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Parallel Memory Retrieval in Dual-Task Situations: II. Episodic Memory

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Three experiments asked whether subjects could retrieve information from a 2nd stimulus while they retrieved information from a 1st stimulus. Subjects performed recognition judgments on each of 2 words that followed each other by 0, 250, and 1,000 ms (Experiment 1) or 0 and 300 ms (Experiments 2 and 3). In each experiment, reaction time to both stimuli was faster when the 2 stimuli were both targets (on the study list) or both lures (not on the study list) than when 1 was a target and the other was a lure. Each experiment found priming from the 2nd stimulus to the 1st when both stimuli were targets. Reaction time to the 1st stimulus was faster when the 2 targets came from the same memory structure at study (columns in Experiment 1; pairs in Experiment 2; sentences in Experiment 3) than when they came from different structures. This priming is inconsistent with discrete serial retrieval and consistent with parallel retrieval.

This article is concerned with the possibility of parallel retrieval from episodic memory in dual-task situations. Can people begin to recognize one stimulus before they have finished recognizing another? Questions like this have been important in the memory literature since the 1960s, because they bear on the involvement of attention in retrieval and on the automaticity and capacity demands of retrieval (e.g., Baddeley, Lewis, Eldridge, & Thompson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Jacoby, 1991; Johnston, Greenberg, Fisher, & Martin, 1970; Johnston, Wagstaff, & Griffith, 1972; Martin, 1970; Moscovitch, 1994; Park, Smith, Dudley, & Lafronza, 1989; Trumbo & Milone, 1971). This specific question has become important in the attention literature recently, where it bears on the nature of processing bottlenecks in the *psychological refractory period* (PRP) procedure. Two recent sets of studies examined memory retrieval in the PRP procedure but reached opposite conclusions. Carrier and Pashler (1995) argued that subjects could not begin retrieving information from the second stimulus until they had finished retrieving information from the first stimulus, whereas Hommel (1998), Logan and Schulkind (2000), and Logan and Gordon (in press) argued they could. The purpose of this article is to attempt to resolve these opposite conclusions, first by replicating Logan and Schulkind's (2000) and Logan and Gordon's (in press) results in an episodic memory procedure that is more comparable to Carrier and Pashler's (1995) and then by providing theoretical analyses that account for both sets of results. Following those analyses, we relate the results and conclusion to broader issues in the memory literature, concerning attention, automaticity, and capacity demands in retrieval.

The Psychological Refractory Period and Memory Retrieval

The PRP procedure involves two stimuli, S1 and S2, presented with some interval between their onsets (stimulus onset asynchrony or SOA), usually between 0 and 1,000 ms. Subjects perform Task1 on S1 to produce response R1 with latency RT1 and Task2 on S2 to produce response R2 with latency RT2. Stimuli and responses are usually discrete, so timing can be controlled very carefully and measured very accurately. Typically, RT2 is strongly affected by SOA, increasing sharply with a slope approaching -1 as SOA approaches 0. By contrast, RT1 is usually unaffected by SOA, as if subjects "protect" it, concentrating dual-task interference on RT2 (for reviews see Bertelson, 1966; Kahneman, 1973; Pashler, 1994; Smith, 1967; Welford, 1952).

Locus of Slack Logic

Much of the research on the PRP is organized around a conceptual framework called the *locus of slack logic* (Pashler & Johnston, 1989; Schweickert, 1978; Schweickert & Townsend, 1989; Townsend & Schweickert, 1989). The logic assumes that Task1 and Task2 can each be described in terms of a series of processing stages that extends from stimulus to response. One of the stages, shared by the two tasks, is a *processing bottleneck* that can only serve one task at a time. Much of the research on the PRP has been devoted to discovering the locus of the bottleneck in terms of the processing stages that underlie performance. A great deal of evidence suggests that the *response selection* stage, which chooses among alternative response categories, is the major bottleneck in the PRP procedure (for a review, see Pashler, 1994; for a dissenting view, see Meyer & Kieras, 1997). The *perceptual encoding* stage, which forms a "cleaned-up" representation of the stimulus, is prior to response selection and prior to the bottleneck (also see Pashler, 1994).

Since discovering the response-selection bottleneck, researchers have been trying to discover other processes or other computational functions that produce central bottlenecks. For example, Jolicoeur and colleagues have argued that consolidation of traces in short-term memory involves a central bottleneck similar to the

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one seen in the PRP task (Jolicoeur, 1998, 1999a, 1999b; Jolicoeur & Dell'Acqua, 1998, 1999). The research on memory retrieval in the PRP task was carried out for the same purpose, to delineate the properties and computational functions of the central bottleneck. One intriguing possibility is that there is a single central bottleneck that is responsible for all limitations on central processing. Alternatively, there may be different bottlenecks for different central processes.

If there is a single central bottleneck, the question addressed in the present experiments is particularly crucial. The formal arguments underlying the locus of slack logic assume explicitly that the bottleneck stage is serial and discrete (Schweickert, 1978; Schweickert & Townsend, 1989; Townsend & Schweickert, 1989). Thus, if memory retrieval is performed by the central bottleneck, then retrieval from S1 and S2 should also be serial and discrete. It should not be possible to retrieve information about S2 before finishing retrieval of information about S1. Evidence to the contrary would challenge the idea that retrieval is a discrete processing stage, and that would challenge a fundamental assumption underlying the locus of slack logic. Potentially, such evidence could undermine the conceptual framework upon which much of the current PRP research is based and cause it to collapse.

The locus of slack logic hinges on the assumption that the processing bottleneck is a serial, discrete stage that cannot begin processing S2 until it has finished processing S1. On this assumption, Task2 has to wait until Task1 is finished with the bottleneck, and the time spent waiting is called *slack*. By contrast, Task2 processes before the bottleneck can go on in parallel with Task1. There is no need to wait and, thus, no slack in the prebottleneck processes. Slack occurs only before the bottleneck stage, so the bottleneck can be localized by experimental manipulations that uncover the locus at which slack occurs.

The locus of slack can be identified in terms of interactions between SOA and factors that affect Task2 difficulty. Factors that affect Task2 processes before the bottleneck will interact *underadditively* with SOA, producing smaller effects at shorter SOAs. Factors that affect Task2 processes at or after the bottleneck will produce null interactions with SOA; the joint effects will be additive (Pashler, 1984; Pashler & Johnston, 1989; Schweickert, 1978; Schweickert & Townsend, 1989; Townsend & Schweickert, 1989).

Task2 difficulty factors that affect processes prior to the bottleneck produce underadditive interactions because their effects are "absorbed into the slack" when SOA is short but not when SOA is long. Prebottleneck processes can go on in parallel, and so continue to operate during the slack period when Task1 occupies the bottleneck. If SOA is short and the slack period is long, both easy and hard versions of Task2 prebottleneck processing may have time to finish during the slack time, so there would be no effect of Task2 difficulty in RT2. If SOA is long enough that there is no waiting, then neither the easy version nor the hard version can finish during the slack period, so Task2 difficulty should affect RT2. Together, the predictions for short and long SOAs predict an underadditive interaction between SOA and prebottleneck Task2 difficulty factors.

Task2 difficulty factors that affect bottleneck or postbottleneck processes will not interact with SOA because they cannot begin until Task2 gets access to the bottleneck stage. Once Task2 gets access to that stage, there is no further slack to absorb the difficulty effects. The difference between the easy and hard versions will be the same at each SOA (i.e., the Task2 Difficulty × SOA interaction will be null; see Pashler & Johnston, 1989; Schweickert, 1978; Schweickert & Townsend, 1989; Townsend & Schweickert, 1989).

Carrier and Pashler (1995)

Carrier and Pashler (1995) used the locus of slack logic to examine parallel retrieval from episodic memory in the PRP procedure. Task1 was tone discrimination; subjects had to indicate whether S1 was high or low in pitch. In one experiment, Task2 was cued recall. Subjects saw a word and had to report the word that was associated with it in a previous study period. Retrieval difficulty was manipulated by presenting words once or twice. The key result was the null interaction between retrieval difficulty and SOA in the RT2 data. The effects were clearly additive. In a second experiment, Task1 was also tone discrimination but Task2 was recognition instead of cued recall. Retrieval difficulty was manipulated by presenting words zero, one, or five times at study. The results replicated Experiment 1. The RT2 interaction between SOA and frequency of presentation was null. The difficulty effect was the same magnitude at each SOA. In terms of the locus of slack logic, these null interactions suggest that memory retrieval is a bottleneck or postbottleneck process. These results suggest that memory retrieval cannot go on in parallel with Task1 response selection; memory retrieval and response selection are serial and discrete.

Crosstalk From Task2 to Task1

The locus of slack logic makes assumptions about the time at which retrieval begins but bases its inferences on measures of the time at which retrieval finishes (i.e., in terms of retrieval difficulty effects in RT2). Recently, several researchers have developed a *crosstalk logic* that measures the time at which retrieval begins in order to test the assumption about starting times inherent in the locus of slack logic. For example, Logan and Schulkind (2000) ran a PRP experiment in which S1 and S2 were both single digits and subjects had to make a parity (odd vs. even) judgment about S1 and another parity judgment about S2. RT1 and RT2 were both faster when S1 and S2 were in the same category (*congruent*; both odd or both even) than when they were in different categories (*incongruent*; one odd and one even). Similar results have been found with letter-digit discrimination (Logan & Schulkind, 2000), digit magnitude discrimination (Logan & Gordon, 2001; Logan & Schulkind, 2000), form judgments (picture vs. word; Logan & Gordon, in press), animacy judgments (Logan & Gordon, in press), Stroop interference (Hommel, 1998; Logan & Gordon, in press), and lexical decisions (Logan & Schulkind, 2000).

These congruency effects represent *crosstalk* between tasks, in that the stimulus for one task influences the categorization of the stimulus for the other task. The RT1 effects are particularly interesting because they suggest that subjects can retrieve the category that S2 belongs to before they finish retrieving the category that S1 belongs to. This suggests that retrieval from semantic memory is not discrete and serial.

The crosstalk logic depends on a basic property of discrete serial processes: They cannot start until the processes that precede them finish. The discreteness implies that serial discrete processes cannot be influenced by processes that have not yet finished because those processes have not yet begun. By contrast, a basic property of parallel processes is that they can start before other processes have finished. Thus, parallel processes can be influenced by processes that have not finished yet, if those processes start before the processes in question finish (Townsend & Ashby, 1983). From this perspective, subjects in the crosstalk experiments must have retrieved information about the category membership of S2 while they were retrieving information about the category membership of S1.

Critical Differences

Carrier and Pashler's (1995) experiments differ from the crosstalk experiments (i.e., Hommel, 1998; Logan & Gordon, in press; Logan & Schulkind, 2000) in several ways, three of which may be critical. First, Carrier and Pashler studied retrieval from episodic memory (recognition and cued recall), whereas the crosstalk experiments studied retrieval from semantic memory. To address Carrier and Pashler's experiments directly, we must replicate the crosstalk procedure with an episodic memory task.

Second, in Carrier and Pashler's (1995) experiments, the task set changed from Task1 to Task2. Task1 was always tone discrimination. Task2 was either cued recall or recognition. The crosstalk experiments found evidence of parallel retrieval only when the task set was the same for S1 and S2; when the task set was different, there was no evidence of parallel retrieval (Logan & Gordon, in press; Logan & Schulkind, 2000). For example, Logan and Schulkind (2000) presented digits as S1 and S2, had subjects perform parity judgments or magnitude judgments (greater or less than 5) on them, and found crosstalk from S2 to S1 only when the task set was the same (i.e., Task1 and Task2 were both parity judgments or both magnitude judgments). When the task set was different (i.e., Task1 parity and Task2 magnitude or vice versa), there was no crosstalk, even though stimulus conditions were identical. Changing sets between tasks appeared to block retrieval (also see Logan & Gordon, in press). It may be that Carrier and Pashler failed to find evidence of parallel retrieval because the set to discriminate tone pitch for Task1 may have blocked retrieval of episodic information associated with S2. Thus, to find evidence of parallel retrieval, we should examine a situation in which both Task1 and Task2 are episodic memory tasks.

Third, Carrier and Pashler's (1995) conclusions derive from the locus of slack logic, which focuses on interactions between Task2 difficulty factors and SOA, whereas Hommel's (1998), Logan and Schulkind's (2000), and Logan and Gordon's (in press) conclusions derive from an analysis of crosstalk from S2 to S1, which focuses on Task1 rather than Task2. The crosstalk logic provides evidence about the time at which retrieval begins, which is the main issue in these experiments, so we used it instead of the locus of slack logic to design our experiments and interpret our data.

The Present Experiments

The present experiments adapted the crosstalk procedures to an episodic memory task: judgment of recognition. Subjects studied lists of words (Experiment 1), lists of word pairs (Experiment 2), and lists of sentences (Experiment 3) and then performed a PRP experiment in which S1 and S2 were both words. Task1 and Task2 were both recognition judgments. Subjects had to indicate separately whether S1 was old or new (on the study list or not) and whether S2 was old or new. We manipulated SOA between S1 and S2 (0, 250, or 1,000 ms in Experiment 1 and 0 or 300 ms in Experiments 2 and 3) to see if we would replicate the standard PRP effects.

Our main focus was on the possibility of crosstalk from Task2 to Task1, because it would rule out serial discrete-stage retrieval. We examined crosstalk in two ways: one general and one specific. First, we examined general crosstalk by looking at the congruency of S1 and S2. In congruent trials, S1 and S2 were both old or both new. In incongruent trials, S1 was old and S2 was new or vice versa. If information about the memorial status of S2 can be retrieved while subjects are processing S1, then there should be a congruency effect on RT1. RT1 should be faster when S1 and S2 are both old or both new than when one is old and the other is new. By contrast, if information about the memorial status of S2 cannot be retrieved while subjects are processing S1—if memory retrieval is serial and discrete—then there should be no crosstalk from Task2 to Task1. RT1 should be the same whether S1 and S2 are congruent or incongruent.

Second, we examined specific crosstalk by looking for *episodic priming* (McKoon & Ratcliff, 1979, 1980; Neely & Durgunoglu, 1985; Ratcliff & McKoon, 1978, 1981) from S2 to S1. Logan and Schulkind (2000) found semantic priming from S2 to S1 in dual lexical-decision tasks, so we looked for the episodic analogue of semantic priming in our experiments. The study items were presented in structures that may be preserved in episodic memory. In Experiment 1, the structures were three columns of four words; in Experiment 2, they were word pairs; and in Experiment 3, they were sentences. We selected trials in which S1 and S2 were both old and separated them into trials in which S1 and S2 came from the same memory structure and trials in which S1 and S2 came from different memory structures. Dell, Ratcliff, and McKoon (1981), McKoon and Ratcliff (1979), and Neely and Durgunoglu (1985) showed that reaction time (RT) was faster in successive recognition judgments when the two words came from the same memory structure than when they came from different memory structures. If subjects can retrieve associations specific to the structure that S2 came from while they are processing S1, RT1 should be faster when the words come from the same memory structure. We analyzed episodic priming post hoc in Experiment 1. Experiments 2 and 3 were designed specifically to test for episodic priming from S2 to S1.

We did not expect memory performance to be perfect. Accuracy should be much lower than the conventional 90% or 95% correct in typical RT studies, and low accuracy challenges the interpretation of RT. We dealt with this challenge by running different replications of the same experiment varying the number of study trials each item received. Experiment 1 was run in three replications, and Experiment 2 was run in two replications. In one replication, subjects studied each item only once. In another replication, subjects studied the same set of items throughout the experiment. We expected higher accuracy when items were studied repeatedly, and we hoped to see the same patterns in the RT data (i.e., crosstalk) in all versions of the experiment.

Experiment 1

The first experiment looked for crosstalk between recognition judgments performed on S1 and S2. Subjects performed a series of 14 study-test blocks. In the study block, a list of 12 words was presented, organized in three columns of four words. Subjects were told to study the words until they were ready to be tested on them. Study time was recorded. When subjects were ready, a series of 12 PRP trials began. Each PRP trial presented two words as S1 and S2 with an SOA of 0, 250, or 1,000 ms between them. Task1 was to decide whether S1 appeared on the study list; Task2 was to decide whether S2 appeared on the study list.

We ran three replications of Experiment 1. In Experiment 1a, subjects saw a new list of *targets* (old items) in each study block, and they saw new *lures* (new items) in each test block, mimicking standard practice in memory research. Experiment 1b was the same in all respects, except that the same set of targets and lures were used throughout the experiment. Subjects saw the same list of targets in each of the 14 study blocks, and they were tested against the same lures in each of the 14 test blocks. Experiment 1c was the same as well, except that the target items repeated throughout the experiment and a new set of lures was presented in each test block.

If retrieval can be parallel, as the crosstalk experiments suggest (Hommel, 1998; Logan & Gordon, in press; Logan & Schulkind, 2000), then subjects should be able to retrieve something about the memorial status of S2 while they are processing S1 and, consequently, produce crosstalk in RT1. If retrieval is serial and discrete, as Carrier and Pashler (1995) suggested, then there should be no crosstalk from S2 to S1.

Method

Subjects. The subjects were 96 volunteers from an introductory psychology course who served for course credit. There were 32 subjects in each of the three replications of the experiment.

Apparatus and stimuli. The stimuli were sampled at random for each subject from a pool of 339 five-letter nouns selected from the Kučera and Francis (1967) word frequency norms. The mean frequency was 75.27 per million, and the range was 8 to 787 per million. On a study trial, 12 words were selected and displayed in three columns of four words in lowercase. In Experiment 1a, a different set of 12 study words (targets) was selected for each study trial. In Experiments 1b and 1c, one set of 12 study words (targets) was selected at the beginning of the experiment and was presented on each study trial, occupying the same position in the 3 × 4 matrix on each presentation. The three columns were centered in the computer screen. In the coordinates of the IBM 80-row × 24-column text screen, the leftmost column began at row 11, column 20; the center column began at row 11, column 30; and the rightmost column began at row 11, column 40. The next words in each column appeared in rows 12, 13, and 14. The top of the screen contained a message, beginning at row 8 and column 10, that said "STUDY THIS LIST." The bottom of the screen contained a message, beginning in row 21, column 10, that said "PRESS SPACE BAR WHEN YOU ARE READY TO BE TESTED." The study list was exposed until subjects pressed the space bar, whereupon the screen was replaced by a blank screen and a 2,000-ms delay elapsed before the first test trial began. The time required to study the list was recorded in 16ths of a second.

On each test trial, there were three displays if SOA was zero and four displays if SOA was greater than zero. The first display was a fixation display, consisting of two rows of four dashes separated by spaces (i.e., - - - -). One row began in row 12, column 35; the other began in row 15, column 35. The fixation display was exposed for 500 ms, whereupon it was extinguished and replaced by the next display. If SOA was zero, the next display contained two words in lowercase that appeared between the positions of the two rows in the fixation display, one beginning in row 13, column 36, and one beginning in row 14, column 36. This two-word display was exposed for a 1,000-ms period, and then it was extinguished and replaced by a blank screen, which stayed on for 3,500 ms, until the next trial began. If SOA was greater than zero, the display after fixation contained one lowercase word in the top position (beginning at row 13, column 36). It was exposed until the SOA expired, whereupon it was replaced by a display containing two lowercase words, one beginning in row 13, column 36 and one beginning in row 14, column 36. From the subject's perspective, it looked like the first word stayed on throughout both displays and was joined by the second word after the SOA. The two-word display was exposed for 1,000 ms and then extinguished and replaced by a blank screen, which remained on for 3,500 ms until the next trial began.

The stimuli were displayed on Gateway 2000 Crystalscan 1024 NI monitors controlled by Gateway 2000 486 computers. Subjects responded to the top stimulus by pressing the period key with the index finger of their right hand or the slash key with the middle finger of their right hand. They responded to the bottom stimulus by pressing the *X* key with the index finger of their left hand or the *Z* key with the middle finger of their left hand. Timing was accurate to 1 ms. SOA was 0, 250, or 1,000 ms.

Procedure. The experiment consisted of 14 study-test blocks. Each block began with the exposure of a 12-word study list, which subjects were told to read to themselves at least three times before proceeding. When they were ready, they initiated the test trials by pressing the space bar. Then they received 12 PRP trials, in which they saw two words separated by an SOA of 0, 250, or 1,000 ms, and their task was to make a separate recognition judgment about each word. They were told explicitly to respond to S1 (the top word) before S2. Each word on the study list was presented once in the set of test trials. There were four different trial types at each SOA, defined by the type of words that were presented. On target-target trials, both S1 and S2 appeared in the study list. On lure-lure trials, neither S1 nor S2 appeared on the study list. On target-lure trials, S1 appeared on the study list and S2 did not. On lure-target trials, S1 did not appear on the study list but S2 did. The order of these trials and SOAs was randomized separately for each subject. At the end of the experiment, subjects were asked to recall the words on the last study list by writing them down on a piece of paper.

Subjects were allowed to rest after the test trials on Blocks 1, 2, 5, and 10. The experimenter stayed in the room for Blocks 1 and 2 to be sure the subjects knew how to perform the task properly. Subjects were tested in groups of two or three on separate computers that faced orthogonal walls of a large room.

In Experiment 1a, a new set of targets was sampled on each study trial and a new set of lures was used in each set of test trials. In Experiment 1b, one set of targets and one set of lures were selected at the beginning of the experiment and used in all 14 blocks. In Experiment 1c, one set of targets was selected at the beginning of the experiment and used in all 14 blocks, but a new set of lures was selected for each set of test trials.

There were four rules for mapping recognition decisions onto response keys. Eight subjects in each replication of the experiment used each rule. From left to right, the rules were TLTL, TLLT, LTTL, and LTLT, where T = target and L = lure. Subjects were told to rest their fingers lightly on the response keys throughout each test block.

Data analysis. We computed mean RT and accuracy for each subject in each combination of conditions, and we analyzed them in 3 (replications: Experiments 1a, 1b, and 1c) × 2 (target or lure) × 2 (congruent [both targets or both lures] or incongruent [one target and one lure]) × 3 (SOA: 0, 250, and 1,000 ms) analyses of variance (ANOVAs). We performed separate ANOVAs for RT1 and RT2, and for R1 accuracy and R2 accuracy. The accuracy scores were hit rates for target trials and correct rejection rates for lure trials. The summary tables for these ANOVAs are presented in Table 1. The RT ANOVAs in Table 1 are based on analyses in which RTs were included only if both R1 and R2 were correct. The accuracy ANOVAs in Table 1 are based on analyses in which accuracy was scored independently for R1 and R2.

Results

The mean RTs in each replication of the experiment are presented in Figure 1 as a function of SOA and congruency. The left-hand panels (A, C, and E) present RTs to targets; the right-hand panels (B, D, and F) present RTs to lures. Within each panel, the solid lines represent RT1 and the broken lines represent RT2. The mean hit rates and correct rejection rates for each replication of the experiment are presented as a function of SOA and congruency in Table 2.

Effects of replication. Subjects spent an average of 232.55, 118.77, and 93.98 s studying the memory lists in Experiments 1a, 1b, and 1c, respectively. We performed a one-way ANOVA on the study times with replications as a between-subjects factor, and found a significant main effect of replications, $F(2, 93) = 60.88$, $p < .01$, $MSE = 2{,}870.14$. Subsequent least significant difference (LSD$_{.05}$) tests showed that each replication differed significantly from the others.

The mean number of targets recalled after the last test block was 4.5, 9.8, and 9.4 for Experiments 1a, 1b, and 1c, respectively. We performed a one-way ANOVA on these data with replications as a between-subject factor and found a significant main effect of replication, $F(2, 93) = 47.81$, $p < .01$, $MSE = 5.89$. Subsequent LSD$_{.05}$ tests showed that Experiment 1a differed from Experiments 1b and 1c, which did not differ from each other.

As we anticipated, accuracy was not very high in the PRP test blocks, particularly when study items were presented only once. To compare accuracy on the recognition task with the kind of accuracy measure that is standard in the PRP literature, we averaged the probability of a correct "old" judgment (hit rate) and the probability of a correct "new" judgment (correct rejection). For R1, the average value was 0.79, 0.82, and 0.88 for Experiments 1a, 1b, and 1c, respectively. For R2, the average value was 0.77, 0.83, and 0.87 for Experiments 1a, 1b, and 1c, respectively. The replication effect was significant for both R1 and R2 (see Table 1).

Across replications of the experiment, RT covaried with accuracy, being faster when accuracy was higher. The average values were 1,175, 1,114, and 1,006 ms for RT1 and 1,339, 1,274, and 1,113 ms for RT2 for Experiments 1a, 1b, and 1c, respectively.

Table 1
Summary Tables for Analyses of Variance From Experiment 1

Effect	*df*	*MSE*	*F*	*MSE*	*F*
		RT1		RT2	
E	2, 93	1,111,719.16	2.52	993,151.36	5.26*
T	1, 93	25,107.19	39.56*	27,624.76	1.26
E × T	2, 93	25,107.19	2.85	14,400.14	2.71
C	1, 93	18,141.93	29.27*	32,343.61	92.53*
E × C	2, 93	18,141.93	0.22	32,343.61	0.07
T × C	1, 93	23,492.02	1.17	18,924.62	16.05*
E × T × C	2, 93	23,492.02	2.85	18,924.62	6.70*
S	2, 186	39,802.72	11.62*	36,460.20	973.03*
E × S	4, 186	39,802.72	2.25	36,460.20	1.76
T × S	2, 186	15,183.18	0.18	16,202.51	1.16
C × S	4, 186	16,198.85	18.90*	18,713.61	33.46*
E × T × S	4, 186	15,183.18	0.91	16,202.51	0.88
E × C × S	4, 186	16,198.85	0.62	18,713.61	0.82
C × S × T	2, 186	14,400.14	2.07	14,388.83	0.25
E × C × S × T	4, 186	14,400.14	0.52	14,388.83	1.96
		R1		R2	
E	2, 93	1,499.78	6.24*	1,120.70	8.39*
T	1, 93	239.54	0.08	253.76	15.03*
E × T	2, 93	239.54	12.36*	253.76	11.97*
C	1, 93	90.41	22.74*	147.85	21.78*
E × C	2, 93	90.41	2.04	147.85	2.91
T × C	1, 93	84.15	4.70*	75.28	15.36*
E × T × C	2, 93	84.15	0.73	75.28	0.97
S	2, 186	77.16	14.95*	132.66	14.88*
E × S	4, 186	77.16	0.36	132.66	1.54
T × S	2, 186	72.28	0.19	60.55	0.45
C × S	4, 186	71.59	2.60	94.76	1.75
E × T × S	4, 186	72.28	0.69	60.55	0.56
E × C × S	4, 186	71.59	0.91	94.58	0.64
C × S × T	2, 186	56.74	2.20	69.21	1.12
E × C × S × T	4, 186	56.74	0.45	69.21	0.34

Note. E = experiment; T = target or lure; C = congruency; S = stimulus onset asynchrony.
* $p < .05$.

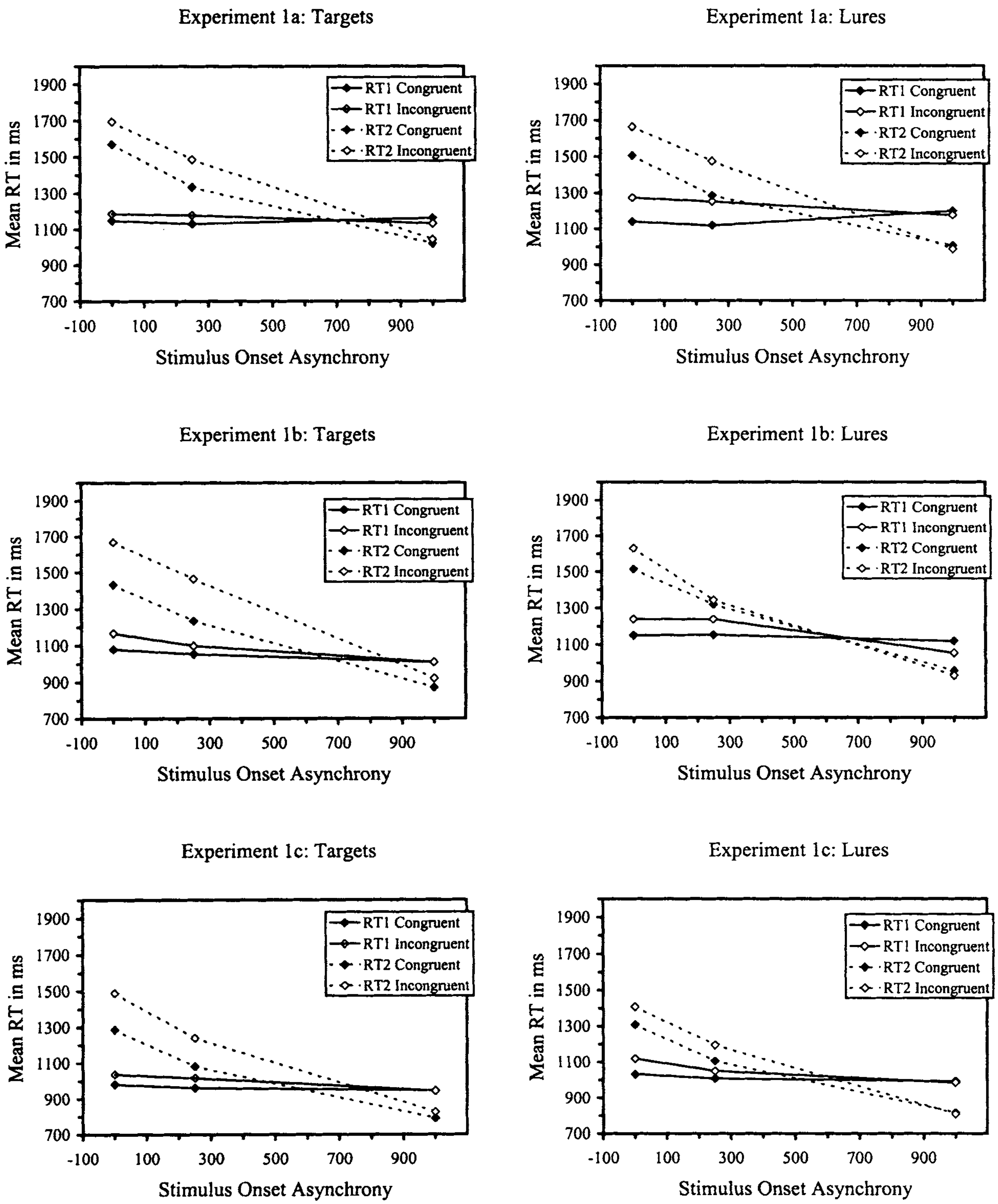

Figure 1. Mean reaction time (RT) to the first stimulus (RT1, solid lines) and the second stimulus (RT2, broken lines) in Experiments 1a, 1b, and 1c as a function of stimulus onset asynchrony for targets and lures. Response congruity—same (filled diamonds) versus different (open diamonds)—is the parameter.

Table 2
Accuracy Scores (Hit Rates for Targets, Correct Rejection Rates for Lures) for R1 and R2 in Experiments 1a, 1b, and 1c as a Function of Stimulus Onset Asynchrony (SOA)

SOA	Target same	Target diff.	Lure same	Lure diff.
		Experiment 1a: R1		
0	0.76	0.71	0.81	0.78
250	0.79	0.76	0.85	0.78
1,000	0.77	0.77	0.87	0.81
		Experiment 1a: R2		
0	0.74	0.65	0.81	0.76
250	0.77	0.70	0.84	0.81
1,000	0.79	0.72	0.86	0.85
		Experiment 1b: R1		
0	0.84	0.82	0.79	0.75
250	0.83	0.84	0.81	0.78
1,000	0.85	0.88	0.82	0.79
		Experiment 1b: R2		
0	0.84	0.81	0.81	0.81
250	0.83	0.81	0.83	0.80
1,000	0.88	0.86	0.83	0.86
		Experiment 1c: R1		
0	0.90	0.84	0.89	0.84
250	0.89	0.89	0.88	0.86
1,000	0.91	0.90	0.91	0.88
		Experiment 1c: R2		
0	0.88	0.79	0.89	0.87
250	0.87	0.83	0.89	0.89
1,000	0.91	0.85	0.90	0.90

Note. diff. = different.

The RT2 effects were significant, but the RT1 effects were not (see Table 1). Despite these differences, the patterns of SOA and crosstalk effects were very similar across replications of the experiment. There were seven interactions involving replications of the experiment in each ANOVA presented in Table 1. Of the 28 interactions involving replication in the four ANOVAs, only 3 were significant (Replications × Target vs. Lure × Congruency in the RT2 ANOVA and Replications × Target in the R1 and R2 accuracy ANOVAs).

Basic PRP effects. The RT data showed the standard PRP effects in each version of the experiment. RT1 was not affected much by SOA, but RT2 was strongly affected. Averaged over the three versions of the experiment, RT2 dropped 218 ms as SOA increased from 0 to 250 ms, yielding a slope of −0.87, which is close to the theoretically expected slope of −1.0. By contrast, RT1 dropped by 26 ms over the same range; the RT2 effect was almost an order of magnitude larger. The SOA effect was significant in both RT1 and RT2 ANOVAs, but the *F* ratio was an order of magnitude larger in the RT2 ANOVA (see Table 1).

There were also SOA effects in the accuracy data. R1 accuracy increased from 0.81 to 0.85 as SOA increased from 0 to 1,000 ms. R2 accuracy increased by the same amount. This result points out the importance of timing in dual-task situations (also see Pashler, 1994).

Crosstalk. To analyze crosstalk between S1 and S2, we separated RT1 and RT2 into trials in which S1 and S2 were *congruent* (both targets or both lures) and trials in which S1 and S2 were *incongruent* (one target and one lure). Crosstalk is evidenced by a difference between congruent and incongruent conditions. By this criterion, there was substantial crosstalk from S2 to S1 in the RT1 data (M = 43 ms) and even more crosstalk from S1 to S2 in the RT2 data (M = 102 ms). The main effect of congruency was significant in both the RT1 and RT2 ANOVAs (see Table 1). The congruency effect appeared in the RT1 and RT2 data from each replication of the experiment. Its magnitude was about the same in each replication, despite variation between replications in overall RT and accuracy.

Crosstalk was stronger at short SOAs than at the long one for both RT1 and RT2. To assess the significance of the crosstalk effects, we computed Fisher's LSD for $p < .05$ using the error term from the highest order interaction (Replications × Target × Congruency × SOA; see Table 1). For RT1, the critical value was 34 ms. By this criterion, the crosstalk effect was significant at the 0- and 250-ms SOA for each replication of the experiment for both targets and lures (Experiments 1a, 1b, and 1c). The effect at the 1,000-ms SOA was not significant in any condition except for lures in Experiment 1b, where it was significantly negative.

For RT2, the critical LSD$_{.05}$ value was 34 ms. By this criterion, the crosstalk effect was significant at the 0-ms SOA for targets and lures in each replication. It was significant at the 250-ms SOA for all conditions except lures in Experiment 1b, where it was nonsignificant. The effect was significant at the 1,000-ms SOA in Experiment 1b, targets, and in Experiment 1c, targets. It was not significant in the remaining conditions.

We assessed crosstalk in the accuracy data by separating hits and correct rejections into congruent and incongruent conditions, as we did with the RT data. The means in each replication for targets (hit rates) and lures (correct rejection rates) are presented in Table 2. Overall, R1 accuracy was significantly higher (by 0.03) when S1 and S2 were congruent than when they were incongruent. The same was true of R2 (by 0.03). Crosstalk tended to be stronger at the short SOAs, averaging 0.04 for R1 and 0.05 for R2 at SOA = 0.

Episodic priming. This experiment was not designed to test for episodic priming, so our analysis is post hoc and the conditions relevant to episodic priming were not systematically balanced across SOA, and so on. Nevertheless, we proceeded. Our post hoc analysis motivated a more systematic investigation in Experiments 2 and 3. We assumed that subjects may have picked up the three-column structure of the word lists in the study trials. We separated target-target test trials from the rest and divided them into those in which S1 and S2 came from the same column (*related* trials) and those in which S1 and S2 came from different columns (*unrelated* trials). We included only trials with SOA = 0 or SOA = 250 because these were the only trials that showed the general crosstalk effect. The means across subjects are presented in Table 3.

There was a small amount of episodic priming. Averaged over replication, RT1 was 19 ms faster when S1 and S2 came from the same column, and RT2 was 23 ms faster. The main effect of relatedness was not significant in a 3 (replication) × 2 (RT1 vs.

Table 3
Episodic Priming Effects in RT1 and RT2 and in R1 and R2 Accuracy in Experiments 1a, 1b, and 1c

	Exp. 1a	Exp. 1b	Exp. 1c
	RT1		
Related	1,132	1,051	960
Unrelated	1,145	1,079	978
Priming	13	29*	18*
	RT2		
Related	1,415	1,306	1,132
Unrelated	1,129	1,322	1,172
Priming	14	16	40*
	R1 accuracy		
Related	0.77	0.86	0.95
Unrelated	0.78	0.82	0.88
Priming	−0.01	0.04*	0.07*
	R2 accuracy		
Related	0.77	0.90	0.91
Unrelated	0.75	0.82	0.87
Priming	0.02	0.08*	0.04*

Note. Exp. = experiment.
$^*p < .05$.

RT2) × 2 (related vs. unrelated) ANOVA on the RT data, but we analyzed the relatedness effect in each replication by calculating $\mathrm{LSD}_{.05}$ from the highest order interaction (*MSE* = 3,911.64). The critical value was 18 ms. By this criterion, episodic priming was significant in RT1 in Experiments 1b and 1c and significant in RT2 in Experiment 1c (see Table 3). Thus, episodic priming was stronger when the three-column structure was presented 14 times (Experiments 1b and 1c) than when it was presented only once (Experiment 1a).

The accuracy results were more robust. Averaged over replication, R1 was 0.03 more accurate when S1 and S2 came from the same column, and R2 was 0.05 more accurate. The main effect of relatedness was significant in the accuracy ANOVA, $F(1, 93) = 13.66$, $p < .01$, *MSE* = 116.85. Again, we computed $\mathrm{LSD}_{.05}$ from the highest order interaction. The critical value was 0.025. By this criterion, there was significant episodic priming for R1 and for R2 in Experiments 1b and 1c (see Table 3). Again, episodic priming was stronger when the structure was repeated more often.

Discussion

RT and accuracy varied across replications of the experiment. Performance was faster and more accurate when targets were repeated (Experiments 1b and 1c) than when new targets appeared on each study list (Experiment 1a). Nevertheless, the same pattern of SOA and crosstalk effects appeared in each replication. The standard PRP effects obtained: RT2 was strongly affected by SOA, while RT1 was weakly affected. The most important results with respect to the goals of this article were the crosstalk effects, particularly crosstalk effects in RT1 and R1 accuracy. We found strong crosstalk for both responses in each replication of the experiment. RT1 was faster when S1 and S2 were both targets than when one was a target and the other was a lure. R1 accuracy was higher in the same conditions. This crosstalk is consistent with parallel retrieval: Subjects must have retrieved information from S2 while processing S1, because the memorial status of S2 affected RT1 and R1 accuracy. The crosstalk is inconsistent with serial discrete retrieval, which predicts no crosstalk from S2 to S1 because S2 retrieval cannot start until S1 retrieval is finished.

The episodic priming effects observed at the 0- and 250-ms SOAs provide converging evidence against serial discrete retrieval. Subjects were faster and more accurate to respond on target-target trials if both targets came from the same memory structure (display column) than if they came from different ones. In order for episodic priming to occur, subjects must have retrieved information from S2 while they were processing S1, and this is inconsistent with the hypothesis that retrieval is serial and discrete. The episodic priming effects were not very strong, however. Their weakness could be due to the post hoc nature of the analyses. We did not balance factors like SOA with target-target relatedness, and that may have weakened the effects. Also, the columnar structure of the displays may not have been very compelling as an organization for encoding into memory. Episodic priming is typically observed with word pairs and sentences as structures. Consequently, we replicated the experiment with a more careful manipulation of target-target relatedness.

Experiment 2

The second experiment looked for specific and general crosstalk between recognition judgments performed on S1 and S2. We manipulated congruency between S1 and S2 to assess general crosstalk effects, as in Experiment 1. If there is crosstalk, RT1 and RT2 should be faster and R1 and R2 should be more accurate when S1 and S2 are congruent than when they are incongruent. We manipulated target-target relatedness to assess specific crosstalk effects, looking for episodic priming. There were 10 study-test blocks. Each study trial presented eight pairs of words. Following the study trial, there were 16 PRP trials in which subjects performed recognition judgments on S1 and S2. There were two SOAs: 0 and 300 ms. There was an equal number of target-target, target-lure, lure-target, and lure-lure trials at each SOA. We manipulated relatedness in the target-target trials. Half of the target-target trials at each SOA involved two words from the same pair (related), and half involved two words from different pairs (unrelated).

If retrieval is parallel, we should expect crosstalk effects and episodic priming. If retrieval is serial and discrete, we should expect no crosstalk effects and no episodic priming. As before, the RT1 and R1 data are the most critical in contrasting these hypotheses. RT1 cannot be affected by Task2 processes that have not begun.

We conducted two separate replications of the experiment. Experiment 2a used new targets and new lures in each study-test block, whereas Experiment 2b used the same targets for each study-test block but presented new lures in each test block. As in Experiment 1, we expected RT to be faster and accuracy to be higher when targets are presented repeatedly. Our goal was to see if the critical crosstalk and episodic priming effects would replicate across variation in baseline RT and accuracy.

Method

Subjects. The subjects were 64 volunteers from an introductory psychology course who served for course credit. There were 32 subjects in each of the two replications of the experiment.

Apparatus and stimuli. The apparatus and stimuli were essentially the same as those used in Experiment 1. We used 320 of the words from the list we used in Experiment 1 to construct two lists of 160 word pairs. Each list was constructed by randomly pairing the 320 words. Half of the subjects in each replication used one list of pairs, and the other half used the other list of pairs. Within each list, the assignment of pairs to conditions (SOA, congruency, relatedness) was randomized for each subject.

On study trials, target words were presented in eight rows of two, beginning at row 4 column 20 of the IBM text screen. There were two spaces between the words in a pair. As before, the message "STUDY THIS LIST" appeared at the top of the screen, beginning in row 2, column 10, and the message "PRESS SPACE BAR WHEN YOU ARE READY TO BE TESTED" appeared at the bottom of the screen, beginning in row 22, column 10. In Experiment 2a, a new study list appeared on each study trial. In Experiment 2b, the same study list appeared on each study trial. To facilitate organization of the study list in terms of pairs, the order of the pairs in the study list was randomized before each presentation. The pairs remained the same, but their serial positions changed.

The test trials were the same as in Experiment 1 except that there were two SOAs: 0 and 300 ms.

Procedure. The procedure was essentially the same as in Experiment 1. Subjects were told to read each pair on the study list three times before proceeding to the test trials. There were 10 study-test blocks, and each block involved 16 PRP trials, during which each word in each pair was presented once. As before, subjects were told explicitly to respond to S1 (the top word) before S2. The congruency manipulation created four kinds of test trial: target-target, target-lure, lure-target, and lure-lure. Each occurred four times at each SOA. Within the target-target trials, there were two related trials and two unrelated trials at each SOA. In related trials, S1 and S2 came from the same pair; in unrelated trials, S1 and S2 came from different pairs. The order of SOAs, congruency, and relatedness conditions was randomized separately for each subject.

The instructions and counterbalancing were essentially the same as in Experiment 1. There was no surprise recall test at the end of the experiment.

Data analysis. Mean RT and accuracy were computed for each subject in each combination of conditions and analyzed in 2 (replication: Experiment 2a and 2b) × 2 (target or lure) × 2 (congruency) × 2 (SOA: 0 or 300 ms) ANOVAs. We performed separate ANOVAs in each replication, as before. The summary tables for these ANOVAs are presented in Table 4. We analyzed episodic priming effects in target-target trials in 2 (replication) × 2 (relatedness: from same pair or from different pairs) × 2 (SOA) ANOVAs. The summary tables for these ANOVAs are presented in Table 5.

Table 4
Summary Tables for Analyses of Variance From Experiment 2

Effect	*df*	*MSE*	*F*	*MSE*	*F*
		RT1		RT2	
E	1, 62	1,099,458.81	4.09*	1,178,086.83	7.30*
T	1, 62	27,267.05	11.96*	16,639.77	3.72
E × T	1, 62	27,267.05	0.00	16,639.77	3.51
C	1, 62	35,110.68	63.33*	49,480.44	123.15*
E × C	1, 62	35,110.68	0.04	49,480.44	0.05
T × C	1, 62	16,745.94	3.89	25,933.41	7.86*
E × T × C	1, 62	16,745.94	3.95	25,933.41	0.36
S	1, 62	11,717.92	14.79*	14,272.02	616.61*
E × S	1, 62	11,717.92	2.25	14,272.02	0.91
T × S	1, 62	9,908.11	0.79	6,093.31	1.67
C × S	1, 62	8,626.15	3.01	10,723.31	3.99
E × T × S	1, 62	9,908.11	0.65	6,093.31	0.00
E × C × S	1, 62	8,626.15	0.93	10,723.31	0.70
C × S × T	1, 62	7,283.10	0.80	9,497.62	0.35
E × C × S × T	1, 62	7,283.10	0.37	9,497.62	1.17
		R1		R2	
E	1, 62	1,275.04	0.15	1,039.03	0.57
T	1, 62	145.60	7.75*	129.08	17.98*
E × T	1, 62	145.60	0.01	129.08	1.85
C	1, 62	177.14	2.87	227.71	14.05*
E × C	1, 62	177.14	3.34	227.71	1.51
T × C	1, 62	63.19	0.00	75.69	20.90*
E × T × C	1, 62	63.19	1.00	75.69	0.17
S	1, 62	32.23	10.69*	61.48	9.96*
E × S	1, 62	32.23	1.19	61.48	2.86
T × S	1, 62	41.68	0.79	72.06	1.31
C × S	1, 62	60.38	5.18*	58.01	4.61*
E × T × S	1, 62	41.68	3.94	72.06	0.17
E × C × S	1, 62	60.38	0.00	58.01	1.48
C × S × T	1, 62	37.75	2.28	41.68	0.04
E × C × S × T	1, 62	37.75	0.13	41.68	3.94

Note. E = experiment; T = target or lure; C = congruency; S = stimulus onset asynchrony.
* $p < .05$.

Table 5
Analyses of Variance from the Episodic Priming Analyses of Target–Target Trials in Experiment 2

Effect	*df*	*MSE*	*F*	*MSE*	*F*
		RT1		RT2	
E	1, 62	502,773.41	5.49*	527,509.76	9.98*
R	1, 62	15,357.49	0.08	13,728.92	0.99
E × R	1, 62	15,357.49	0.48	13,728.92	0.06
S	1, 62	19,780.69	11.38*	22,007.13	161.81*
E × S	1, 62	19,780.69	0.15	22,007.13	0.05
R × S	1, 62	17,466.72	4.38*	18,018.16	2.10
E × R × S	1, 62	17,466.72	0.18	18,018.16	0.81
		R1		R2	
E	1, 62	883.30	0.51	598.69	0.51
R	1, 62	80.88	5.92*	100.60	22.43*
E × R	1, 62	80.88	0.39	100.60	0.56
S	1, 62	70.55	0.14	88.46	2.14
E × S	1, 62	70.55	2.00	88.46	0.87
R × S	1, 62	77.61	1.13	74.55	3.45
E × R × S	1, 62	77.61	5.48*	74.55	7.57*

Note. E = experiment; R = relatedness; S = stimulus onset asynchrony.
* $p < .05$.

Results

The mean RTs in each replication of the experiment are presented in Figure 2. The left-hand panels present RT to targets. The right-hand panels present RT to lures. Within each panel, the solid lines represent RT1 and the broken lines represent RT2. The mean hit rates and correct rejection rates for each replication of the experiment are presented as a function of SOA and congruency in Table 6.

Effects of replication. The average study time was longer in Experiment 2a, in which targets were presented only once, than in Experiment 2b, in which targets were presented repeatedly for 10 test blocks (*M*s = 250.90 and 111.49 s, respectively). We tested the reliability of this difference with a one-way between-subjects ANOVA and found it was highly significant, $F(1, 62) = 80.87$, $p < .01$, $MSE = 7{,}695.17$. In the test trials, RT was slower in Experiment 2a than in Experiment 2b (*M*s = 1,555 and 1,340 ms, respectively). Accuracy was nonsignificantly higher in Experiment 2a than in Experiment 2b (*M*s = 0.82 and 0.80, respectively; see Table 4). Nevertheless, the effects of SOA and congruency were the same across replications. Of 28 interactions with replication in the four ANOVAs in Table 4, none was significant.

Basic PRP effects. In each replication, RT2 was strongly affected by SOA, but RT1 was mostly unaffected. RT2 dropped by 262 ms as SOA increased from 0 to 300 ms, producing a slope of −0.87, close to the expected slope of −1.0. RT1 increased by 36 ms over the same SOAs. Accuracy was lower when SOA = 0 for both R1 and R2, underscoring the importance of timing in dual-task memory studies.

Crosstalk. There was strong crosstalk from S2 to S1 in the RT1 and R1 accuracy data in both replications of the experiment. In Experiment 2a, RT1 was 135 ms faster when S1 and S2 were congruent than when they were incongruent, and RT2 was 223 ms faster. R1 accuracy was 0.04 higher when S1 and S2 were congruent, and R2 accuracy was 0.07 higher. In Experiment 2b, RT1 was 129 ms faster when S1 and S2 were congruent, and RT2 was 214 ms faster. R1 accuracy was 0.01 higher when S1 and S2 were congruent, and R2 accuracy was 0.04 higher. These conclusions were supported by significant main effects of congruency in the ANOVAs on RT1, RT2, R1 accuracy, and R2 accuracy (see Table 4).

Crosstalk was stronger when SOA was 0 ms than when SOA was 300 ms. We assessed the significance of the crosstalk effects by computing Fisher's LSD from the highest order interaction in each ANOVA (i.e., Replication × Target × Congruency × SOA). For RT1, the critical value for $p < .05$ was 30 ms. By this criterion, the congruency effects were significant at both SOAs in both experiments. For RT2, the critical value for $p < .05$ was 34 ms. By this criterion, the congruency effects were significant at both SOAs in both experiments.

The accuracy results were consistent with the RT results, although accuracy crosstalk was stronger in Experiment 2a than in Experiment 2b. For R1 accuracy, the critical value of $\text{LSD}_{.05}$ was 0.022. By this criterion, the congruency effects were significant for all conditions in Experiment 2a, but they were nonsignificant for Experiment 2b in all conditions except lures at the 300-ms SOA, where the crosstalk was significantly negative (i.e., performance was worse when S1 and S2 were congruent). For R2 accuracy, the critical value of $\text{LSD}_{.05}$ was 0.023. By this criterion, the congruency effect was significant in all conditions of Experiment 2a except for lures at the 300-ms SOA. The congruency effect was significant for targets at both SOAs in Experiment 2b and nonsignificant for lures at both SOAs.

Episodic priming. We assessed episodic priming by comparing target-target trials in which S1 and S2 came from the same pairs (i.e., they were *related*) with target-target trials in which S1 and S2 came from different pairs (i.e., they were *unrelated*). The mean values in each condition are presented in Table 7. The RT1 data and R1 accuracy are most relevant to our hypotheses about parallel retrieval: Averaged over SOA, the relatedness effect was −16 ms in Experiment 2a, in which targets were presented only once, and 7 ms in Experiment 2b, in which targets were presented 10 times. The main effect of relatedness was not significant, nor was the interaction between relatedness and replications (see the RT1 ANOVA in Table 5). Episodic priming was strongly moderated by SOA, however, as evidenced by a significant interaction between relatedness and SOA (see Table 5). In both experiments, episodic priming was positive at SOA = 0 (i.e., related was faster than unrelated) but negative at SOA = 300 (i.e., related was slower than unrelated). We tested the significance of the individual episodic priming effects by calculating $\text{LSD}_{.05}$ from the highest order interactions in the ANOVAs in Table 5. The results of this analysis appear in Table 7. By this criterion, there was no episodic priming in RT1 in Experiment 2a, but there was significant priming in RT1 at the 0-ms SOA in Experiment 2b.

The R1 accuracy data also show evidence of episodic priming. Averaged over SOA, the relatedness effect was 0.04 in Experiment 2a and 0.02 in Experiment 2b. The main effect of relatedness was significant in the ANOVA on R1 accuracy (see Table 5). There was a significant three-way interaction among relatedness, replication, and SOA, which we analyzed post hoc with Fisher's LSD test. The critical value for $p < .05$ was 0.031. By this criterion, episodic priming was significant only at SOA = 0 in Experiment 2a.

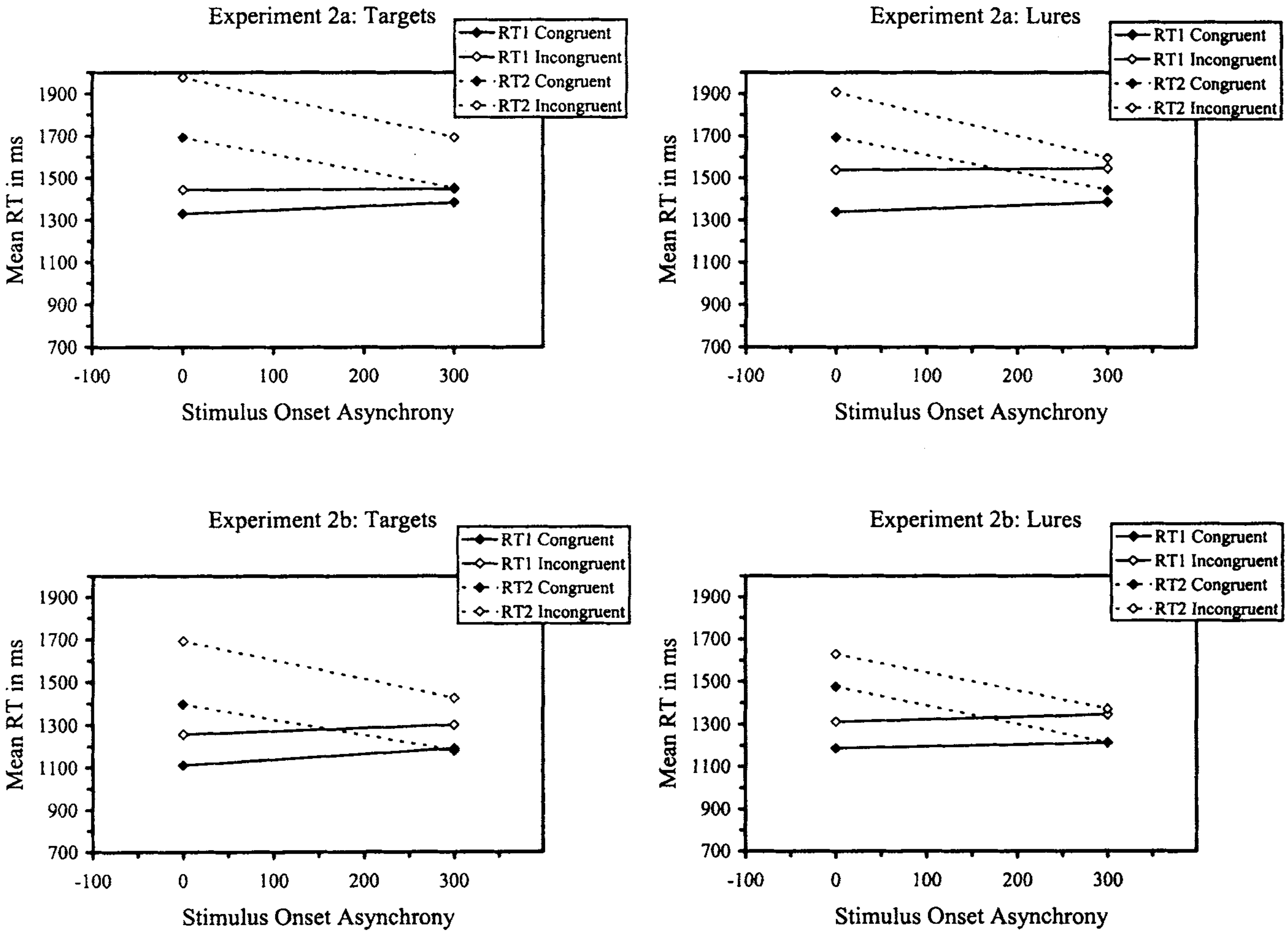

Figure 2. Mean reaction time (RT) to the first stimulus (RT1, solid lines) and the second stimulus (RT2, broken lines) in Experiments 2a and 2b as a function of stimulus onset asynchrony for targets and lures. Response congruity—same (filled diamonds) versus different (open diamonds)—is the parameter.

Episodic priming also occurred in the RT2 data. The main effect of relatedness was not significant in the RT2 ANOVA, nor were any of its interactions. Nevertheless, we looked for episodic priming at each SOA in each experiment using Fisher's LSD$_{.05}$ from the highest order interaction. The critical value was 47 ms. By this criterion, the relatedness effect was significant at SOA = 0 in Experiment 2b and nowhere else.

There were strong episodic priming effects in the R2 accuracy data. Averaged over replication and SOA, accuracy was 0.06 higher when S1 and S2 were related than when they were unrelated. The main effect of relatedness was significant in the R2 accuracy ANOVA (see Table 5). The critical value of Fisher's LSD$_{.05}$ was 0.031. By this criterion, there was significant episodic priming at SOA = 0 in Experiment 2a and at both SOAs in Experiment 2b (see Table 7).

Discussion

RT varied across replications of the experiment, but the effects of SOA and crosstalk were the same in both replications. The basic PRP effects obtained in both replications: RT2 was strongly affected by SOA, while RT1 was largely unaffected. There was strong crosstalk in both RT1 and RT2. The RT1 crosstalk is consistent with parallel retrieval and inconsistent with serial discrete retrieval.

We found some evidence for episodic priming in this experiment. It appeared in the RT1 data only when targets were presented repeatedly, but it appeared more strongly in the R1 accuracy data when targets were only presented once. This episodic priming suggests that subjects were able to retrieve very specific information from S2 while they were attempting to retrieve information from S1.

Experiment 3

The third experiment replicated the second using sentences rather than word pairs as study items. Our goal was to find strong episodic priming when targets appear just once on the study list. McKoon and Ratcliff (1980) found strong episodic priming when subjects studied sentences and were tested with single words (also

Table 6

Accuracy Scores (Hit Rates for Targets; Correct Rejection Rates for Lures) for R1 and R2 in Experiments 2a and 2b as a Function of Stimulus Onset Asynchrony (SOA)

SOA	Target same	Target diff.	Lure same	Lure diff.
		Experiment 2a: R1		
0	0.84	0.80	0.83	0.76
300	0.86	0.83	0.82	0.80
		Experiment 2a: R2		
0	0.80	0.70	0.85	0.79
300	0.83	0.72	0.83	0.81
		Experiment 2b: R1		
0	0.83	0.82	0.78	0.77
300	0.82	0.82	0.79	0.82
		Experiment 2b: R2		
0	0.83	0.73	0.82	0.81
300	0.84	0.80	0.83	0.85

Note. diff. = different.

see Ratcliff & McKoon, 1978, 1981), and we expected to replicate their findings in the PRP procedure.

Subjects saw eight sentences on each study trial, and they were tested for memory for the words of the sentences in the following PRP test trials. We assessed general crosstalk by comparing target-target and lure-lure test trials with target-lure and lure-target test trials. If subjects can retrieve information about S2 while processing S1, target-target and lure-lure trials should produce better performance than target-lure and lure-target trials. We assessed specific crosstalk by looking for episodic priming. We divided target-target trials into those in which S1 and S2 came from the same sentence (related) and those in which S1 and S2 came from different sentences (unrelated). If subjects can retrieve specific information about S2 while they are processing R1, then performance should be better on related trials than on unrelated trials.

Method

Subjects. The subjects were 32 volunteers from an introductory psychology course who received course credit for participating.

Apparatus and stimuli. These were the same as in Experiment 2, except that sentences were presented in the study lists instead of word pairs. We made two lists of sentences from the two lists of word pairs we had in Experiment 2. The first word of a pair from Experiment 2 was the subject of a sentence in Experiment 3, and the second word of a pair was the object of that sentence. Gordon D. Logan wrote the sentences, and Julie A. Delheimer edited them for clarity and simplicity. For example, the pair "child-woman" became "The child became a woman" and "rebel-bluff" became "The rebel watched from the bluff." The sentences were presented in the study trial in the same manner as the word pairs, except that they began at column 10 of the IBM text screen rather than column 20.

Procedure. The procedure was essentially the same as in Experiment 2a. Subjects performed 10 study-test blocks, in which new targets and lures appeared each block. The test blocks presented single words as S1 and S2 in the PRP procedure, with SOAs of 0 and 300 ms.

Data analysis. We analyzed the RT1 and RT2 data and the R1 and R2 accuracy data in 2 (target vs. lure) × 2 (congruent vs. incongruent) × 2 (SOA) ANOVAs. The summary tables appear in Table 8. We analyzed episodic priming with 2 (related vs. unrelated) × 2 (SOA) ANOVAs. The summary tables for those ANOVAs appear in Table 9.

Results

The mean RTs are presented in Figure 3 as a function of SOA and congruency. The solid lines represent RT1, and the dotted lines represent RT2. The left-hand panel presents data from target trials, and the right-hand panel presents data from lure trials. The mean accuracy scores (hit rates for targets, correct rejection rates for lures) for R1 and R2 are presented as a function of SOA and congruency in Table 10. The average study time was 304.00 s with a standard deviation of 98.00.

Basic PRP effects. The basic PRP effects replicated once again. RT1 was largely unaffected by SOA but RT2 was strongly affected. RT1 increased by 36 ms as SOA increased from 0 to 300 ms. RT2 decreased by 259 ms over the same range, producing a slope of −0.86, which is close to the expected slope of −1.0. Accuracy averaged 0.79 for R1 and 0.78 for R2.

Crosstalk. There was strong crosstalk in both RT1 (M = 57 ms) and RT2 (M= 126 ms). The main effects of congruency were significant in both the RT1 and RT2 ANOVAs (see Table 8). We analyzed the congruency effects in each condition using $\text{LSD}_{.05}$ from the highest order interaction (Target × Congruency × SOA). For RT1, the critical value was 43 ms; by this criterion there was significant crosstalk for targets and lures at both SOAs. For RT2,

Table 7

Episodic Priming Effects in RT1 and RT2 and in R1 and R2 Accuracy in Experiments 2a and 2b as a Function of Stimulus Onset Asynchrony (SOA)

Variable	Exp. 2a		Exp. 2b	
		RT1		
SOA	0	300	0	300
Related	1,324	1,404	1,092	1,199
Unrelated	1,336	1,361	1,140	1,164
Priming	12	−43	48*	−35
		RT2		
SOA	0	300	0	300
Related	1,684	1,452	1,374	1,182
Unrelated	1,704	1,455	1,431	1,161
Priming	20	3	57*	−21
		R1 accuracy		
SOA	0	300	0	300
Related	0.88	0.86	0.83	0.83
Unrelated	0.80	0.86	0.83	0.80
Priming	0.08*	0.00	0.00	0.03
		R2 accuracy		
SOA	0	300	0	300
Related	0.85	0.83	0.86	0.88
Unrelated	0.75	0.83	0.80	0.80
Priming	0.10*	0.00	0.06*	0.08*

Note. Exp. = experiment.
* $p < .05$.

Table 8
Summary Tables for Analyses of Variance From Experiment 3

Effect	*df*	*MSE*	*F*	*MSE*	*F*
		RT1		RT2	
T	1, 31	19,020.06	17.28*	20,576.98	1.33
C	1, 31	24,818.06	8.22*	41,550.25	24.47*
T × C	1, 31	10,701.17	0.00	23,055.94	3.36
S	1, 31	10,787.28	7.44*	14,365.25	300.76*
T × S	1, 31	6,835.08	0.03	11,362.58	0.01
C × S	1, 31	4,677.75	0.37	8,807.56	4.35*
C × S × T	1, 31	7,083.85	0.25	10,310.51	0.33
		R1		R2	
T	1, 31	289.40	3.79	358.15	3.80
C	1, 31	71.16	23.19	64.40	59.45*
T × C	1, 31	96.93	0.15	60.43	9.33*
S	1, 31	64.31	6.22*	114.10	0.99
T × S	1, 31	64.60	0.05	81.85	1.22
C × S	1, 31	72.27	4.55*	59.63	7.57*
C × S × T	1, 31	67.09	1.14	88.09	0.36

Note. T = target or lure; C = congruency; S = stimulus onset asynchrony.
*$p < .05$.

the critical value was 52 ms; by this criterion there was significant crosstalk for targets and lures at both SOAs.

There was strong crosstalk in the accuracy data as well. For R1, responses were 0.05 more accurate when S1 and S2 were congruent. For R2, the advantage was 0.08. The main effect of congruency was significant in both accuracy ANOVAs (see Table 8). We analyzed congruency effects in each condition using LSD$_{.05}$ from the Target × Congruency × SOA interaction. For R1, the critical value was 0.042. By this criterion, there was significant crosstalk for SOA = 0 for both targets and lures. For R2, the critical value was 0.048. By this criterion, there was significant crosstalk at both SOAs for targets and significant crosstalk at SOA = 0 for lures.

Episodic priming. We assessed episodic priming by comparing target-target trials in which S1 and S2 came from the same sentence (i.e., they were related) with target-target trials in which S1 and S2 came from different sentences (i.e., they were unrelated). The mean values in each condition are presented in Table 11. Most relevant to our hypotheses are the RT1 data and R1 accuracy. The relatedness effect was only 6 ms, averaged over SOA, but it was modulated strongly by SOA, being large and positive (52 ms) at SOA = 0 and large and negative (−41 ms) at SOA = 300. The main effect of relatedness was not significant, but the interaction between relatedness and SOA was significant (see Table 10). We tested the significance of the individual episodic priming effects by calculating LSD$_{.05}$ from the highest order interaction in the RT1 ANOVA in Table 10. The critical value was 66 ms. By this criterion, the episodic priming effect was not significant at either SOA.

The R1 accuracy data also show evidence of episodic priming. Averaged over SOA, the relatedness effect was 0.02. However, the main effect of relatedness was not significant in the ANOVA on R1 accuracy, nor was the interaction between relatedness and SOA (see Table 10). Nevertheless, we analyzed the individual priming effects using LSD$_{.05}$ from the highest order interaction. The critical value was 0.047. By this criterion, episodic priming was significant at SOA = 0.

Episodic priming also occurred in the RT2 data (M=51 ms). The main effect of relatedness was significant in the RT2 ANOVA. We looked for episodic priming at each SOA in each experiment using LSD$_{.05}$ from the highest order interaction. The critical value was 80 ms. By this criterion, the relatedness effect was significant at SOA = 0. Episodic priming also occurred in the R2 accuracy data (M= 0.085). The main effect of relatedness was significant in the R2 accuracy ANOVA (see Table 10). The critical value of Fisher's LSD$_{.05}$ was 0.055. By this criterion, there was significant episodic priming at both SOAs.

Discussion

This experiment replicated the standard PRP effects and showed strong crosstalk from S2 to S1 in RT1 and R1 accuracy, contrary to serial discrete retrieval and consistent with parallel retrieval. Episodic priming was stronger in this experiment than it was in the previous experiments in which items were presented only once, suggesting that sentences provide more episodic structure to support priming than word pairs (Experiment 2) or columns (Experiment 1).

General Discussion

The experiments were conducted to see whether subjects could retrieve information from S2 before they finished retrieving information from S1 in the PRP procedure. Each experiment showed a strong PRP effect. RT1 was hardly affected by SOA, but RT2 was strongly affected, decreasing sharply as SOA increased from 0 to 250 or 300 ms. The slope of the decrease in this range was about −0.87, across all experiments, which is very close to the theoretical ideal of −1.0. The clarity of the basic PRP results in all the separate replications suggests we can use methods of analysis on our data that were developed with more typical PRP tasks in which accuracy was near ceiling.

Each experiment showed crosstalk from S2 to S1 for both targets and lures. This crosstalk suggests that subjects began processing S2 before they finished processing S1, which is contrary to

Table 9
Analyses of Variance From the Episodic Priming Analyses of Target–Target Trials in Experiment 3

Effect	*df*	*MSE*	*F*	*MSE*	*F*
		RT1		RT2	
R	1, 31	9,927.20	0.09	14,037.61	5.76*
S	1, 31	12,190.91	2.31	23,049.97	84.18*
R × S	1, 31	70,218.78	4.20*	24,576.75	2.54
		R1		R2	
R	1, 31	128.93	1.19	120.06	18.97*
S	1, 31	115.22	0.68	125.40	0.10
R × S	1, 31	83.77	3.02	116.13	0.00

Note. R = relatedness; S = stimulus onset asynchrony.
*$p < .05$.

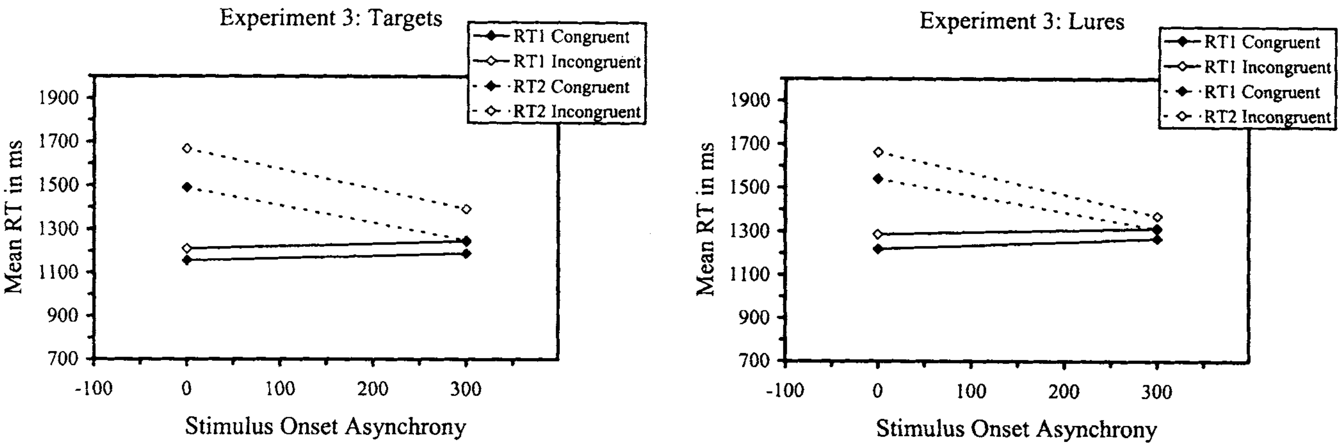

Figure 3. Mean reaction time (RT) to the first stimulus (RT1, solid lines) and the second stimulus (RT2, broken lines) in Experiment 3 as a function of stimulus onset asynchrony for targets and lures. Response congruity—same (filled diamonds) versus different (open diamonds)—is the parameter.

serial, discrete retrieval. If retrieval was serial and discrete, the memorial status of S2 should have no impact on S1 processing; yet it did. Thus, the data disconfirm a basic prediction of serial discrete processing models (Townsend & Ashby, 1983). In our view, the crosstalk effects provide strong evidence for parallel retrieval.

Each experiment showed some episodic priming from S2 to S1. On target-target trials, RT1 was generally faster and R1 was generally more accurate when S1 and S2 came from the same memorial structure than when they came from different memorial structures. Columns (Experiment 1), word pairs (Experiment 2), and sentences (Experiment 3) all produced episodic priming. In Experiments 1 and 2, the effects were stronger when targets were repeated throughout the experiment than when targets were presented only once. Experiment 3 found episodic priming with single-target presentations using sentences in the study lists. The episodic priming results are more specific than the general crosstalk between response categories, but they lead to the same conclusions. In order for S2 to prime S1, subjects must have begun to retrieve specific episodic information from S2 before they finished retrieving specific episodic information from S1. Thus, the episodic priming results also provide evidence against serial discrete retrieval and, consequently, evidence for parallel retrieval.

Table 10
Accuracy Scores (Hit Rates for Targets, Correct Rejection Rates for Lures) for R1 and R2 in Experiment 3 as a Function of Stimulus Onset Asynchrony (SOA)

SOA	Target same	Target diff.	Lure same	Lure diff.
		R1		
0	0.82	0.76	0.80	0.71
300	0.84	0.80	0.79	0.77
		R2		
0	0.80	0.68	0.84	0.76
300	0.81	0.72	0.81	0.79

Note. diff. = different.

Crosstalk and the Locus of Slack Logic

The present evidence for parallel retrieval, taken from analysis of crosstalk effects, contrasts sharply with Carrier and Pashler's (1995) evidence for serial retrieval, taken from the locus of slack logic. The results in each case are quite strong. We observed crosstalk in six independent replications of our basic experiment. Carrier and Pashler (1995) observed additive effects of retrieval difficulty and SOA in two different experiments with different retrieval tasks (cued recall and recognition). This is not the first time the two methods have yielded opposite conclusions. Pashler and Johnston (1989) found locus-of-slack evidence that response selection runs in series, finding additive effects of response repetition and SOA; Hommel (1998), Logan and Schulkind (2000), and Logan and Gordon (in press) found crosstalk evidence for parallel response selection, finding response repetition effects from R2 to R1. Fagot and Pashler (1992) found evidence that the processes that resolve response conflict in the Stroop (1935) task run in

Table 11
Episodic Priming Effects in Experiment 3 as a Function of Stimulus Onset Asynchrony (SOA)

	Reaction time			
Variable	RT1		RT2	
SOA	0	300	0	300
Related	1,132	1,208	1,445	1,243
Unrelated	1,184	1,167	1,540	1,249
Priming	52	−41	95*	6
	Accuracy			
	R1		R2	
SOA	0	300	0	300
Related	0.85	0.83	0.85	0.85
Unrelated	0.80	0.84	0.76	0.77
Priming	0.05*	−0.01	0.09*	0.08*

$^* p < .05$.

series; Hommel (1998) and Logan and Gordon (in press) found Stroop-type crosstalk from S2 to S1, suggesting parallel processing. In the remainder of this section, we consider four ways to interpret our crosstalk results and the contradiction between crosstalk and locus-of-slack results.

Retrieval is parallel; locus of slack results are invalid. The first interpretation accepts our crosstalk results as evidence against the hypothesis that retrieval is serial and discrete and draws the implication that previous conclusions based on the locus-of-slack are invalid. The formal developments of the locus of slack logic assume explicitly that the bottleneck stage is serial and discrete (Schweickert, 1978; Schweickert & Townsend, 1989; Townsend & Schweickert, 1989). The present experiments suggest that that assumption is false, so the formal arguments cannot be applied to PRP memory retrieval data.

Put differently, it is not clear what locus of slack models would predict if the assumption of discrete processing were abandoned. The mathematics have not been worked out, and the processes have not been simulated. McClelland (1979) investigated the consequences of abandoning the discrete processing assumption in stage analyses of single tasks and found that *cascaded* stages produced patterns of additivity similar to discrete stages, but they produced patterns of interaction that differed markedly. Thus, it is difficult to anticipate the consequences of abandoning the discrete stage assumption in the locus of slack logic. The worst-case scenario is that all of the conclusions drawn from locus-of-slack arguments are invalid.

Retrieval is parallel; locus of slack results are robust. The second interpretation also accepts our crosstalk results as evidence against serial discrete retrieval but suggests that the consequences of violating the assumption are not very severe.[1] The locus of slack logic may be robust enough to tolerate relatively minor violations of the assumption of discrete processing. The conclusions may still hold if processing is approximately discrete. The literature contains many examples of models that are robust with respect to violations of assumptions and, consequently, are applied to situations in which their assumptions are known to be false. The assumption of normally distributed data in ANOVA is a prominent example. Logan and Gordon's (in press) model of the PRP task, which assumes exponentially distributed processing times, may be a more relevant example. The exact distribution of processing times is unlikely to be exponential, yet the model provides a reasonable account of the data.

At present, we do not know the severity of the consequences of violating the assumption of discrete processing in the locus of slack logic. The method may be robust over a broad range of violations, or it may fail completely with minor violations. The answer awaits further research and theory development.

Retrieval is serial; there are two stages. The third possibility is that retrieval involves two processing stages. The first is parallel and is tapped by the crosstalk logic. The second is serial and discrete and is tapped by the locus of slack logic. Indeed, formal models in the memory literature often distinguish between two processes in retrieval. The most prominent example may be Raaijmakers and Shiffrin's (1981) and Gillund and Shiffrin's (1984) *search of associative memory* model, that distinguishes between *sampling* and *recovery* processes in retrieval. The sampling process operates first. It forms a retrieval cue and probes memory with it, and the retrieval cue activates memory traces that were associated with it. Then the recovery process attempts to generate a response appropriate to the experimental instructions from the activated traces. It may be possible that crosstalk reflects the sampling process, which is parallel, and locus of slack interactions reflect the recovery process, which is discrete and serial.

The plausibility of this interpretation depends on the separability and the seriality of sampling and recovery processes. They are not very separable in some theories of recognition. Ratcliff (1978; Ratcliff & McKoon, 1988), for example, proposed an evidence-accumulation model of recognition, in which a sampling process continuously measures the "resonance" between a retrieval cue and memory, and a recovery process continuously compares the amount of accumulated resonance with a threshold, generating an "old" or "new" response once the threshold is exceeded. Accumulating evidence and testing the threshold are logically or functionally distinct processes, but they work very closely together and so may not be easily separable as processing stages.[2] Logan and Gordon (in press) proposed a similar evidence-accumulation model for semantic memory retrieval in the PRP situation. Again, accumulating evidence (sampling) and threshold testing (recovery) are concurrent and contingent processes that may be hard to construe as separate stages.

The literature on retrieval processes in recognition suggests another two-process interpretation. Several researchers argued that recognition can be accomplished by a judgment of *familiarity* or a judgment of *recollection* (Atkinson & Juola, 1974; Gardiner, 1988; Jacoby, 1991; Mandler, 1980; Tulving, 1985). Familiarity judgments are thought to be quick, automatic, and global, whereas recollection judgments are thought to be slower, more deliberate, and based on retrieval of specific contextual information. In Atkinson and Juola's (1974) model, familiarity preceded recollection, and recollection occurred only if familiarity failed. This model would fit well with the present data: Crosstalk would reflect the first, familiarity stage, and locus-of-slack interactions would reflect the second, recollection stage. However, more recent approaches may not fit the data as well. Familiarity and recollection are treated as mutually exclusive processes, with performance on a given trial depending on one but not the other (Gardiner, 1988; Jacoby, 1991; Mandler, 1980; Tulving, 1985). Modern theorists have not been very specific about the temporal relations between these processes, focusing on prediction of accuracy rather than RT, but the theories seem to be proposing alternative single-stage processes for recognition rather than two stages in series. If that is the case, then the predictions may diverge substantially from the locus of slack predictions. A mixture of two single-stage processes is likely to behave quite differently from two discrete stages in series. Thus, recent research on familiarity and recollection is unlikely to resolve the conflict between crosstalk and locus-of-slack studies of memory retrieval in the PRP.

Retrieval is parallel; something intervenes to make it discrete. The crosstalk results show that information about S2 was retrieved before retrieval from S1 was complete, in that it affected RT1 and R1 accuracy. The results do not necessarily imply that the information retrieved about S2 during S1 processing has an effect on the later choice of R2 (i.e., on Task2 response selection) although

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[1] We are grateful to Hal Pashler for pointing out this interpretation.

[2] We are grateful to Jeff Miller for pointing out this interpretation.

they certainly are consistent with that conclusion. However, it is possible that all of the information acquired during S1 processing is 'flushed' from the system before Task2 response selection begins, so that Task2 response selection is sensitive only to information retrieved after the flushing occurs. This intervening event—flushing—would make Task2 response selection discrete, in that it would begin only after the flushing occurred. Information acquired before the flushing would have no impact on Task2 response selection, and so could not be said to participate in Task2 response selection. Thus, information about S2 may be retrieved during S1 processing, but Task2 response selection does not begin until after Task1 has finished (see Pashler, 1993).[3]

The idea of flushing adds substantial complexity to the simple stage framework that organizes PRP research, threatening the elegance of its account. Moreover, the idea that flushing intervenes to preserve the discreteness of Task2 response selection seems ad hoc, like a "patch" added with no other purpose than to save the stage framework. However, there is reason to believe that flushing may be an important computational function in PRP tasks and in serially ordered behavior in general, where it prevents response perseveration (i.e., repetitions of R1). Something like flushing occurs in a large number of theories of serially ordered behavior (for a review, see Dell, Burger, & Svec, 1997). In those theories, several responses are activated at once, and the one with the highest activation is chosen and executed. The chosen response is inhibited after it is executed, or else it would remain the most highly activated response and so would be chosen again, perseveratively. Self-inhibition removes the just-executed response from consideration and allows the next response in the series to be chosen and executed. This self-inhibition is a kind of flushing. We believe it is necessary to allow choice of R2 in the PRP procedure.

Logan and Gordon (in press) incorporated the idea of flushing in their theory of crosstalk effects in the PRP task to prevent perseveration of R1. In their theory, evidence accumulates in response counters and the values in the counters are compared with a difference threshold. As soon as one of the counters contains K more units of information than any other counter, the response associated with that counter is chosen and executed. To prevent perseveration, the difference between the counters must be reduced to a value smaller than K. This is accomplished by an operation that reduces the values in the counters to 10% of their values at the time the response was chosen.

In Logan and Gordon's (in press) model, flushing is not complete, so information about S2 that was retrieved during S1 processing remains available in the response counters to influence Task2 response selection, attenuated by 90%. Formally, one could argue that Task2 response selection begins during Task1, because units of information about S2 that were acquired during S1 processing influence choice of R2. The difference between Logan and Gordon's partial flushing and the complete flushing that preserves discreteness is a matter of degree. It seems likely that less flushing is required to prevent perseveration than to restore discrete processing. In Logan and Gordon's model, response perseveration could be prevented by a relatively small amount of flushing (the difference between counters needs to be reduced to a value slightly less than K), and that may not be enough to make Task2 response selection discrete. Future research will be necessary to determine the relation between these two consequences of flushing.

Attention, Automaticity, and Capacity Demands of Retrieval

Many studies in the memory literature have used dual-task methodology to address questions about the role of attention, automaticity, and capacity demands in retrieval (e.g., Baddeley et al., 1984; Craik et al., 1996; Jacoby, 1991; Johnston et al., 1970, 1972; Martin, 1970; Moscovitch, 1994; Park et al., 1989; Trumbo & Milone, 1971). In this section, we consider the implications of our results for the memory literature.

Attention. Memory researchers sometimes use dual-task methodology to "remove attention" from the memory task. Our PRP procedure is unlikely to have done that, because both tasks were memory tasks and both tasks required subjects to attend to words on the computer screen. Attention is more likely to have been delayed than removed. It may be possible to remove attention in dual-task situations in which S1 or S2 or both are presented briefly, so that attention to one stimulus may preclude attention to the other (e.g., Duncan, 1980; Moray, Fitter, Ostry, Favreau, & Nagy, 1976; Pohlmann & Sorkin, 1976), but even those situations require choice among responses for the two tasks, and that choice may be postponed rather than omitted (Jolicoeur, 1998, 1999a, 1999b).

Automaticity. Memory researchers sometimes use dual-task methodology to separate automatic from attentional or strategic processing, arguing that only automatic processes can operate in dual-task situations (e.g., Jacoby, 1991). Our present evidence for parallel processing is consistent with the idea that retrieval is automatic, in that automatic processes are characteristically parallel (Logan, 1988), but our data do not rule out alternative interpretations. The parallel processing we observed may have been due to division of attention between tasks. Automaticity would require that one task received attention while the other did not, and our data provide no evidence on that issue.

Capacity demands. Memory researchers use dual-task methodology to measure the capacity demands of retrieval (e.g., Johnston et al., 1970, 1972). Our evidence for parallel processing is consistent with the idea that retrieval is unlimited in capacity, because unlimited-capacity processes are often characterized as parallel. However, the evidence is also consistent with the idea that retrieval is limited or fixed in capacity, because limited- and fixed-capacity processes can also be parallel (Townsend & Ashby, 1983). Indeed, Logan and Gordon's (in press) model of crosstalk effects in the PRP situation assumes limited-capacity parallel processing.

Methodological implications. Our results lead directly to a specific conclusion about serial discrete retrieval but do not imply much about related issues, like attention, automaticity, and capacity demands. We believe this reflects the current state of theoretical development in the attention literature. Issues like these have been debated since the 1950s, and researchers agree that the issues are separable if not separate. Specific experimental designs have been developed to address specific issues. For example, the locus of slack logic leads to factorial designs that manipulate Task2 difficulty and SOA to localize the bottleneck in processing. Designs that are optimized to address one issue are not necessarily opti-

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[3] We are grateful to Hal Pashler for pointing out that flushing could make Task2 response selection discrete.

mized to address the others. Researchers should be aware of these constraints when designing studies that address the role of attention, automaticity, and capacity demands in memory retrieval.

The strong and consistent effects of SOA on RT and accuracy that we observed in each experiment reinforce a central point made in the PRP literature: Dual-task interference depends heavily on the timing of the two tasks. Dual-task experiments that fail to synchronize tasks by controlling timing precisely are likely to underestimate the magnitude of dual-task interference. Unfortunately, dual-task experiments in the memory literature often do not control timing very precisely. To cite a prominent example, Jacoby (1991) had subjects perform a self-paced anagram task while they performed an experimenter-paced digit task. The tasks were not synchronized, so the critical events in one task may have occurred while the other was relatively undemanding (i.e., at a long SOA). This would underestimate dual-task interference, particularly with automatic processes, which are fast and provide a smaller "temporal target" that can be subjected to interference than slower, strategic processes (Logan, 1988; Van Selst, Ruthruff, & Johnston, 1999). Jacoby's (1991) conclusion that automatic processes do not suffer dual-task interference warrants replication with closer control over timing.

Conclusions

The present experiments demonstrate general and specific crosstalk from S2 to S1 in the PRP procedure. These results suggest that subjects can retrieve information about S2 while they are busy retrieving information about S1. This conclusion contradicts the idea that retrieval is a discrete serial processing stage and threatens to undermine the stage-theoretic framework that organizes much work on the PRP procedure. Instead, we hope that the contradiction can be resolved in a way that elaborates current theory and teaches us something about retrieval.

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