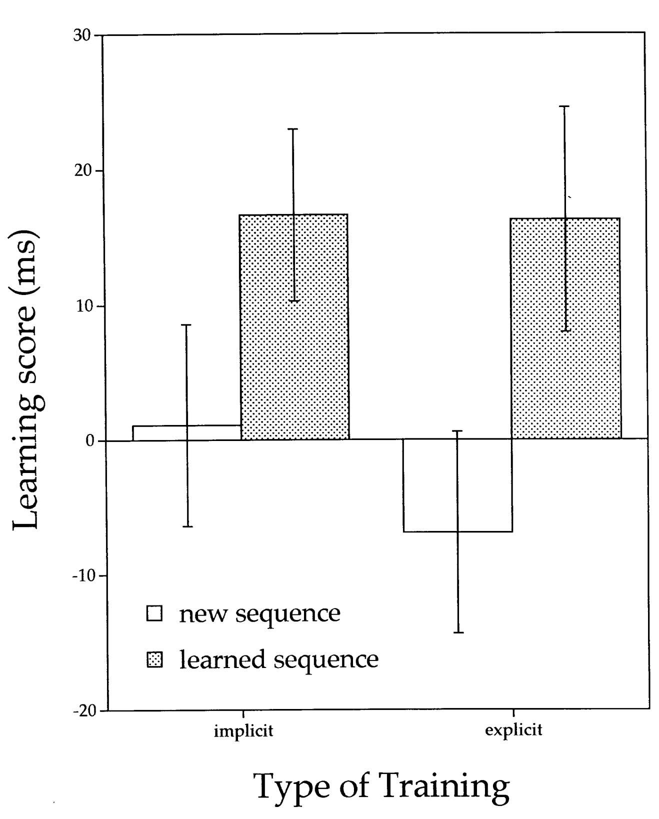

Fig. 2. Summary learning measure at transfer. Learning was measured by subtracting the mean response time on sequenced trials from the mean response time on random trials. Results are shown separately for subjects who were given implicit- or explicit-learning instructions during training and who saw a new or a previously seen sequence during transfer. Error bars are standard errors.

at transfer, nor did the type of training interact with the type of transfer sequence (*F*s < 1.0). Thus, the results of the SRT task were consistent with the hypothesis that implicit and explicit learning of a sequence in a motor task can occur in parallel.

Accuracy was uniformly high (95–98% correct for each block for each condition), and there were no reliable effects of accuracy, which is unsurprising, given that the instructions were to respond as quickly as possible without making many errors.

Confidence Rating

Confidence ratings are shown in Table 1. They were subjected to an analysis of variance, which showed no effects of training instructions or of sequence type, and no interaction (all Fs < 1.1, ps > .20). Thus, participants were not able to distinguish whether or not they had seen the sequence during the transfer block. We also examined separately the SRT performance of subjects who were unsure about the presence of a sequence or thought they were in the random group (ratings of 4 or lower). Among these subjects, those who saw old sequences still showed learning at transfer ($F > 7.0$), and there was no difference in the learning between subjects receiving implicit or explicit training ($F < 1.0$)

Table 1. *Frequency of confidence ratings, by condition*

	Confidence rating								
Group	1	2	3	4	5	6	7	Mean	*SD*
Implicit learning									
New transfer sequence	2	8	2	3	9	5	1	4.1	1.5
Learned transfer sequence	1	4	6	4	13	2	0	4.0	1.3
Explicit learning									
New transfer sequence	1	4	5	2	11	4	2	4.3	1.6
Learned transfer sequence	0	4	5	8	8	4	1	4.2	1.3

Note. Rating of 1 = "Confident I was in the all-random group," rating of 7 = "Confident I was in the some-sequence group."

Recall

Free recall was scored as the number of positions in the sequence correctly recalled. To reduce spurious hits, we used the criterion that for a position to be scored as correctly recalled, it had to be included within a correctly recalled segment consisting of a minimum of three consecutive positions, but these recalled segments did not themselves need to be consecutive. For example, if a subject saw 314324123142 and recalled 123143, the score would be 6, because both 123 and 143 occurred in the sequence.

There was a significant difference between the implicit- and explicit-learning groups in the number of sequence locations recalled, as would be expected, $F(1, 117) = 37.6$, $MSE = 8.5$, $p < .001$. Mean recall was 8.5 ($SD = 3.40$) for the explicit-learning group and 5.3 ($SD = 2.33$) for the implicit-learning group. To evaluate this latter figure, we calculated random-control scores by rescoring each subject's recall as if the sequence seen during training had been some other, randomly selected pattern; in this way, we obtained an estimate of guessing performance. Mean guessing performance was 4.6 ($SD = 2.6$), meaning that the free recall of the implicit group was not significantly better than guessing, $F(1, 59) = 2.7$, $MSE = 5.4$, $p > .10$.

Although the free recall means were patterned as would be expected, it is possible that some individuals in the explicit-learning condition failed to follow instructions and did not try to learn the sequence explicitly, and, conversely, that some participants in the implicit-learning condition noticed the sequence and learned it explicitly. To evaluate the effect of this possibility, we conducted all of the analyses a second time, eliminating implicit-instruction participants who scored half a standard deviation above the random-control mean score (cutoff = 6 or higher; 33 participants eliminated) and explicit-instruction participants who scored half a standard deviation lower than the random-control mean score (cutoff = 3 or lower; 11 participants eliminated). The results of all analyses were qualitatively unchanged, although the reduction in power meant that the effect of sequence type at transfer (i.e., whether the transfer sequence was the training sequence or a new sequence) was marginal ($p = .05$).

DISCUSSION

These results indicate that implicit and explicit learning are not mutually exclusive in motor-skill learning. Rather, when explicit knowledge is acquired, implicit learning can still occur in parallel, thus supporting the prediction of the COBALT model (Willingham, 1998).

Why, then, did Grafton et al. (1995) and Hazeltine et al. (1997) not observe evidence of parallel learning in the PET imaging study? One possibility is that the hemodynamic change in the implicit-learning structures was approaching asymptote when explicit training began. In these experiments, each participant was first trained with a distracting secondary task (mostly implicit learning) and then trained without the secondary task (mostly explicit learning). Thus, when explicit learning began, participants had already undergone an implicit training session, and further activation in brain structures associated with implicit learning might have been proportionally smaller than that observed during the first training session, and therefore more difficult to detect. A second possibility is that the distracting secondary task (which had the effect of suppressing explicit knowledge) led to radically different implicit learning. This explanation is at least plausible, given that a secondary task has been shown to affect the expression of implicit knowledge (Frensch, Lin, & Buchner, 1998).

The results reported here have implications for motor-skill learning and for automaticity. It has been difficult to integrate the roles of consciously directed movement and unconscious processes in motor-skill learning. It is clear that explicit memory can contribute to skilled performance; a beginning tennis player will try to remember a coach's advice the next time he or she takes to the court. These explicit memories ("bend your knees," "keep your wrist firm") will be used to guide motor behavior in the nascent motor skill. At the same time, most theories of motor-skill learning have made only a small place for such explicit processes, usually at the very start of training (Adams, 1971; Fitts, 1964; Schmidt, 1975). The present results suggest that explicit memory can be used to guide motor behavior while implicit learning occurs in parallel, based on the motor behavior being executed.

This relationship between implicit and explicit learning also has an important implication for the development of automaticity in motor-skill learning. It is typically thought that a person need not be aware of engaging processes that support an automatic behavior, as in driving a car. Early in training, however, the processes that support the behavior are quite accessible to awareness, and, indeed, people learning a skill tend to feel that these conscious processes are driving their behavior. One account of the development of automaticity is that these conscious representations are, with practice, transformed into a different, unconscious representation (Anderson, 1993). The present results suggest a different account. They suggest that the conscious, explicit process supports behavior until the simultaneously acquired implicit representation is sufficiently well developed to support behavior, at which time the explicit process is simply not used any longer; it does not transform into another representation.

An implication of this view is that implicit learning is the basis for automaticity in at least some skills. It is premature to draw firm conclusions on this point, but this view and Anderson's (1993) do share at least one important feature: immunity to impoverished attentional resources. Perhaps the hallmark of automaticity is that requirements for attentional resources are low or absent. Implicit sequence learning in the SRT task may show this characteristic as well. It was initially thought that a secondary task impeded learning of the sequence (e.g., Nissen & Bullemer, 1987), but later work showed that this was a performance effect (Frensch et al., 1998), perhaps due to changes in the response-to-stimulus interval (Frensch & Miner, 1994; Stadler, 1995; Willingham, Greenberg, & Thomas, 1997), and that other secondary tasks (such as a memory load) did not affect learning as much as was originally thought (Stadler, 1995).

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REFERENCES

Adams, J.A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior, 3,* 111–149.

Anderson, J.R. (1993). *Rules of the mind.* Hillsdale, NJ: Erlbaum.

Curran, T., & Keele, S.W. (1993). Attentional and nonattentional forms of sequence learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 189–202.

Fitts, P.M. (1964). Perceptual-motor skill learning. In A.W. Melton (Ed.), *Categories of human learning* (pp. 243–285). New York: Academic Press.

Frensch, P.A., Lin, J., & Buchner, A. (1998). Learning versus behavioral expression of the learned: The effects of a secondary tone-counting task on implicit learning in the serial reaction time task. *Psychological Research, 61,* 83–98.

Frensch, P.A., & Miner, C.S. (1994). Effects of presentation rate and individual differences in short-term memory capacity on an indirect measure of serial learning. *Memory & Cognition, 22,* 95–110.

Grafton, S.T., Hazeltine, E., & Ivry, R. (1995). Localization of independent cortical systems in human motor learning. *Journal of Cognitive Neuroscience, 7,* 497–510.

Hazeltine, E., Grafton, S.T., & Ivry, R. (1997). Attention and stimulus characteristics determine the locus of motor-sequence encoding: A PET study. *Brain, 120,* 123–140.

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

Rauch, S.L., Savage, C.R., Brown, H.D., Curran, T., Alpert, N.M., Kendrick, A., Fischman, A.J., & Kosslyn, S.M. (1995). A PET investigation of implicit and explicit sequence learning. *Human Brain Mapping, 3,* 271–286.

Schacter, D.L., & Tulving, E. (1994). *Memory systems 1994.* Cambridge, MA: MIT Press.

Schmidt, R.A. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82,* 225–260.

Stadler, M.A. (1995). The role of attention in implicit learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 674–685.

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

Willingham, D.B., Greenberg, A.R., & Thomas, R.C. (1997). Response-to-stimulus interval does not affect implicit motor sequence learning, but does affect performance. *Memory & Cognition, 25,* 534–542.

Willingham, D.B., Nissen, M.J., & Bullemer, P. (1989). On the development of procedural knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 1047–1060.

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