Implicit Learning of Unique and Ambiguous Serial Transitions in the Presence and Absence of a Distractor Task

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Three experiments investigated the effects of task load, time of secondary task onset, and response-stimulus time interval on direct and indirect measures of learning in the M. J. Nissen and P. Bullemer (1987) task. Experiment 1 demonstrated that both unique and ambiguous serial transitions can be learned in the absence and presence of an attentional distractor task. Experiment 2 showed that the time of secondary task onset affects the degree to which unique and ambiguous serial transitions are learned. Experiment 3 demonstrated that the learning of a sequential transition is affected by the length of the time interval between the response to a stimulus and the presentation of the next stimulus. The findings replicate and extend results reported by A. Cohen, R. I. Ivry, and S. W. Keele (1990) and provide important empirical constraints for a process model of implicit serial learning.

The classic result in many recent experiments on implicit serial learning has been a functional dissociation between direct and indirect measures of learning under incidental task instructions, such that "subjects are able to acquire specific procedural knowledge (i.e., processing rules) not only without being able to articulate what they have learned, but even without being aware that they had learned anything" (Lewicki, Czyzewska, & Hoffman, 1987, p. 523). Such dissociations have now been reported with a number of different experimental paradigms, for instance: (a) artificial grammar learning (e.g., Mathews et al., 1989; Reber, 1987, 1989; Servan-Schreiber & Anderson, 1990), (b) system's control (e.g., Berry & Broadbent, 1984; Hayes & Broadbent, 1988), and (c) serial pattern learning (e.g., A. Cohen, Ivry, & Keele, 1990; Curran & Keele, 1993; Knopman, 1991; Knopman & Nissen, 1987; Lewicki et al., 1987; Lewicki, Hill, & Bizot, 1988; Nissen & Bullemer, 1987; Nissen, Knopman, & Schacter, 1987; Nissen, Willingham, & Hartman, 1989; Willingham, Nissen, & Bullemer, 1989).

We are concerned with the mechanisms underlying implicit learning in the serial pattern learning paradigm. Although we acknowledge that findings demonstrating a functional dissociation between direct and indirect measures are important in their own right, we submit that they do little to further our understanding of the processes underlying serial learning. Specifically, dissociations do not tell us why and under which conditions serial learning, implicit or explicit, occurs. We therefore examine the conditions under which implicit serial learning occurs to establish and refine empirical constraints on process models of implicit serial learning, specifically of implicit serial learning as it occurs in the Nissen and Bullemer (1987) paradigm. A number of important findings describing situations in which implicit learning does and does not occur have already been reported. As an example, consider the findings described by Nissen and Bullemer. In their study, subjects performed a four-choice serial reaction time (RT) task in which the stimuli were asterisks that appeared at one of four locations, arranged linearly on a computer screen. Only one asterisk was presented at any time, with the order of asterisks following either a repeating sequence of locations in one experimental condition or a random sequence of locations in another condition. Subjects’ task was to press a key that corresponded to the asterisk’s present location as fast as they could.

Under single task conditions, that is, when subjects performed only the key-pressing task, Nissen and Bullemer (1987) reported that indirect measures of task performance, that is, reaction times, (a) decreased reliably faster, over practice trials, for the repeating sequence than for random sequences 1

1 Although the distinction between implicit and explicit serial learning is an important one (e.g., Lewicki, 1986; Lewicki, Czyzewska, & Hoffman, 1987; Lewicki, Hill, & Bizot, 1988; Stadler, 1989; Willingham, Nissen, & Bullemer, 1989), the use of the terms has not always been consistent in the literature. The implicit–explicit dichotomy has been taken to refer to either (a) the conditions under which learning occurs (e.g., Reber, 1989), (b) the type of measure applied to assess serial learning (e.g., Johnson & Hasher, 1987; Richardson-Klavehn & Bjork, 1988), or (c) the memory and learning processes underlying task performance in serial tasks (e.g., Merkile & Reingold, 1991). To avoid any confusion, we use the terms implicit and explicit to refer to the hypothetical learning processes underlying task performance in serial tasks. The terms incidental and intentional are used to refer to whether instructions established a learning task for subjects, and the terms direct and indirect describe the type of measure applied to assess learning.
and (b) increased reliably when subjects were transferred from the repeating to random sequences, although direct measures of task performance (i.e., cued recall, predicting an event in the sequence given preceding events as cues) demonstrated that subjects were not necessarily aware of the repeating sequence. More interestingly, under dual task conditions, that is, when a secondary tone-counting task was performed concurrently with the key-pressing task, learning of the repeating sequence did not occur. On the basis of these and similar results (e.g., Nissen et al., 1987), Nissen and Bullemer argued that attention to the sequence of stimuli is necessary for a repeating serial pattern to be learned.

In an attempt to replicate the Nissen and Bullemer (1987) findings, A. Cohen et al. (1990) reported that even under dual task conditions some types of repeating sequences are apparently learned, whereas other types are not learned. Specifically, A. Cohen et al. used three different types of repeating sequences: unique, ambiguous, and hybrid. In the unique sequences, every element of the repeating sequence had a unique association with the next element in the sequence (e.g., 12354, where the numbers from 1 to 5 denote, from left to right, five screen locations at which the stimulus could appear). That is, a given element was consistently followed by a second element (e.g., Element 1 was always followed by Element 2). In the ambiguous sequences, in contrast, each element was followed by two different elements at different serial positions in the repeating sequence (e.g., 12321). For example, Element 1 was followed by Element 2 at Position 2, but by Element 3 at Position 6. Finally, hybrid sequences contained both unique and ambiguous components (e.g., 123134).

A. Cohen et al. (1990) reported that, under single task conditions, subjects learned all three types of repeating sequences, although learning was most pronounced for the unique sequences and least pronounced for the ambiguous sequences (see also Stadler, 1992b). Under dual task conditions, however (i.e., when subjects performed a concurrent tone-counting task), A. Cohen et al. found that only the unique and hybrid sequences were learned but the ambiguous sequences were not learned. To explain these results, the authors hypothesized that two different learning mechanisms may underlie learning in the Nissen and Bullemer (1987) task: (a) a mechanism that forms associations between sequentially presented stimuli and (b) a mechanism that forms hierarchical memory representations of stimulus configurations (Keele & Summers, 1976). A. Cohen et al. hypothesized that the former mechanism may operate implicitly, whereas the latter mechanism may require attention to be performed. Thus, the authors hypothesized that the secondary task interferes with the operation of the hierarchical coding mechanism but not the operation of the associative learning mechanism.

Our experiments are based on the A. Cohen et al. (1990) framework and deal exclusively with learning in what A. Cohen et al. termed hybrid sequences, that is, sequences that contain both unique and ambiguous serial transitions. Hybrid sequences are particularly interesting because by contrasting learning of the unique and ambiguous components within hybrid sequences, it is possible to better understand the specifics of the associative learning mechanism proposed by A. Cohen et al. To understand why this is the case, consider the following argument: Assume, for the moment, that the associative learning mechanism was a simple form of classical conditioning that merely tied together pairs of successive stimuli. One would then predict that only the unique, but not the ambiguous, components of a hybrid sequence could be learned by this mechanism. Because the hierarchical learning mechanism would appear to be capable of learning both unique and ambiguous transitions, one would predict that differential learning takes place for unique and ambiguous transitions within hybrid sequences under both single and dual task conditions, and furthermore, that ambiguous serial transitions are not learned at all in a dual task situation.

Consistent with the predictions stated above, A. Cohen et al. (1990) found that learning of the hybrid sequences was, overall, more pronounced than learning of completely ambiguous sequences and was, overall, less pronounced than learning of completely unique sequences under both single task and dual task conditions. However, an informal comparison of the unique and ambiguous transitions within the hybrid sequences did not reveal any differences (A. Cohen & Curran, 1993). To explain this finding, A. Cohen and Curren (1993) hypothesized that the associative learning mechanism cannot be "a form of classical conditioning in which two actions are linked by a simple association" (p. 1435) but rather must be "some form of a (presumably complex) associative mechanism." (A. Cohen & Curran, 1993, p. 1435) that is capable of learning ambiguous transitions under at least certain conditions, such as in the presence of unique transitions in a repeating sequence.

A. Cohen et al.'s (1990) rather informal finding that unique and ambiguous transitions are learned equally well in hybrid sequences is clearly crucial to an understanding of the nature of the associative learning mechanism. The first goal of our research was therefore to reexamine, in a more formal manner, A. Cohen et al.'s claim that unique and ambiguous serial transitions are learned equally well within hybrid sequences. If we can replicate the finding that unique and ambiguous transitions are learned equally well, then we need to assume that the associative learning mechanism must be a somewhat more complex mechanism that does not merely associate successive events. If, on the other hand, we find that only unique, but not ambiguous, transitions are learned in the presence of a distractor task, then a relatively simple associative mechanism may account for the data presented by A. Cohen et al.

**Experiment 1**

The main purpose of Experiment 1 was to examine whether both unique and ambiguous serial transitions are learned under single task and dual task conditions, that is, in the absence and presence of an attentional distractor task. The primary task was identical to the task introduced by Nissen and Bullemer (1987) and differed from the one used by A. Cohen et al. (1990) only in that the stimuli presented were asterisks rather than X marks. That is, subjects performed a four-choice serial RT task in which the stimuli were asterisks that appeared at one of four locations, arranged linearly on a computer screen.

All subjects were shown different versions of A. Cohen et al.'s (1990) hybrid sequences, that is, sequences that contained
unique as well as ambiguous pairwise transitions. Roughly one third of the subjects were randomly assigned to the single task condition in which only the key-pressing task was performed, whereas the remaining two thirds received an additional secondary, tone-counting, task. Learning of the repeating sequence was assessed by introducing a new transfer sequence when the initial training phase had been completed. For half of the subjects in both the single and dual task conditions, the unique transitions in the repeating sequence were changed. For the remaining half, the ambiguous transitions were changed.

In addition, in a second phase of the experiment, subjects performed the equivalent of Nissen and Bullemer’s (1987) generate task, in which they were asked to predict where the stimulus would appear next. The generate task was assumed to be a direct, rather than an indirect, measure of serial learning to reveal the extent to which knowledge about the repeating sequence had been learned explicitly rather than implicitly.

Method

Subjects

The subjects were 59 male and 77 female undergraduates at the University of Missouri at Columbia, who received course credit in introductory psychology for participating in the experiment. Subjects ranged in age from 17 to 29 years ($M = 19.5, SD = 1.9$) and were randomly assigned to one of the four experimental conditions.

Materials

Stimuli and apparatus. Stimuli were presented on a 9-in. (22.9 cm) diagonal video screen controlled by a Macintosh SE microcomputer. For the key-pressing task, the stimulus was an asterisk, $0.50 \times 0.50$ cm, centered at one of four horizontal locations, 5.2 cm below the top of the screen. Two adjacent locations were separated horizontally by 5 cm and were underlined such that the asterisk appeared above one of the four lines. At a viewing distance of approximately 60 cm, each pair of adjacent locations was separated by 4.78° of visual angle.

The stimuli for the secondary, tone-counting task were low-pitched (1000 Hz) and high-pitched (2500 Hz) tones generated by the computer and were played through the computer’s external loudspeakers. The duration of the tones was 50 ms.

Responses to the primary task were made by pressing one of four keys on the second row from the bottom on the microcomputer keyboard. The keys for the letters $Z$ and $C$ were pressed with the left middle and index fingers; the keys for 1 and 3 were pressed with the right index and middle fingers. Each of the two groups of keys had center-to-center distances of 4 cm. Each key was covered with white felt coverings labeled 1 and 2 for keys $Z$ and $C$, and labeled 3 and 4 for keys 1 and 3. Responses to the secondary task were made by typing a number on the number keypad.

Procedure. Subjects were individually tested. Instructions to all tasks were presented on the screen. Forty-four subjects performed in the single task (key-pressing task) condition, and 92 subjects performed in the dual task condition (key-pressing and tone-counting tasks). Each trial started with the appearance of an asterisk at one of the four locations (i.e., 1, 2, 3, 4) were presented above the asterisks.

The final phase of the experiment involved the generate task (e.g., A. Cohen et al., 1990; Nissen & Bullemer, 1987). In this phase, subjects were shown the correct sequence of asterisks for the original repeating

Subjects were asked to rest two fingers of their left hand on the keys labeled 1 and 2 and two fingers of their right hand on the keys labeled 3 and 4, respectively. They were instructed to press the key labeled 1 if the asterisk appeared at Location 1, to press the key labeled 2 if the asterisk appeared at Location 2, and so on. Subjects completed 40 practice trials during which the asterisk appeared at random at the four locations. During the practice trials only, the location numbers for the four transitions (i.e., 1, 2, 3, 4) were presented above the asterisks.

For subjects in the dual task condition, the secondary, tone-counting task was introduced after they had completed 20 practice trials on the key-pressing task.

For the secondary task, subjects were instructed to count the number of high-pitched tones, ignoring the low-pitched ones, for each block of 120 trials. After each block of trials, subjects were asked to report the number of high-pitched tones. The sequence of high-pitched and low-pitched tones was randomly determined for each subject such that the probability of a high-pitched tone occurring was 0.55. The actual number of high-pitched tones presented within a trial ranged from 50 to 83. Subjects were not given feedback on their performances on the tone-counting and key-pressing tasks.

Subjects were told to respond to the key-pressing task as quickly as possible without making errors. The presence of a repeating sequence was not mentioned. The learning situation was thus incidental. All subjects completed a total of 12 blocks of trials. Within each trial block, a repeating sequence of Length 6 was continuously recycled exactly 20 times without break. Successive trial blocks were separated by a short rest period, the duration of which was determined by the subject.

Each subject received a different, semirandomly selected, repeating sequence of Length 6. All repeating sequences were derived from one of three different structural patterns, ABCBDC, ADCABC, and ADDBC. To determine the repeating sequence for any given subject, one of the three structural patterns was randomly selected. Then, Locations 1 through 4 were randomly assigned to the events within the structural pattern. For example, if the selected structural pattern was ABCBDC, then, in terms of screen locations, both 321241 and 432312 were possible repeating sequences.

The three structural patterns were hybrid sequences (A. Cohen et al., 1990) in the sense that both unique and ambiguous pairwise transitions occurred within the same sequence. Within the pattern ABCBDC, for example, the transitions AB and DC were unique in that A was always followed by B, and D was always followed by C. In contrast, all remaining transitions, BC, CB, BD, and CA, were ambiguous. That is, half of the time C followed B, but for the other half, D followed B. The same held true for the two remaining transitions, CB and CA. The presence of both unique and ambiguous transitions within the same pattern allowed us to compute RTs separately for the two types of transitions. Specifically, for Pattern ABCBDC, the responses to Positions 2 and 6 were responses to unique transitions, whereas the responses to the remaining four positions were responses to ambiguous transitions.

Each subject completed a total of 10 trial blocks with the repeating sequence (Blocks 1–8 and 11 and 12) and 2 trial blocks with a modified sequence (Blocks 9 and 10). Trial blocks with the repeating sequence always started from the same position in the sequence. The modified sequences were constructed such that for half of the subjects in both the single task and dual task conditions, the unique transitions of the repeating sequence were altered, whereas for the other half of the subjects, the ambiguous transitions were altered. For example, if the original repeating sequence was 123243, then the modification of the unique transitions might have resulted in a new sequence 122423, whereas the modification of the ambiguous transitions might have resulted in a new sequence 123432 (modifications in italics).

The final phase of the experiment involved the generate task (e.g., A. Cohen et al., 1990; Nissen & Bullemer, 1987). In this phase, subjects were shown the correct sequence of asterisks for the original repeating.
pattern and were asked to indicate where the asterisk would appear next by pressing the corresponding key. Instructions clearly stated that throughout most of the experiment (i.e., excluding Blocks 9 and 10), a single sequence of positions had been continuously recycled, and subjects were asked to recall this sequence. Accuracy was emphasized, and subjects were told that RTs would no longer be recorded. The main dependent variables of interest were (a) the RTs to the key-pressing task and (b) the accuracy of prediction in the generate task. Independent variables were task load (between subjects, single vs. dual), type of transfer task in Trial Blocks 9 and 10 (between subjects, unique change vs. ambiguous change), type of transition (within subject, unique vs. ambiguous), and practice block (within subject; 1–12). After eliminating data from subjects who did not perform the tone-counting task adequately in the dual task conditions, there remained 22 subjects in the single task–ambiguous change condition, 22 subjects in the single task–unique change condition, 31 subjects in the dual task–unique change condition, and 32 subjects in the dual task–ambiguous change condition.

Given our $N$ and $\alpha = \beta = .05$, it was possible to detect “large effects” (J. Cohen, 1977) for the task load and type of transfer task, between-groups comparisons. Therefore, $\alpha$ was set to .05 for all statistical tests reported. Individual $p$ values will be omitted. For reliable effects, partial $R^2$ values ($\eta^2$) are reported as a measure of relative effect size, that is, the proportion of variance explained by the effect relative to the total variance not explained by other experimental variables (cf. J. Cohen, 1977, p. 412).

**Results**

For clarity of presentation, the results are organized into three main sections. In the first section, we test whether the repeating hybrid sequence was learned at all in both the single task and dual task conditions. This test was essentially a replication of the findings reported by A. Cohen et al. (1990).

In the second section, we compare learning of the unique and ambiguous serial transitions within the repeating sequence, and in the third section, we describe the results for the generate task.

Overall, subjects made relatively few errors in the primary, key-pressing task. Therefore, error data were not analyzed (mean error rates were 2.7%, 2.1%, 7.0%, and 5.8% for the four experimental conditions, single task–unique change, single task–ambiguous change, dual task–unique change, and dual task–ambiguous change, respectively).

**Learning of Hybrid Sequences in the Absence and Presence of a Distractor Task**

First, data were discarded for all subjects in the dual task conditions for whom the reported number of high-pitched tones differed from the actual number presented by more than 10%, on average across all trial blocks. Under this procedure, data for 17 subjects in the dual task–unique change condition and 12 subjects in the dual task–ambiguous change condition were deleted from all reported data analyses, resulting in 31 remaining subjects in the dual task–unique change condition and 32 remaining subjects in the dual task–ambiguous change condition.

Then, for all subjects, the median RTs of correct responses were determined separately for the unique and ambiguous parts of the repeating sequence in each of the 12 trial blocks (see Procedure section for a discussion of what constituted the unique and ambiguous components of the repeating sequence). The resulting mean RTs (averaged over subjects) in the single task and dual task conditions are presented in Figure 1 separately for the unique and ambiguous transitions within the repeating sequence.

Degree of learning, for each subject, was quantified as the RT difference between Trial Block 8 (last trial block with repeating sequence) and Trial Block 9 (first trial block with transfer task). Overall, that is, averaged over the unique and 2 In most studies of the Nissen and Bullemer (1987) task that used the generate task in the past, subjects were not told to reproduce a previous sequence but rather were simply asked to guess where the asterisk would appear next. As Perruchet and Amorim (1992) pointed out, the lack of information on the relation between study and test phases in those experiments classified the generate task as an indirect, rather than direct, memory test (Richardson-Klavehn & Bjork, 1988).

3 In the analyses reported here, RTs for the ambiguous transitions were averaged over all four ambiguous transitions within the repeating sequence. However, two of the four spatial locations involving the ambiguous transitions occurred less frequently than the remaining locations. To exclude the possibility that any RT difference between unique and ambiguous transitions reflected a difference in frequency, we repeated all analyses reported here and in Experiments 2 and 3 excluding spatial positions that occurred less frequently. The resulting findings were virtually identical to the ones reported here.
ambiguous parts of the repeating sequence, RTs increased from 343.4 ms (Block 8) to 438.6 ms (Block 9) in the single task condition and from 654.5 ms (Block 8) to 689.0 ms (Block 9) in the dual task condition. A 2 (task load: single task vs. dual task, between subjects) x 2 (block of trials: 8 vs. 9, within subject) analysis of variance (ANOVA) on subjects’ response times yielded reliable main effects of task load, $F(1, 105) = 120.64$, $M_{S_e} = 33.853.01, s^2 = .53$, and of block of trials, $F(1, 105) = 82.56$, $M_{S_e} = 2.638.24, s^2 = .44$, as well as a reliable interaction between task load and block of trials, $F(1, 105) = 18.04$, $M_{S_e} = 2.638.24, s^2 = .15$.

Separate ANOVAs for the single task and dual task conditions revealed that the 95.2 ms increase in RT from Block 8 to Block 9 in the single task condition was reliable, $F(1, 43) = 58.84, M_{S_e} = 3.385.08, s^2 = .58$, as was the 34.5 ms increase in RT in the dual task condition, $F(1, 62) = 17.71, M_{S_e} = 2.120.27, s^2 = .22$. Taken together, the analyses indicated that learning of the repeating sequence occurred in both the single task and dual task conditions. This result replicates A. Cohen et al.’s (1990, Experiment 4) finding that hybrid repeating sequences can be learned in both the absence and presence of a distractor task.

Learning of Unique and Ambiguous Serial Transitions in the Absence and Presence of a Distractor Task

Training phase. As can also be seen in Figure 1, the RTs for the unique transitions within the repeating sequence appeared to be faster, on average, than the RTs for the ambiguous transitions in both the single task and dual task condition. The mean RT difference (RT ambiguous − RT unique), averaged across all trial blocks of the training phase (Trial Blocks 1–8), was 15.2 ms in the single task condition and 8.4 ms in the dual task condition. A 2 (task load: single vs. dual, between subjects) x 2 (type of transition: unique vs. ambiguous, within subject) x 8 (block of trials: 1–8, within subject) ANOVA on subjects’ RTs from the training phase yielded reliable main effects of task load, $F(1, 105) = 179.37, M_{S_e} = 240.088.29, s^2 = .63$; of transition, $F(1, 105) = 8.01, M_{S_e} = 7.200.70, s^2 = .07$; and block of trials, $F(7, 735) = 152.06, M_{S_e} = 4.049.38, s^2 = .59$. Only the interaction between type of transition and block of trials was reliable, $F(7, 735) = 10.12, M_{S_e} = 455.93, s^2 = .09$; all other interactions, $p > .10$.

Follow-up analyses revealed that, in the single task condition, the main effects of type of transition, $F(1, 43) = 4.07, M_{S_e} = 10.028.17, s^2 = .09$, and of block of trials, $F(7, 301) = 72.18, M_{S_e} = 3.046.21, s^2 = .63$, were reliable, as was the interaction between type of transition and block of trials, $F(7, 301) = 4.94, M_{S_e} = 467.81, s^2 = .10$. In the dual task condition, the main effect of type of transition was marginally significant, $F(1, 62) = 3.37, M_{S_e} = 5.239.72, p < .07, s^2 = .05$, and both the main effect of blocks of trials, $F(7, 434) = 92.61, M_{S_e} = 4.745.12, s^2 = .60$, and the interaction between type of transition and block of trials were reliable, $F(7, 434) = 5.40, M_{S_e} = 447.70, s^2 = .08$. In summary, the findings for the training phase indicate that unique transitions were learned better than ambiguous transitions in both the absence and presence of a distractor task.

Transfer effects. An analysis of the RT data from Trial Blocks 8 (last block in training phase) and 9 (first transfer block) confirmed the findings reported for the training phase. Table 1 contains the average RTs in Trial Blocks 8 and 9 for all experimental conditions. As can be seen in Table 1, in the single task conditions, the unique transitions were more affected by the unique change than by the ambiguous change, whereas the ambiguous transitions were more affected by the ambiguous change than by the unique change. A similar pattern was found for the unique transitions in the dual task conditions, although here the ambiguous transitions were as much affected by the unique change as they were affected by the ambiguous change.

A 2 (task load: single vs. dual, between subjects) x 2 (type of transfer task: unique change vs. ambiguous change, between subjects) x 2 (type of transition: unique vs. ambiguous, within subject) x 8 (block of trials: 8 vs. 9, within subject) ANOVA yielded reliable main effects of task load, $F(1, 103) = 120.10, M_{S_e} = 67.982.43, s^2 = .54$, and of block of trials, $F(1, 103) = 81.35, M_{S_e} = 5.344.45, s^2 = .04$, but no reliable main effects of type of transfer task and of type of transition. Of the two-way interactions, the interaction between type of transition and type of transfer task was reliable, $F(1, 103) = 5.25, M_{S_e} = 3.030.79, s^2 = .05$, as were the interactions between block of trials and task load, $F(1, 103) = 17.88, M_{S_e} = 5.344.45, s^2 = .15$, and between block of trials and type of transition, $F(1, 103) = 33.95, M_{S_e} = 2.286.08, s^2 = .25$. In addition, the three-way interaction among type of transition, block of trials,
and task load was reliable, $F(1,103) = 4.66$, $MS_e = 2,286.08, s^2 = 0.04$, as was the interaction among type of transition, block of trials, and type of transfer task, $F(1,103) = 10.29$, $MS_e = 2,286.08, s^2 = 0.04$. Finally, the four-way interaction among all four independent variables was reliable as well, $F(1, 103) = 4.35, MS_e = 2,286.08, s^2 = 0.04$.

When we average over type of transfer task, it becomes more obvious that the unique transitions were generally more affected by the modification of the repeating sequence than the ambiguous transitions. In the single task condition, mean RTs increased by 132.7 ms for the unique transitions and by 57.6 ms for the ambiguous transitions. In the dual task condition, the mean RT increases were 51.8 ms and 17.2 ms for the unique and ambiguous transitions, respectively. Follow-up ANOVAs indicated that the increase in RT was reliable for both the unique, $F(1, 43) = 67.57, MS_e = 5,729.71, s^2 = 0.61$, and ambiguous transitions in the single task condition, $F(1, 43) = 15.64, MS_e = 4,674.83, s^2 = 0.27$, as well as for the unique transitions in the dual task condition, $F(1, 62) = 27.46, MS_e = 3,082.99, s^2 = 0.31$. The RT increase was marginally significant for the ambiguous transitions in the dual task condition, $F(1, 62) = 3.22, MS_e = 2,901.62, s^2 = 0.05, p < 0.07$.

In summary, analyses of the transfer effects indicated that both unique and ambiguous transitions appeared to be learned under single task and dual task conditions, although unique transitions were generally learned better than ambiguous transitions. Furthermore, the difference between learning of the unique and the ambiguous transitions was reliably larger in the single task (132.7 ms vs. 57.6 ms) than the dual task (51.8 ms vs. 17.2 ms) condition, as indicated by the reliable three-way interaction among type of transition, block of trials, and task load.

**Generate Task: Direct Measure of Serial Learning**

Figure 2 contains the results of the generate task separately for the single task and dual task conditions and the unique and ambiguous parts of the repeating sequence. Recall that the generate task was assumed to capture the extent to which the repeating task had been learned explicitly, rather than implicitly. A 2 (task load: single vs. dual, between subjects) x 2 (type of transition: unique vs. ambiguous, within subject) ANOVA on the arcsine-transformed accuracy scores (Winer, 1971) from the first trial only yielded a reliable main effect of task load, $F(1, 105) = 18.81, MS_e = 1.32, s^2 = 0.15$; all other effects, $F < 1$. Most important, accuracy did not differ reliably for the unique and ambiguous transitions within the repeating sequence. The mean percentages correctly predicted were 73.7%, 74.0%, 49.1%, and 48.9% for the single task–unique transition, single task–ambiguous transition, dual task–unique transition, and dual task–ambiguous transition conditions, respectively. If one considers that the expected value, under random guessing, would be 33% if subjects learned that the same location never occurred twice in a row, and 25% if subjects did not learn anything, it becomes clear that the amount of explicit serial learning demonstrated in this task was substantial, even in the dual task condition.

Separate ANOVAs for the single task and dual task conditions with type of transition (unique vs. ambiguous) and trials (1–20) as within-subject variables on the arcsine-transformed accuracy scores from all 20 prediction trials yielded only a reliable main effect of trials in the single task condition, $F(19, 817) = 3.85, MS_e = 0.559, s^2 = 0.08$, but reliable main effects of both trials, $F(19, 1,178) = 20.51, MS_e = 0.758, s^2 = 0.25$, and type of transition, $F(1, 62) = 5.93, MS_e = 2.768, s^2 = 0.09$ in the dual task condition. As can be seen in Figure 2, subjects in the dual task, but not the single task, condition predicted the unique transitions of the repeating sequence reliably better than the ambiguous transitions of the sequence.

To examine whether the results obtained in the dual task condition with the indirect, RT measure were due to subjects' awareness of the repeating sequence, we ran the analyses described in the previous section for the dual task condition after we removed data for all subjects ($n = 19$) in the dual task condition for which the initial (Trial 1) prediction score on either the unique or the ambiguous or both parts of the repeating sequence was higher than 50%. The removal of the subjects resulted in new mean scores of 23.2% and 23.8% for the unique and ambiguous transitions in the dual task condition, respectively, essentially reflecting random performance. Although the resulting analyses had lower statistical power and therefore led to fewer statistically reliable results than the previous analyses, the pattern of findings obtained was qualitatively identical to that reported in the previous section. We conclude, therefore, that the findings obtained for the dual task condi-

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4 Averaging over the type of transfer task variable was possible because the number of subjects receiving the unique change was equal to the number of subjects receiving the ambiguous change in both the single task (32 subjects in each transfer condition) and the dual task condition (31 subjects in the unique change condition vs. 32 subjects in the ambiguous change condition).

5 The arcsine transformation was used because the dependent variable on the generate task had only six levels (i.e., number correct on Trial 1) and did thus not meet the assumption of normality required for ANOVA. However, informal ANOVAs on the raw scores (here and in subsequent experiments) yielded qualitatively identical results.
tion with the indirect measure of serial learning were not due to subjects' explicit knowledge of the repeating sequence.

Discussion

The main goals of Experiment 1 were to reexamine A. Cohen et al.'s (1990) finding that, within a hybrid repeating sequence, unique and ambiguous serial transitions are learned equally well. The results of Experiment 1 indicate that, first, hybrid sequences were learned in both the single task and dual task condition, although the effects were much smaller in Experiment 1 (95.2 ms and 34.5 ms increases in RT as a result of modifying the repeating sequences in the single and dual task condition, respectively) than in A. Cohen et al. (Experiment 4, hybrid sequence; approximately 260 ms and 55 ms, in the single and dual task condition, respectively). This difference in the magnitude of effects, we believe, is likely because only parts of the repeating sequence were modified in Experiment 1. In contrast, A. Cohen et al. presented random sequences during the transfer phase.

Second, and more important, both unique and ambiguous serial transitions appeared to be learned in the single task and dual task conditions. The empirical finding concerning learning of the ambiguous transitions in the dual task condition was only marginally significant. However, as will be seen in Experiments 2 and 3, the general conclusion, namely that even ambiguous transitions can be learned in the presence of a distractor task, is supported by similar subsequent findings. Third, unique transitions were generally learned better than ambiguous transitions and, finally, the difference between the two types of transitions was more pronounced in the single task than the dual task condition, although this particular finding may, at least partly, be explained as a floor effect in the dual task condition.

The crucial findings of Experiment 1 are the second and third findings because they speak directly to the specifics of the associative learning mechanism proposed by A. Cohen et al. (1990). First, the finding that ambiguous transitions are learned under dual task conditions is consistent with A. Cohen et al.'s argument that the associative learning mechanism is capable of producing more than simple pairwise associations between successive stimuli. That is, it appears that the associative learning mechanism is capable of learning both unique and ambiguous transitions at least under some circumstances (see also Cleeremans & McClelland, 1991; Frensch, 1991, 1994; French & Geary, 1993; Jordan, 1986; Jordan & Rumelhart, 1992). Second, however, it appears that the mechanism is generally more effective with unique than with ambiguous transitions.

Experiment 2 was conducted to further explore the properties of the associative learning mechanism proposed by A. Cohen et al. (1990). Specifically, the experiment was designed to test if and how the mechanism relied on short-term memory. In Experiment 2, only the dual task situation was used, and the time of onset of the secondary, tone-counting task was systematically manipulated. Our working hypothesis was that the manipulation of the tone onset would reveal whether the learning mechanism relied on short-term memory. We expected that presenting the secondary stimulus at different times after the primary stimulus had been presented would disrupt the formation of new associative patterns in short-term memory to different degrees, if indeed the operation of the associative learning mechanism is dependent on the temporary retention of elements in short-term memory.

As a by-product, in Experiment 2 we also tested whether only one learning mechanism, namely the associative mechanism, can account for learning under dual task conditions, as has been proposed by A. Cohen et al. (see also Curran & Keele, 1993). By using hybrid repeating sequences, we were able to separate, again, the effects of the experimental manipulation on learning of unique and ambiguous serial transitions. If learning of unique and ambiguous transitions is achieved by the same learning mechanism, then the time-of-onset manipulation should affect learning of the unique and ambiguous transitions in a qualitatively identical manner. If, however, different learning mechanisms are responsible for learning of unique and ambiguous transitions, then the time-of-onset manipulation might affect learning of the unique and ambiguous transitions differently.

Experiment 2

The basic design of Experiment 2 was identical to that of Experiment 1, except that (a) only the dual task situation was used (b) the time of onset of the secondary task was varied systematically, and (c) a free recall phase was added (before the generate task began) in which subjects were asked to explicitly recall any parts of the repeating sequence they had encountered during the course of the experiment. The recall results provided a validity check for the results obtained with the generate task (Perruchet & Amorim, 1992).

Method

Subjects

The subjects were 71 male and 85 female undergraduates at the University of Missouri at Columbia, who received course credit in introductory psychology for participating in the experiment. Subjects ranged in age from 17 to 48 years (M = 19.7, SD = 3.3) and were randomly assigned to one of the experimental conditions.

Materials

Stimuli and apparatus. Stimuli and apparatus were identical to those used in the dual task condition in Experiment 1.

Procedure. The procedure was identical to the one described for the dual task condition in Experiment 1 with the exceptions noted above. The time of tone onset was manipulated such that the tone was presented either simultaneously with the primary stimulus (i.e., asterisk), 350 ms or 700 ms after the onset of the primary stimulus. The tone onset times were chosen rather arbitrarily to cover as wide a range as possible. In addition, the time between a subject's response and the presentation of the next stimulus was increased to 500 ms, from 200 ms in the previous experiment.

Design

The main dependent variables of interest were (a) the response times to the key-pressing task, (b) the accuracy of recall in the recall task, and (c) the accuracy of prediction in the generate task. Independent variables were time of tone onset (between subjects; 0 ms vs. 350
ms vs. 700 ms), type of transfer task in Trial Blocks 9 and 10 (between subjects; unique change vs. ambiguous change), type of transition (within subject; unique vs. ambiguous), and practice block (within-subject; 1-12). After eliminating data from subjects who did not perform the tone-counting task adequately (using the same 10% criterion as in Experiment 1), there remained 21 subjects in the 0 ms-unique change condition, 20 subjects in the 0 ms-ambiguous change condition, 22 subjects in the 350 ms-unique change condition, 21 subjects in the 350 ms-ambiguous change condition, 20 subjects in the 700 ms-unique change condition, and 20 subjects in the 700 ms-ambiguous change condition.

Results

The results are again organized into three main sections. In the first section, we test whether manipulating the tone onset affected, overall, learning of the repeating hybrid sequence. In the second section, we compare learning of the unique and ambiguous serial transitions in the various experimental conditions, and in the third section, we present the results for the recall and generate tasks.

Again, subjects made few errors in the primary, key-pressing task. Therefore, error data were not analyzed (mean error rates were 1.1%, 1.3%, and 1.6% for the three experimental conditions, 0 ms, 350 ms, and 700 ms, respectively).

Learning of Hybrid Sequences as a Function of Time of Tone Onset

For all subjects, the median RT of correct responses was determined in each of the 12 trial blocks, separately for the unique and ambiguous transitions, as had been done in Experiment 1. A visual inspection of the RT data in the 700 ms condition indicated the presence of two distinct subgroups, subjects whose RTs clustered around 500 ms and subjects whose RTs clustered around 1,100 ms, with no overlap between the RT distributions from the two groups (see Figure 3).

Conceptually, subjects in the former subgroup appeared to respond to the key-pressing task first, that is, before the tone was presented, whereas subjects in the latter subgroup appeared to wait for the tone before they performed the key-pressing task. The two subgroups responded differently to the experimental manipulations. Therefore, the 700 ms condition was divided further into a 700 ms-key-first condition (subjects who responded to the key-pressing task before the tone was presented) and a 700 ms-tone-first condition (subjects who waited for the tone before they performed the key-pressing task). There were 21 subjects in the former group and 19 subjects in the latter group. Although the classification of subjects into these two subgroups did not constitute an experimental manipulation, we will, for ease of presentation, refer to four, rather than three, experimental conditions.

Mean RTs for the four experimental conditions are presented in Figure 4, separately for the unique (upper panel) and ambiguous (lower panel) parts of the repeating sequence. As

Figure 3. Distribution of response times (RTs) in the 700-ms condition in Experiment 2.

Figure 4. Mean response time (RT) as a function of time of secondary task onset and block of trials in Experiment 2. Upper panel: unique serial transitions; lower panel: ambiguous serial transitions.
can be seen, overall RT performance varied substantially among the conditions. Subjects in the 700 ms-key-first condition responded slightly faster, on average, than subjects in the 0 ms condition, who, in turn, responded faster than subjects in the 350 ms condition. Subjects in the 700 ms-tone-first condition were the slowest. In addition, learning of the repeating sequences also differed, as indicated by a comparison of the RT increases following the introduction of the transfer sequence. On average (over the unique and ambiguous parts of the repeating sequence), RTs increased by 32.2 ms, 6.9 ms, and 72.9 ms in the 0 ms, 350 ms, and 700 ms–key-first conditions, respectively, whereas RTs decreased by 22.8 ms in the 700 ms-tone-first condition. A 4 (tone onset: 0 ms vs. 350 ms vs. 700 ms–key first vs. 700 ms–tone-first between subjects) x 2 (block of trials: 8 vs. 9, within subject) ANOVA on subjects’ RTs for the repeating sequence revealed reliable main effects of tone onset, \( F(3, 120) = 142.10, M^2 = .78, \) and of trial block, \( F(1, 120) = 18.38, M^2 = 1,618.71, s^2 = .13, \) as well as a reliable interaction between tone onset and trial block, \( F(3, 120) = 10.42, M^2 = 1,618.71, s^2 = .21. \)

Follow-up analyses for each of the four experimental conditions revealed that both the 0 ms and the 700 ms–key-first conditions showed reliable increases in RT between trial blocks 8 and 9, \( F(1, 40) = 16.84, M^2 = 1,262.18, s^2 = .30, \) and \( F(1, 20) = 19.00, M^2 = 2,937.60, s^2 = .49, \) for the two conditions, respectively. In contrast, the RT increase was not reliable in the 350 ms condition, whereas the 700 ms–tone-first condition did not demonstrate an increase in RT when the repeating sequence was modified. In summary, varying the tone onset substantially affected both overall speed of performance and the amount of learning of the repeating sequence, such that learning was more pronounced in the 0 ms and 700 ms–key-first conditions than in the two remaining conditions.

### Learning of Unique and Ambiguous Serial Transitions as a Function of Tone Onset

#### Training phase.

For the training phase, the mean RT differences between the two types of transitions within the repeating sequence (RT ambiguous – RT unique) were 9.4 ms, 1.5 ms, 14.5 ms, and −7.7 ms, for the 0 ms, 350 ms, 700 ms–key-first, and 700 ms–tone-first conditions, respectively. Separate 2 (type of transition: unique vs. ambiguous, within-subject) x 8 (block of trials: 1–8, within-subject) ANOVAs were conducted for each of the four experimental conditions. In the 0 ms condition, both the main effect of type of transition, \( F(1, 40) = 9.52, M^2 = 1,510.21, s^2 = .19, \) and the main effect of block of trials, \( F(7, 280) = .104.68, M^2 = 2,260.05, s^2 = .72. \) were reliable, whereas the interaction between type of transition and block of trials was not reliable. In the 700 ms–key-first condition, all three effects were reliable, \( F(1, 20) = 8.65, M^2 = 2,032.27, s^2 = .30; F(7, 140) = 29.94, M^2 = 5,424.08, s^2 = .60; \) and \( F(7, 140) = 5.49, M^2 = 208.34, s^2 = .22, \) for the main effects of type of transition, blocks of trials, and the interaction, respectively. In the remaining two conditions, only the main effects of block of trials were reliable, \( F(7, 294) = 27.00, M^2 = 7,380.15, s^2 = 0.39, \) and \( F(7, 126) = 19.56, M^2 = 3,604.74, s^2 = .52, \) for the 350 ms and the 700 ms–tone-first conditions, respectively; all other effects, \( p > .05. \). These findings indicate that an advantage of unique serial transitions over ambiguous transitions under dual task conditions was obtained only for the 0 ms and the 700 ms–key-first conditions.

#### Transfer effects.

An analysis on the RT data from Trial Block 8 (last block in training phase) and Trial Block 9 (first transfer block) confirmed the findings reported for the training phase. Table 2 contains the mean RTs in Trial Blocks 8 and 9 for all experimental conditions. A four-way ANOVA with tone onset (0 ms vs. 350 ms vs. 700 ms–key first vs. 700 ms–tone first) and type of transfer task (unique change vs. ambiguous change) as between-subjects variables, and type of transition (unique vs. ambiguous) and block of trials (8 and 9) as within-subject variables yielded reliable main effects of tone onset, \( F(3, 116) = 135.17, M^2 = 4,5071.54, s^2 = .78, \) type of transition, \( F(1, 116) = 5.86, M^2 = 782.99, s^2 = .05, \) and of block of trials, \( F(1, 116) = 17.80, M^2 = 3,289.50, s^2 = .13. \) Only interactions with block of trials were reliable, \( F(3, 116) = 11.15, M^2 = 3,289.50, s^2 = .22; F(3, 116) = 31.84, M^2 = 626.44, s^2 = .45; \) and \( F(3, 116) = 11.95, M^2 = 626.44, s^2 = .24, \) for the interactions between block of trials and tone onset,

#### Table 2

*Average Reaction Times in Trial Blocks 8 (Last Block in Training Phase) and 9 (First Transfer Block) as a Function of Experimental Condition (Experiment 2)*

<table>
<thead>
<tr>
<th>Experimental condition</th>
<th>Unique transitions</th>
<th>Ambiguous transitions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trial block 8</td>
<td>Trial block 9</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>0 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unique change</td>
<td>523.0</td>
<td>99.2</td>
</tr>
<tr>
<td>Ambiguous change</td>
<td>472.67</td>
<td>97.2</td>
</tr>
<tr>
<td>350 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unique change</td>
<td>699.1</td>
<td>106.6</td>
</tr>
<tr>
<td>Ambiguous change</td>
<td>678.8</td>
<td>163.7</td>
</tr>
<tr>
<td>700 ms, key first</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unique change</td>
<td>449.2</td>
<td>122.8</td>
</tr>
<tr>
<td>Ambiguous change</td>
<td>432.8</td>
<td>89.2</td>
</tr>
<tr>
<td>700 ms, tone first</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unique change</td>
<td>1,072.2</td>
<td>54.2</td>
</tr>
<tr>
<td>Ambiguous change</td>
<td>1,106.7</td>
<td>89.4</td>
</tr>
</tbody>
</table>

*Note.* Means and standard deviations are given in milliseconds.
between block of trials and type of transition, and among block of trials, tone onset and type of transition, respectively; all other effects, \( p > .05 \).

Because neither the main effect of type of transfer task nor any of the interactions involving type of transfer task were statistically reliable, we collapsed over the two types of transfer tasks for subsequent analyses. On average, RTs for the unique transitions increased by 51.4 ms, 17.6 ms, and 109.9 ms in the 0 ms, 350 ms, and 700 ms-key-first conditions, respectively, and decreased by 28.7 ms in the 700 ms-tone-first condition. The increase in RT was reliable in both the 0 ms condition, \( F(1, 40) = 26.41, MS_e = 2,053.85, sR^2 = .40, \) and the 700 ms-key-first condition, \( F(1, 20) = 24.83, MS_e = 5,102.70, sR^2 = .55, \) and was marginally reliable in the 350 ms condition, \( F(1, 42) = 3.18, MS_e = 2,099.93, p < .09, \) but was not reliable for the 350 ms condition, although the effects were generally smaller, were qualitatively similar to those found with unique serial transitions. On average, RTs for the ambiguous transitions increased by 13.0 ms, 5.3 ms, and 36.0 ms in the 0 ms, 350 ms, and 700 ms-key-first conditions, respectively, and decreased by 16.8 ms in the 700 ms-tone-first condition. The increase in RT was reliable in the 700 ms-key-first condition, \( F(1, 40) = 6.87, MS_e = 1,977.71, sR^2 = .26, \) and was marginally reliable in the 0 ms condition, \( F(1, 40) = 3.20, MS_e = 1,077.83, p < .09, \) but was not reliable for the 350 ms condition, \( F(1, 42) < 1. \)

In summary, separate analyses on the RTs from the unique and ambiguous serial transitions indicated that both types of transitions appeared to be similarly affected by the experimental manipulation of the tone onset. Both unique and ambiguous serial transitions were learned best in the 700 ms-key-first condition, second best in the 0 ms condition, and third best in the 350 ms condition, although the effects were generally larger for the unique transitions than the ambiguous transitions. The two types of transitions did not appear to be learned in the 700 ms-tone-first condition.

Free-Recall and Generate Tasks: Direct Measures of Serial Learning

Free-recall task. The sequences recalled by subjects were scored according to whether the entire sequence was recalled correctly or was recalled partially correct. A recalled sequence was scored as partially correct when more than two, but fewer than all six, successive locations were correctly recalled. Using this measure, 9 of 41 subjects in the 0 ms condition (22.0%), 14 of 43 subjects in the 350 ms condition (32.6%), 3 of 21 subjects in the 700 ms-key-first condition (14.3%), and 2 of 19 subjects in the 700 ms-tone-first condition (10.5%) correctly recalled all or parts of the repeating sequence. When compared with the results discussed in the previous section, it can be seen that the results obtained with the indirect (i.e., RT) and direct measures were quite different. For example, although the 700 ms-key-first and 700 ms-tone-first conditions differed greatly on the indirect measure of learning, they did not differ on the direct measure.

Generate task. Figure 5 contains the results of the generate task, separately for the four experimental conditions. When the scores for the first trial were averaged over the unique and ambiguous transitions and compared with the recall data, the results obtained with the generate task closely mirrored those obtained with the recall task, although the group difference on the arcsine-transformed scores from the first prediction trial was not statistically reliable, \( F(3, 120) < 1. \)

It is interesting to note that although the prediction scores for the two types of transitions did not differ on the first prediction trial in any of the experimental groups, subjects generally appeared to predict the unique parts of the sequence better than the ambiguous parts, as indicated by reliable type of transition effects in two of the four conditions (i.e., 350 ms and 700 ms-key first). In the remaining two conditions, the type of transition effect fell just short of significance.

In summary, the results obtained with the direct measures of learning demonstrate that the effects of the experimental manipulation obtained with the indirect measure were not likely due to subjects' becoming more aware of the repeating sequence in those conditions that showed the most amount of learning (i.e., 0 ms and 700 ms-key first). Nevertheless, a substantial number of subjects were able to partially recall the repeating sequence before the generate task began. We therefore reran the analyses described in the previous sections after discarding data from all subjects who correctly recalled parts of or the entire repeating sequence in the free-recall task. Although the resulting analyses had lower statistical power and therefore led to fewer statistically reliable results than the previous analyses, the pattern of findings obtained was qualitatively identical to that reported in the previous sections.

Discussion

The two main goals of Experiment 2 were to (a) replicate the previous finding (Experiment 1) that both unique and ambiguous serial transitions are learned under dual task conditions and (b) examine the effects of manipulating the tone onset on direct and indirect measures of serial learning. When the results of the 0 ms condition in the present experiment are compared with the findings obtained with the dual task condition in Experiment 1 (the 0 ms condition was the most similar to the dual task condition in Experiment 1 in terms of the timing of the two tasks), it is clear that the replication was successful. First, the average difference between the RTs for unique and ambiguous serial transitions (i.e., RT ambiguous - RT unique) during the training phase was approximately 10 ms in both conditions. Second, the increases in RT following the transition from training phase to transfer phase were 51.8 ms and 17.2 ms for the unique and ambiguous transitions, respectively, in Experiment 1 and 51.4 ms and 13.0 ms for the unique and ambiguous transitions, respectively, in Experiment 2. We therefore conclude that both unique and ambiguous serial transitions can be learned in the presence of a distractor task, although unique transitions are generally learned better.

The second goal of Experiment 2 was to examine the effects of the tone-onset manipulation on learning of the repeating sequence. First, the manipulation strongly affected overall response times in the four experimental conditions. Subjects in the 700 ms-key-first condition responded faster, on average, than subjects in the 0 ms condition, who, in turn, responded faster than subjects in the 350 ms condition. Subjects in the 700
Figure 5. Mean percentage correctly predicted as a function of type of serial transition and trial in Experiment 2. Upper panel, left: 0 ms; upper panel, right: 350 ms; lower panel, left: 700 ms-key first; lower panel, right: 700 ms-tone first.

ms–tone-first condition were the slowest. Second, a comparison of Trial Block 8 and Trial Block 9 demonstrated that learning was more pronounced in the 0 ms and the 700 ms-key-first conditions than in the remaining two conditions. This was true for both unique and ambiguous serial transitions. And third, the direct measures of learning (i.e., free recall, generate score) showed a different pattern, indicating that the advantage of the 0 ms and the 700 ms-key-first conditions was not likely due to subjects' being more aware of the repeating sequence.

The finding that the unique and ambiguous serial transitions were affected in a qualitatively similar manner by the tone-onset manipulation is, of course, consistent with the position that only one, presumably associative, learning mechanism is responsible for learning unique and ambiguous transitions in the presence of a distractor task and supports A. Cohen et al.'s (1990) claims (see also A. Cohen & Curran, 1993; Curran & Keele, 1993). However, the effectiveness of the associative learning mechanism clearly varies as a result of manipulating the tone onset. To understand the properties of the mechanism, we therefore need to explain why (a) the experimental manipulation resulted in differences in the overall response times and (b) the manipulation led to differences in degree of learning.

One possible and simple, although rather uninteresting, explanation that seems to account for both of these findings is that the manipulation affected the degree to which subjects paid attention to the primary task. According to this explana-

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6 We thank an anonymous reviewer for pointing out this possible explanation.
tion, subjects responded faster in the 0 ms and the 700 ms–key-first conditions because they paid more attention to the primary task. Consequently, subjects who responded faster, on average, also learned the primary task better. Notice that this view predicts that subjects who paid more attention to the primary task, and therefore responded faster, also showed more explicit knowledge of the repeating sequence. That is, the results obtained with the explicit measures should have mirrored those obtained with the implicit measures, which, however, they did not (see Figures 4 and 5).

In addition, the argument also predicts that the four experimental conditions differed systematically in their error rates on both the primary and secondary task. That is, subjects who paid more attention to the primary task should have made fewer errors on the primary task and more errors on the secondary task. In fact, however, the error rates for the primary task were 1.1%, 1.3%, 2.4%, and 0.7%, for the four experimental conditions, 0 ms, 350 ms, 700 ms–key first, and 700 ms–tone first, respectively. The average deviations from the correct tone count were 3.1%, 4.0%, 6.4%, and 2.7% for the same four conditions. Notice that subjects in the fastest experimental condition, the 700 ms–key-first condition, showed the highest error rate in both the primary and the secondary task. On the basis of the general pattern of results, we feel relatively safe in rejecting the attentional hypothesis.

A second possible explanation, and the one that instigated Experiment 2 and is presently favored by us, is to assume that (a) the experimental manipulation led to systematic differences in the scheduling of the two experimental tasks and that (b) differences in the scheduling led to differences in the effectiveness of the associative learning mechanism by affecting the time span between encodings of successive primary events.

To judge the plausibility of this argument, we need to find out how subjects scheduled the two experimental tasks in the various experimental conditions. For this, in turn, we need to produce independent estimates of how long, on average, it takes subjects to respond to the primary and secondary stimuli in isolation. On the basis of the data from Experiment 1 (Trial Block 8), and assuming, for simplicity, that the primary and secondary tasks are performed serially, rather than in parallel, we estimated the key response to take approximately 450 ms if performed in isolation and the tone response to take approximately 300 ms.7 (Notice that some variability in these estimates does not affect the general conclusions drawn below.)

Thus, the overall response time of 503.6 ms (Trial Block 8) for the 0 ms condition was roughly 50 ms slower than one would expect if all subjects always performed the key-pressing task first. We therefore conclude that the modal strategy in the 0 ms condition was for subjects to perform the key-pressing task first, but that, on a few occasions, the tone-counting task was performed first. This conclusion is supported by the fact that the RT distribution for the 0 ms condition showed a clear peak at approximately 450 ms and a second, much smaller, peak at approximately 750 ms.

The overall response time for the 350 ms condition was 691.7 ms for Trial Block 8. Given our estimates, such a time is roughly 100 ms faster than we would expect if subjects always waited for the tone, identified it as high (i.e., relevant) or low (i.e., irrelevant), then performed the key-pressing task, and finally processed the tone (i.e., incremented the tone count by one). We therefore assume that on occasion, subjects responded to the key-pressing task before the tone was presented. Again, an inspection of the RT distribution for the 350 ms condition showed a clear peak at approximately 750 ms. In addition, it appeared that 5 (of 43) subjects consistently performed the key-pressing task before the tone was presented.

In the 700 ms–key-first condition (average response time = 447.7 ms in Trial Block 8), the modal strategy must have been to perform the key-pressing task first, wait for the tone, and then perform the tone-counting task. In contrast, the mean response time of 1,083.0 ms for subjects in the 700 ms–tone-first condition is consistent with the modal strategy of waiting for the tone, then performing the key-pressing task, and finally processing the tone.

As such, we assume that the experimental manipulation of the tone onset affected the scheduling of the two experimental tasks roughly in the manner described above. The differences in overall response times among the various conditions are thus seen as a reflection of when the key-pressing task was scheduled and not, as was the case with the first possible explanation, as a reflection of how much attention was paid to the primary task.

Why might differences in scheduling lead to differences in the degree of learning? We believe that the most straightforward answer to this question is an explanation in which the scheduling affected the time interval between encodings of successive primary stimuli (see Gillund & Shiffrin, 1984, for example, for a similar assumption). Assuming that the modal strategies described above and our estimates for responding to the key-pressing and the tone-counting tasks are roughly valid, the predicted average time spans between encodings of successive primary stimuli are 950 ms, 1,300 ms, 1,000 ms, and 1,650 ms for the four conditions, 0 ms, 350 ms, 700 ms–key first, and 700 ms–tone first, respectively. Thus, the predicted time spans are shortest for the 0 ms and the 700 ms–key-first conditions, the conditions that also exhibit the most learning. Notice that this general pattern of predicted time spans remains relatively unchanged if we modify our estimates for how long responses to the key-pressing and tone-counting tasks take. We find that, in general, the longer the predicted time interval between encodings of successive stimuli, the smaller the empirically obtained degree of learning. If it is assumed that the primary stimulus is subject to (a) decay, (b) interference in short-term memory, or (c) both, then the scheduling essentially limits the amount of time that successive primary stimuli are simultaneously available in short-term memory. Such an explanation therefore suggests that the associative learning mechanism proposed by A. Cohen et al. (1990) is dependent on the retention of elements in short-term memory.

The explanation offered here assumes that the experimental manipulation in Experiment 2 affected the time scheduling of

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7 Our estimate for the key response time is somewhat slower than the response time obtained for the single task condition in Figure 1 (Trial Block 8) because the degree of explicit knowledge contributing to the response times is much larger under single task than under dual task conditions.
the primary and secondary tasks. The time scheduling, in turn, affected the length of the time interval between encodings of successive primary stimuli. Because the explanation was entirely post hoc and because alternative explanations are possible, it was important to test it more directly. Experiment 3, therefore, was designed to explore directly the hypothesis that the operation of the associative learning mechanism is affected by the duration of the time interval between encodings of successive primary stimuli. In Experiment 3, the length of the time interval between subjects' responses and the presentation of the next stimulus was experimentally varied.

Experiment 3

The basic design of Experiment 3 was similar to that of Experiment 1, although only the dual task situation was used. Again, subjects performed 12 trial blocks on a continuously recycling hybrid sequence. The specifications of the secondary, tone-counting task were identical to those described for Experiment 1. Trial Blocks 1–8, 11, and 12 were, as before, performed with the same repeating hybrid sequence. In Trial Blocks 9 and 10, in contrast to the previous experiments, random sequences of stimuli were presented. Subjects performed both a free-recall task and the generate task after they had completed 12 trial blocks with the key-pressing task.

Most important, half of the subjects were randomly assigned to one of two different experimental conditions, receiving either response–stimulus time Interval Pattern 1 or response–stimulus time Interval Pattern 2. To illustrate, consider one of the structural repeating patterns used in Experiment 3, ABCBDC (see Figure 6). For subjects receiving Interval Pattern 1, the time intervals between the onset of their response and the presentation of the next stimulus (response–stimulus interval, RSI) were selected such that they were equal to 500 ms, 1,500 ms, 500 ms, 1,500 ms, 500 ms, and 1,500 ms for the transitions AB, BC, BD, DC, and CA, respectively. In contrast, for subjects receiving Interval Pattern 2, the corresponding RSIs were 1,500 ms, 500 ms, 1,500 ms, 500 ms, 1,500 ms, and 500 ms for the transitions AB, BC, BD, DC, and CA, respectively.

Notice that, in the Interval Pattern 1 condition, two of the three 500 ms transitions (12 and 43) were unique. The remaining 500 ms transition and all of the 1,500 ms transitions were ambiguous. In contrast, in the Interval Pattern 2 condition, all three of the 500 ms transitions were ambiguous whereas two of the 1,500 ms transitions were unique. In essence, in the former condition, the unique transitions were presented with RSIs of 500 ms, and the ambiguous transitions were presented with RSIs of 1,500 ms. In the latter condition, the pattern was exactly reversed.

If RSI affects the degree of learning, then we expect learning of the unique transitions to be more pronounced in the Interval Pattern 1 condition than in the Interval Pattern 2 condition. The opposite pattern of results is expected for ambiguous transitions. That is, ambiguous transitions should be learned better in the Interval Pattern 2 condition than in the Interval Pattern 1 condition because the time intervals for ambiguous transitions were shorter in the former than the latter condition.

<table>
<thead>
<tr>
<th>Type of Transition</th>
<th>u</th>
<th>a</th>
<th>a</th>
<th>a</th>
<th>u</th>
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<tbody>
<tr>
<td>Repeating Pattern:</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>B</td>
<td>D</td>
<td>C</td>
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<tr>
<td>Interval Pattern 1 (ms):</td>
<td>500</td>
<td>1500</td>
<td>500</td>
<td>1500</td>
<td>500</td>
<td>1500</td>
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<td>Interval Pattern 2 (ms):</td>
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Figure 6. Time interval patterns used in Experiment 3. u = unique; a = ambiguous.

Method

Subjects

The subjects were 23 male and 54 female undergraduates at the University of Missouri at Columbia, who received course credit in introductory psychology for participating in the experiment. Subjects ranged in age from 17 to 33 years (M = 18.6, SD = 2.0) and were randomly assigned to one of the two experimental conditions.

Materials

Stimuli and apparatus. Stimuli and apparatus were identical to those used in the dual task condition in Experiment 1, except that only two structural patterns were used for the repeating sequences, ABCBDC and ABCACD. Half of the subjects received the first structural pattern; the remaining subjects received the second structural pattern.

Procedure. The procedure was identical to the one used in Experiment 1, except that (a) subjects were explicitly asked to recall any part or parts of the repeating sequence they had noticed before they began working on the generate task; (b) during the transfer phase, the stimulus appeared randomly at the four possible locations with the constraint that it could not occur at the same location on consecutive trials, and (c) subjects received, after each block of trial, feedback concerning their error rates on the key-pressing and tone-counting tasks.8

Design

The main dependent variables of interest were (a) the RTs to the key-pressing task, (b) the accuracy of recall in the recall task, and (c) the accuracy of prediction in the generate task. Independent variables were interval pattern (between subjects; Interval Pattern 1 vs. Interval Pattern 2) and practice block (within subject; 1–12). After eliminating data from subjects who did not perform the tone-counting task adequately (using the same 10% criterion as in Experiments 1 and 2), there remained 39 subjects in the Interval Pattern 1 condition and 38 subjects in the Interval Pattern 2 condition.

Results

As before, the results are organized into three main sections. In the first section, we describe a manipulation check to test whether the time interval manipulation (i.e., 500 ms vs. 1,500 ms) had any effect on subjects' response times. In the second section, we compare learning of the unique and ambiguous transitions in the two different interval pattern conditions, and in the third section, we summarize the results for the recall and generate tasks.

8 The feedback was introduced to reduce the number of subjects who had to be eliminated from data analyses because of their failure to perform the tone-counting task properly. In sharp contrast to Experiment 2 in which data for roughly 20% of the subjects in the dual task condition had to be eliminated, data from only 2 out of 79 tested subjects had to be discarded in Experiment 3.
As in the two previous experiments, subjects made few errors in the primary key-pressing task. Therefore, error data were not analyzed (mean error rates were 0.5% and 1.1% for the two experimental conditions, Interval Pattern 1 and Interval Pattern 2, respectively).

**Manipulation Check**

To test whether our time interval manipulation worked as hypothesized, we determined the median reaction time of correct responses for each of the six serial positions of the repeating sequence in each of the eight trial blocks that constituted the original training phase. Figure 7 shows the mean RTs (averaged over all eight trial blocks) for subjects in the two experimental conditions. As can be seen, average RTs varied systematically for the two interval patterns. Short time intervals led to long response times, whereas long time intervals led to short RTs. This RT pattern is to be expected given that subjects needed to perform the tone-counting task concurrently. To illustrate, when the time interval was short, the processing of the tone-counting task prolonged the response to the key-pressing task. That is, the response to the key-pressing task could be initiated only after the tone counting had been completed, thus leading to a relatively longer response time on the key-pressing task. Alternatively, when the time interval was long, tone processing already had been completed when the next stimulus was presented. Thus, the response to the stimulus was, in essence, a single task response. As such, the RT pattern shown in Figure 7 is consistent with the assumption that the experimental manipulation of the time interval between response and stimulus onset was successful.

**Learning of Unique and Ambiguous Transitions: Indirect Measure**

To compare learning of the unique and ambiguous transitions in the two interval pattern conditions, we computed the median RTs for correct responses separately for the two time interval patterns and each of the 12 trial blocks. Figure 8 shows the mean RTs (averaged over subjects) in the two experimental conditions as a function of trial block. Inspection of Figure 8 indicates that the unique transitions (top panel) were processed more slowly but were learned better when the time intervals between response and stimulus onset was 500 ms.

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9 For Trial Blocks 9 and 10 (transfer trials), the RTs were computed only for RSIs that were consistent with the RSIs for Trial Blocks 1–8. For example, the RTs for the unique transitions in the Interval Pattern 1 condition were based only on responses that occurred after RSIs of 500 ms, whereas the RTs for the unique transitions in the Interval Pattern 2 condition were based only on responses that occurred after RSIs of 1,500 ms.
(i.e., in the Interval Pattern 1 condition) than when the time intervals were 1,500 ms (i.e., in the Interval Pattern 2 condition). Processing was slower simply because the short time interval left relatively little time to process the tone. Thus, tone counting prolonged the response to the primary stimulus. More important, the mean increase in RT (Trial Block 9 – Trial Block 8) when the random sequences were introduced was 138.6 ms when the time intervals were 500 ms and 118.2 ms when the time intervals were 1,500 ms. Thus, 500 ms time intervals led to better learning of the unique transitions than 1,500 ms time intervals.

As Figure 8 shows, the pattern obtained with the ambiguous transitions (bottom panel) was similar. That is, overall processing was slower when the time intervals were 500 ms (i.e., in the Interval Pattern 2 condition) than when they were 1,500 ms (i.e., in the Interval Pattern 1 condition). Learning, however, as indicated by the increase in RT following the introduction of the random sequences, was again more pronounced when time intervals were 500 ms. The mean increases in RT (Trial Block 9 – Trial Block 8) were now 105.5 ms when the time intervals were 500 ms and 78.6 ms when the time intervals were 1,500 ms.

A 2 (interval pattern: Interval Pattern 1 vs. Interval Pattern 2, between-subjects) x 2 (type of transition: unique vs. ambiguous, within-subject) x 2 (block of trials: 8 vs. 9, within-subject) ANOVA on subjects' RTs in Trial Block 8 (last block in training phase) and Trial Block 9 (first transfer block) yielded a reliable main effect of block of trials, $F(1, 75) = 860.71$, $MSE = 1,086.58$, $sR^2 = .92$, but no main effects of interval pattern and type of transition. In addition, the interaction between interval pattern and type of transition was reliable, $F(1, 75) = 55.77$, $MSE = 4,171.93$, $sR^2 = .43$, as was the interaction between type of transition and block of trials, $F(1, 75) = 50.29$, $MSE = 507.67$, $sR^2 = .40$. The three-way interaction among interval pattern, type of transition, and block of trials, finally, was reliable as well, $F(1, 75) = 21.18$, $MSE = 507.67$, $sR^2 = .22$.

Separate follow-up ANOVAs for the unique and ambiguous transitions demonstrated that the overall increase in RT from Block 8 to Block 9 differed reliably between the 500 ms versus 1,500 ms time intervals (i.e., the two time interval pattern conditions), as indicated by reliable interactions between interval pattern and block of trials, $F(1, 75) = 4.72$, $MSE = 847.19$, $sR^2 = .06$, and $F(1, 75) = 9.31$, $MSE = 747.06$, $sR^2 = .11$, for the unique and ambiguous transitions, respectively. Together, these analyses indicate that the manipulation of the time interval between subjects' responses and the presentation of the next stimulus affected learning of both the unique and ambiguous transitions. Both types of transitions were learned better when the time interval was 500 ms than when the time interval was 1,500 ms.

**Free-Recall and Generate Tasks: Direct Measures of Serial Learning**

**Free-recall task.** Subjects' free recall of the repeating sequence was scored according to whether the entire sequence was recalled correctly or was recalled as partially correct, as was done in Experiment 2. Again, we scored a recalled sequence as partially correct when more than two, but fewer than all six, successive locations were correctly recalled. Using this measure, 18 of the 39 subjects in the Interval Pattern 1 (5 perfect recallers) and 21 of the 38 subjects in the Interval Pattern 2 condition (9 perfect recallers) correctly recalled all or parts of the repeating sequence.

**Generate task.** Figure 9 contains the results for the generate task. The mean scores correctly predicted on the first trial of the generate task were 56.2% and 58.1% for the Interval Pattern 1 and the Interval Pattern 2 conditions, respectively. The two arcsine-transformed scores did not differ reliably ($F < 1$). Interestingly, when the experimental conditions were compared across all 20 trials of the generate task, the two conditions differed reliably, $F(1, 75) = 4.63$, $MSE = 7.94$, $sR^2 = .06$. Specifically, subjects in the Interval Pattern 2 condition performed better on the generate task than subjects in the Interval Pattern 1 condition (average prediction score over all 20 trials was 78.7% in the former group and 68.6% in the latter group). This difference is consistent with the argument that subjects in the former condition had learned the ambiguous transitions in the repeating sequence better than the unique transitions and therefore had to acquire only the relatively easy-to-learn unique transitions. Subjects in the latter condition, in contrast, had learned the unique transitions in the repeating sequence better than the ambiguous transitions and therefore still had to learn the more difficult ambiguous transitions.

In light of this argument, one may interpret the findings presented in the previous section as reflecting differences in explicit, rather than implicit, knowledge. That is, it could be argued that the 500 ms versus 1,500 ms time-interval manipulation led to differences in explicit knowledge of the repeating sequence and that these differences were responsible for differences in the RTs. As was done for Experiments 1 and 2, we therefore reran the analyses described in the previous section after discarding data from all subjects who correctly recalled parts of or the entire repeating sequence in the free-
recall task. The resulting analyses demonstrated a pattern that was qualitatively identical to that reported in the previous section. We thus conclude that, although differences in explicit knowledge may have contributed to the effects of the 500 ms versus 1,500 ms manipulation, the effects were not dependent on explicit knowledge (see Willingham et al., 1989).

Discussion

The main goal of Experiment 3 was to test the prediction that the duration of the time interval between subjects' response to a stimulus and the presentation of the next stimulus in the key-pressing task would affect serial learning. This is what we found with both the unique and ambiguous transitions within the repeating sequence. The results of Experiment 3 are therefore consistent with the assumptions that (a) the degree to which serial transitions are learned is dependent on the amount of time that the elements of the transition are simultaneously available in short-term memory and (b) a secondary task interferes with serial learning by limiting the amount of time that the elements are simultaneously available in short-term memory.

General Discussion

The main goals of the present research were to investigate empirically whether unique and ambiguous serial transitions could be learned in the presence and absence of a distractor task and to explore the potential mechanisms underlying serial learning. Experiment 1 demonstrated that both unique and ambiguous serial transitions can be learned under both single task and dual task conditions, although unique transitions are generally learned better than ambiguous patterns. Experiment 2 showed that the time of secondary task onset in the dual task condition affects how well both unique and ambiguous transitions are learned, and Experiment 3 demonstrated that the time interval between a subject's response and the presentation of the next stimulus affects learning of both the unique and ambiguous transitions. Together, these results are consistent with the argument that, under dual task conditions and in hybrid repeating sequences, serial transitions are learned to the extent that consecutive stimuli are simultaneously available in short-term memory. Also, a secondary task interferes with the learning of serial transitions by limiting the amount of time that consecutive stimuli are simultaneously available in short-term memory.

Short-Term Memory and Serial Learning

These arguments are also consistent with other findings obtained in our laboratory (Frensch & Miner, 1994) in which we examined, under both incidental and intentional single and dual task conditions, the relation between indirect measures of serial learning and two aspects of short-term memory, namely short-term memory capacity and the activation level of the to-be-learned information in short-term memory. In these experiments, short-term memory capacity was assessed individually by way of traditional memory span measures, and activation level was manipulated as rate of presentation in an RT task similar to the Nissen and Bullemer (1987) task used in the present research. Specifically, the time interval between subjects' responses and the presentation of the next stimulus (RSI) was experimentally manipulated such that RSI was equal either to 500 ms or to 1,500 ms. We found that the rate of presentation reliably affected the indirect measure of learning under both incidental and intentional task instructions and under both single task and dual task conditions. Short-term memory span was reliably related to the indirect measure of learning in some, but not all, experimental conditions.

The argument that serial transitions are learned best when consecutive stimuli are simultaneously available in short-term memory is by no means a new one, of course (see, for instance, Gollan & Shiffrin, 1984) and was anticipated by the ancient principle of association by mental contiguity. The argument should not be taken as implying that serial transitions can be learned only when the components are simultaneously available in short-term memory but rather that learning is more likely to occur under these circumstances. That transitions can be learned even if the number of intervening components exceeds a person's short-term memory span has been demonstrated rather convincingly by Ebbinghaus (1885/1964) in his early research on remote associations, for instance.

It is important to keep in mind that the present dual task results were obtained with a tone-counting distractor task and might not necessarily extend to other types of distractor tasks. Indeed, recent experimental findings by Stadler (1992a) and Goschke (1992), for example, appear to indicate that the amount of interference experienced in a dual task situation varies as a function of the type of distractor task. These results clearly emphasize the need to identify more exactly the location within short-term memory where both the primary and secondary tasks are processed. For instance, in terms of the model of short-term memory described by Baddeley (1986), the primary task could depend on the visual-spatial slave system of working memory. In contrast, the tone-counting task could more heavily depend on the phonological loop (Logie & Baddeley, 1987). Indeed, Goschke, using a visual format for the secondary tone-counting task, found virtually no implicit serial learning when the secondary task had to be accomplished after reaction to the primary stimulus. Within the framework of Baddeley's model, this performance decrement could be due to interference of information within the same subsystem.

How Many Learning Mechanisms?

A. Cohen et al. (1990) interpreted their finding that unique, but not ambiguous, sequences were learned under dual task conditions, as support for the assumption that different learning mechanisms are responsible for learning unique and ambiguous serial transitions. Unique sequences are learned by a process that associates adjacent items. Ambiguous sequences, in contrast, are learned by a mechanism that builds a hierarchic code. Because both unique and ambiguous serial transitions appeared to be learned equally well in hybrid sequences and under dual task conditions, however, A. Cohen et al. concluded that the associative learning mechanism must be a complex mechanism that was capable of learning ambigu-
ous transitions in some circumstances. Although our findings are consistent with such an interpretation, they are also consistent, however, with the argument that, at least when hybrid sequences are used, only one, presumably associative, learning mechanism might operate under both single and dual task conditions.

Such an argument is supported somewhat by the findings that the effects for the experimental manipulations in all experiments were qualitatively the same for unique and ambiguous transitions and is consistent with computational models of serial learning provided recently by Cleeremans and McClelland (1991), Frensch (1991, 1994; Frensch & Geary, 1993), and Jordan (1986; Jordan & Rumelhart, 1992), for instance.

Assuming that such an argument is at least reasonable, the finding that ambiguous transitions are not as well learned as unique transitions may simply reflect the fact that hierarchical patterns (Keele & Summers, 1976) need to be more complex than associative patterns before they can guide performance. To explain, assume the repeating sequence is 123243. Unique transitions of Length 2 are then 12 and 43. That is, given a 1, it is possible to anticipate with certainty that the asterisk will appear next at Location 2. Therefore, as soon as associative patterns of Length 2 have been formed for unique transitions, they will guide performance and reduce response times. In contrast, ambiguous transitions, such as 23 and 24, cannot guide performance until they have been disambiguated (Frensch, 1994).

Disambiguation could mean, for example, that the unique element is used as a parsing point for associative pattern learning (A. Cohen et al., 1990; Keele & Jennings, 1992). Therefore, more complex associative patterns of the form 123 and 431 may need to be formed before this knowledge can guide performance and reduce response times. The finding that unique transitions are learned better than ambiguous transitions might thus simply reflect the fact that it quite likely takes longer to form memory representations of Length 3 than to form representations of Length 2.

In the absence of conclusive empirical support, of course, the only advantage of the one-mechanism explanation over the two-mechanism explanation is one of parsimony. Clearly then, what is needed is a further empirical exploration of the properties of the learning mechanisms underlying serial learning.

References


P&C Board Appoints Editor for New Journal:

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In 1995, APA will begin publishing a new journal, the *Journal of Experimental Psychology: Applied*. Raymond S. Nickerson, PhD, has been appointed as editor. Starting immediately, manuscripts should be submitted to

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Editor, JEP: Applied
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The *Journal of Experimental Psychology: Applied* will publish original empirical investigations in experimental psychology that bridge practically oriented problems and psychological theory. The journal also will publish research aimed at developing and testing of models of cognitive processing or behavior in applied situations, including laboratory and field settings. Review articles will be considered for publication if they contribute significantly to important topics within applied experimental psychology.

Areas of interest include applications of perception, attention, decision making, reasoning, information processing, learning, and performance. Settings may be industrial (such as human–computer interface design), academic (such as intelligent computer-aided instruction), or consumer oriented (such as applications of text comprehension theory to the development or evaluation of product instructions).