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In Search of Cross-Talk Facilitation in a Dual-Cued Recall Task

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Despite earlier evidence that the presence of 2 redundant cues can facilitate activation of a common response, T. C. Rickard and D. Bajic (2004) found no dual-cue facilitation in the case of cued recall, provided that each cue–response association was learned independently. In this study the authors investigated the generality of their results using a dual-task cross-talk design. There was no evidence of dual-cue facilitation for compatible cue trials in the case of associative independence. Race models as well as at least some limited capacity parallel retrieval accounts can be eliminated by these and related results. It appears instead that a preretrieval stage performance bottleneck precludes cued recall through more than 1 independently represented cue–response association at a time.

Keywords: cued-recall, dual-task, redundant cues, cross-talk, facilitation

This article addresses the conditions under which the presence of redundant cues can facilitate memory recall. In addition to the theoretical value of this topic as outlined below, there is applied value in demarcating conditions of redundant-cue facilitation. Consider a task, such as driving, that requires fast and highly accurate responses to cues. A red traffic light, for example, sometimes co-occurs with other cues to stop, such as the red tail lights and deceleration of other cars or pedestrians beginning to cross a street. If redundant cues always yield faster correct responses, then they should be designed into performance environments wherever possible when fast and accurate decisions need to be made. New technologies, for example, might allow computers to sense impending collision and provide an extra warning cue to the driver. On the other hand, if there are some conditions under which redundant cues either do not produce facilitation or perhaps even cause distraction, then cognitive principles will need to be established for predicting redundant cue effects.

Most tasks that have been studied to date exhibit response facilitation in the presence of redundant cues, regardless of whether subjects are intentionally processing both cues. These tasks include target detection (e.g., Miller, 1982), the congruent condition of the Stroop task (for a review see MacLeod, 1991), flanker tasks (Eriksen & Eriksen, 1974), semantic categorization (Logan & Schulkind, 2000), and other choice response time (RT) tasks. Because the Logan and Schulkind (2000) study addressed recall from long-term memory (as opposed to execution of rules in working memory), it is particularly relevant to the current study. On each trial of Logan and Schulkind's first experiment, subjects were presented with two cues, one above the other: two letters, two numbers, a letter and a number, or vice versa. For each cue, starting with the top one, subjects pressed a button that corresponded to the correct stimulus category, letter or number. First task responses were faster on trials with either two letter cues or two number cues (i.e., compatible trials) than on trials having one letter cue and one number cue (i.e., incompatible trials). The authors interpreted these results as reflecting parallel cross talk; the second task stimulus was activating its response while subjects were attempting to perform the first task. Logan and Schulkind also manipulated stimulus onset asynchronicity (SOA) using values of 0, 100, 300, and 900 ms. If the cross-talk effect is in fact the result of parallel activation from both cues to their respective responses, then it should dissipate with increasing SOA. Their basic pattern of results over several experiments, which is depicted in Figure 1, confirmed that expectation.

Although Logan and Schulkind (2000) did not analyze their SOA effect separately for the compatible and incompatible conditions, their graphs clearly showed (over multiple experiments) a dual-cue facilitation effect in the compatible condition; RTs for compatible cues were fastest at the 0-ms SOA level and increased monotonically with increasing SOA (henceforth, a positive SOA slope). There appeared to be no effect of SOA, however, in the incompatible condition. The latter effect is surprising. Typically in related tasks, such as the Stroop task, interference effects due to the simultaneous presence of an incompatible cue are of much greater magnitude than are facilitation effects in the compatible cues version of the task.

These simple effects of SOA within each level of compatibility have not been emphasized in most cross-talk studies to date (Hommel, 1998; Logan & Delheimer, 2001; Logan & Schulkind, 2000). Nevertheless, a greater theoretical understanding of the task is ultimately achieved by considering them directly, and any complete model of the task must explain them. One goal of this article is to describe and test candidate theories at this level. As a matter of definition, we refer to a positive SOA slope as a *cross-talk facilitation effect* (because it implies that the second cue is facilitating first task performance at short SOAs), and we refer to a negative SOA slope, when observed, as a *cross-talk interference effect* (because it implies that the second cue is interfering with

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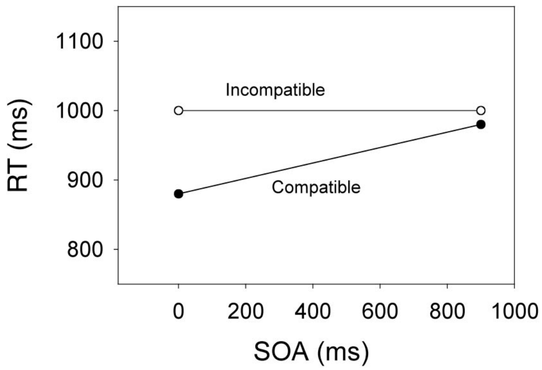

Figure 1. The basic patterns of results of the task conditions (incompatible and compatible) in the Logan and Schulkind (2000) experiments. SOA = stimulus onset asynchronicity; RT = response time.

first task performance at short SOAs). A glossary of terms is given in the Appendix.

One memory task that has not exhibited dual-cue facilitation is cued recall from long-term memory. Rickard and Bajic (2004, Experiments 1 & 2) trained subjects to make a vocal digit response when presented with each of 12 letters. During this single-cue training, letter stimuli were presented one at a time on independent trials. In the subsequent test phase, these single-cue items were mixed with dual-cue items, which were always two letters that had been associated with the same digit response. Thus, all dual-cue trials were compatible. Despite several attempts across five experiments (Experiments 3 through 5 with color and letter cues) to induce facilitation on dual-cue trials, none was observed at any point along the RT distribution, provided that the two cues of a dual-cue item had not previously been seen together very often.

The striking empirical difference between dual-cue performance in Rickard and Bajic's (2004) study and that in Logan and Schulkind's (2000) study leads to a theoretical tension whose resolution is important for understanding cued-recall performance and its underlying cognitive architecture. One candidate account is that the tasks used by Rickard and Bajic had some idiosyncratic property that somehow masked or blocked underlying parallel cue processing. However, those experiments used perhaps the simplest possible design for exploring the issue, and there is no precedent suggesting that subjects would not have simultaneously retrieved from both cues with corresponding facilitation, if they could have. Rickard and Bajic considered a number of alternative accounts of their results, including race models and a subset of limited capacity parallel retrieval models and found none that was competitive with the simple assumption that their subjects could retrieve through only one cue at a time.

Rickard and Bajic (2004) proposed that the critical factor in determining whether facilitation will be observed in dual-cue recall situations is whether the two cue–response associations are acquired, and thus represented, independently. If this condition holds, then retrieval is possible through only one cue–response association at a time. We term this the *associative independence* hypothesis. Rickard (1997) proposed a process model of skill learning that implicitly embodies this assumption. Rickard and colleagues (Nino & Rickard, 2003; Rickard & Bajic, 2004) distilled that model into two principles that when combined yield a more specific *set–cue conjunction* model of dual-cued recall performance. The first principle states that goal-directed learning involves formation of a separate representation in long-term memory for each independently acquired conjunction of the presented cue and the task set (i.e., a set–cue conjunction). For example, if a subject has learned to respond by saying "4" when presented with the letter *M*, then the model assumes that a new node, representing the conjunction of the general (i.e., item nonspecific) task set "retrieve the digit" and the stimulus *M*, has been formed. This set–cue conjunction node is in turn associated with the answer "4." This configuration is presented graphically in Figure 2a for two independently learned associations having a common response.

The second principle states that only one of these set–cue conjunction nodes can be used at any given moment to retrieve a response. Activation from the task set and the cues flows in parallel to the set–cue level, but once a particular set–cue node is selected, activation of all other set–cue nodes drops to baseline, as does activation of any associated response node. Activation of a response can then proceed only through the selected set–cue node.[1] The set–cue model thus embodies an early stage, preretrieval, performance bottleneck

If it is assumed that the parallel processing from the cue level to the set–cue level in Figure 2a produces no or negligible facilitation in selecting a set–cue node, and thus in task RT,[2, 3] then at all points on the distribution, RTs for dual-cue items in the case of associative independence cannot be smaller than those for retrieval through the more efficient of the two component cues (i.e., the cue

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[1] In the simplest quantitative implementation of the set–cue model, one could assume two sequential, additive, and stochastically independent stages of processing: (a) selection of one set–cue node involving parallel processing, and (b) retrieval of the response only from the selected set–cue node. Activation cannot begin to flow from the set–cue level to the response level node until a set–cue node has been selected in the first stage.

[2] There are several reasons to expect this to be the case. First, if selection of a set–cue node reflects a race or other fast parallel process, then the variance in that component of the overall RT is likely small relative to the variance of the answer retrieval stage (i.e., following the set–cue selection stage), resulting in limited facilitation effects in the overall RT. Second, if the preretrieval bottleneck proposed in the set–cue model is correct, then it is possible that selection of a set–cue node on initial dual-cue trials involves some type of time consuming competition, as data from Rickard and Bajic (2004) suggest (see summary above). As such, that stage of processing could result in slowed performance relative to single-cue trials. Third, data from Nino and Rickard (2003) and Rickard and Bajic (2004) indicate that with sufficient dual-cue or dual-task practice, subjects adopt a strategy of retrieving first from a particular cue category (e.g., the left-side cue in Rickard and Bajic, 2004) or response category (e.g., the vocal response task in Nino and Rickard, 2003), in which case there can be no facilitation generated by the parallel processing from the cue level to the set–cue level.

[3] Note that in the cross-talk task explored in this article, subjects are instructed to retrieve using the top cue first (Experiments 1 and 2). Under this condition there can be no response facilitation on compatible cue trials according to the set–cue model, provided that the cue–response associations are independent (i.e., incorrect selection of the bottom cue for first task responding can only delay RT or result in an error). Thus, the set–cue model makes the strongest prediction of absolutely no facilitation for tasks in which instructions determine order of task execution (or, equivalently, when subjects always choose a particular stimulus or response category through which to retrieve first; see Footnote 2).

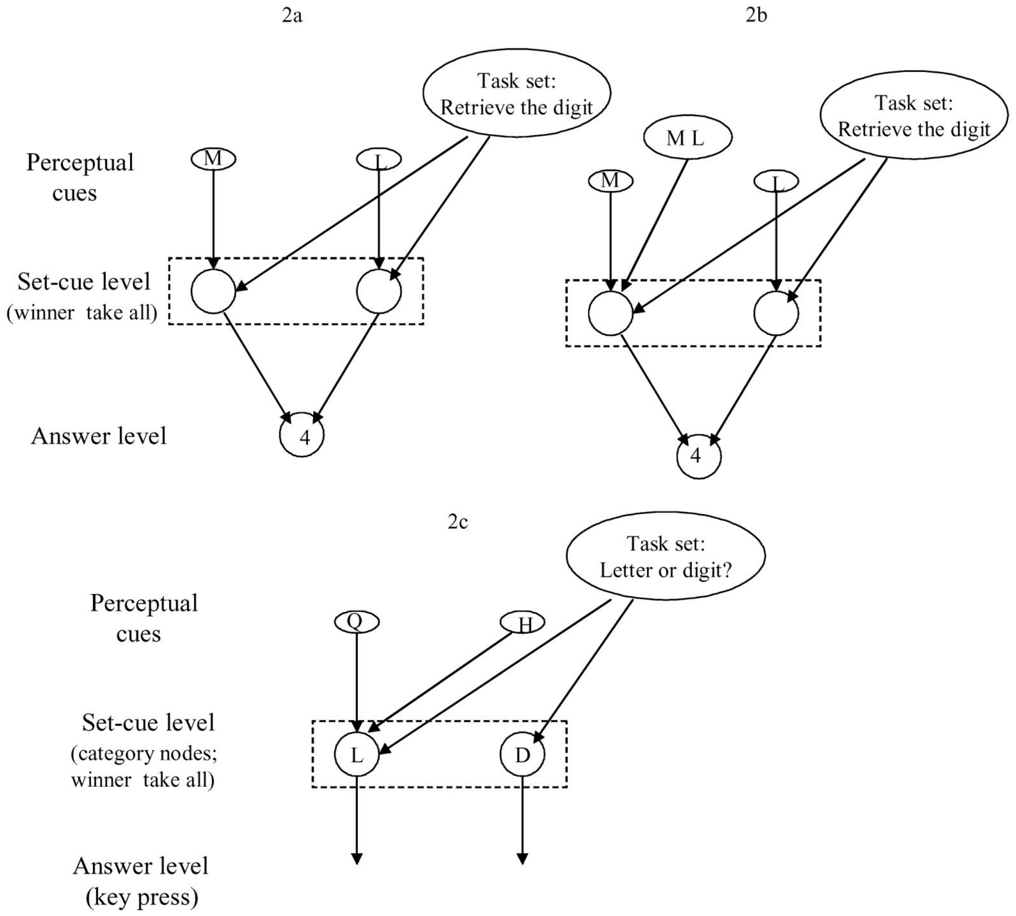

Figure 2. a: The case of two compatible cues independently associated with a common response as specified in the set–cue conjunction model. b: The case of dual-cue chunking for compatible cues as specified in the set–cue conjunction model. c: A possible representation, framed within the set–cue model, of activation convergence for compatible cues in the semantic categorization task.

producing the faster RT on average) when presented by itself (for further discussion see Rickard & Bajic, 2004). Consider the dual-cue item *M L*, in which the associations *M* → 4 and *L* → 4 were acquired in separate sets of single-cue trials, thus setting the condition of associative independence. If the cue *L* yields the faster RT distribution when presented by itself, then that distribution constitutes the lower bound for performance on *M L*. Rickard and Bajic (2004) termed this specific version of the more general set–cue framework the efficient selection model.

On the first two to three dual-cue blocks of the Rickard and Bajic (2004) experiments, mean RTs were actually above the efficient selection boundary across the entire distribution. This effect is sensible in the context of the set–cue model because the cue selection process may initially be inefficient and time consuming because of any of a number of factors. For example, even if subjects have a preferred cue for a given dual-cue item, there may often be brief distraction to the other cue. The possibility that newly presented, nontarget objects can override control in this way is consistent with findings in the attentional capture literature (e.g., Folk & Remington, 1999).

After a modest number of practice blocks, however, dual-cue RTs in Rickard and Bajic's (2004) experiment converged on the efficient selection prediction over the entire distribution. Provided that the two cues of each dual-cue item were left–right reversed from trial to trial (i.e., if *M L* was presented on the first block, *L M* was presented on the second block), this RT convergence held throughout as many as 20 repetitions of each dual-cue item. From the standpoint of the set–cue model, it appears that left–right reversal of dual-cue items from trial to trial prevented or delayed dual-cue chunking (i.e., rerepresentation of the two letters as a single unit, much as letters appear to be chunked into word units; e.g., Liang & Healy, 2002), thus maintaining associative independence throughout practice.

When cues were not spatially reversed from trial to trial (Rickard & Bajic, 2004, Experiments 2, 3, and 5), dual-cue RTs fell below the efficient selection boundary toward the end of practice. However, when those cue pairs were subsequently left–right reversed (Experiment 2) or recombined (Experiment 5) on a transfer test, dual-cue RTs jumped back above the efficient selection boundary. Rickard and Bajic (2004) concluded that because of the constant spatial configuration of the dual-cue items in those experiments during practice, dual-cue chunking was possible, allowing the two cues to be processed as a single cue, thus eliminating the associative independence status of the cue–response associations. On the transfer tests, however, the chunked representations were no longer accessible, and thus dual-cue facilitation was not possible.

To accommodate these results, Rickard and Bajic (2004) elaborated the set–cue model with a simplest-case chunking account. Essentially, the chunked dual-cue representation latches onto the already existing set–cue node for the more efficient cue, resulting in facilitated retrieval latency due to greater salience and (or) activation rate (see Figure 2b). In this model, the retrieval pathway for the less efficient cue plays no role in chunked dual-cue recall. Hence, even in the case of chunked dual-cues, only one associative pathway (from the set–cue level to the response level of representation) at a time is involved in cued recall. This chunking model, which has one free parameter, provided a nearly exact fit to the dual-cue RT distributions toward the end of practice in Experiments 2, 3, and 5 of the Rickard and Bajic study.

In summary, Rickard and Bajic (2004) proposed two nested principles for explaining dual-task and dual-cue performance in cued-recall tasks. The first and broader of these is the associative independence hypothesis, according to which memory retrieval takes place through only one independently learned cue–response association at a time. If, on the other hand, associative independence does not hold (e.g., due to dual-cue chunking), then parallel retrieval may be possible. Operationally, we assume that associative independence can be achieved by training subjects on novel cue–response associations on a series of independent trials prior to beginning the dual-cue phase of the experiment. The second proposal, the set–cue model, is a more specific process implementation of the associative independence hypothesis. This model specifies more precisely both the nature of the retrieval architecture (as is relevant for understanding attentional constraints on cued recall) and the locus of the retrieval bottleneck in the information processing stream.

It is surprising that associative independence has not been tested to date, outside of the Rickard and Bajic (2004) study, as a basic construct in explaining attentional constraints on memory retrieval. Our proposal is that associative independence status is a central, if not the central, explanatory variable in the area of attention and memory retrieval, at least for explicit memory tasks such as cued recall. Even if the more specific set–cue model proposed by Rickard and Bajic proves to be false, it seems quite likely that associative independence status influences dual-retrieval processes in some important sense.

The main purpose of this study was to further test the associative independence hypothesis and the set–cue model for dual-cued recall by use of the same cross-talk design that Logan and Schulkind (2000) used to demonstrate cross-talk facilitation in letter and digit categorization. In the first two experiments, the manipulations, perceptual properties of stimulus presentation, and the timing of events within an experimental trial were nearly identical to those of Logan and Schulkind (2000, Experiment 1). The cognitive task, however, was changed from semantic categorization to cued recall of novel and independently learned paired associates.

Specific Model Predictions

The Set–Cue Model

The set–cue model allows for three possible patterns in the data for the cross-talk task when the cue–response associations are independent. The first and simplest case is that of no main effects and no interaction involving either the compatibility or the SOA manipulations; if subjects must select a single cue for retrieval on each trial, and if they always correctly select the cue for the first task, then the second task cue may not influence first task performance. Here and elsewhere, first task (Task 1) refers to the retrieval of the response from the priority (top) cue, and second task (Task 2) refers to retrieval of the response from the secondary (bottom) cue.

However, if one allows for the possibility of cue distraction (temporary distraction to the nontarget cue at the outset of the trial; see Rickard & Bajic, 2004), then two other patterns in the data might be observed under the condition of associative independence. First, under the assumption that the cue for the second task is progressively less distracting to first task performance as SOA increases, the model is consistent with a negative SOA slope for first task RTs in both the compatible and the incompatible conditions, along with no effect of compatibility and no SOA × Compatibility interaction (see Figure 3a). Note that for the compatible condition, this pattern is the opposite of that observed by Logan and Schulkind (2000).

Second, distraction to the second task cue during first task performance could result in partial retrieval or priming of the second task response before attention is switched back to the first task cue. If the cues for the two tasks are incompatible, having two different responses, then a competition process may ensue at the response level, further delaying response selection for the first task

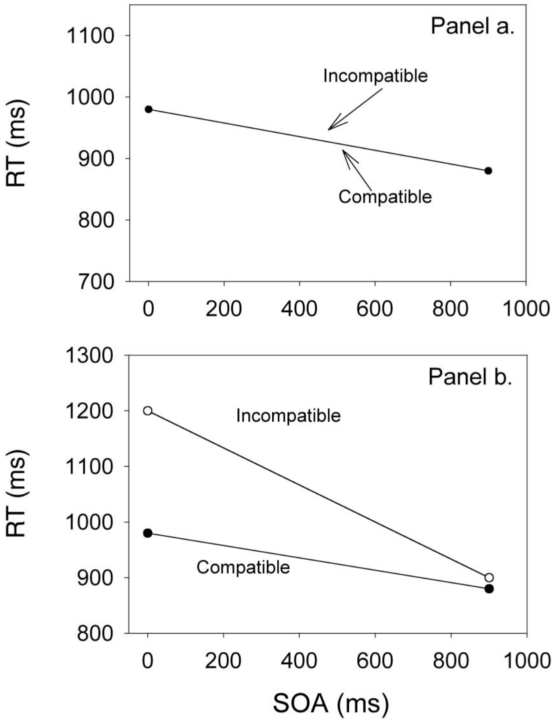

Figure 3. a: The first task response time (RT) prediction of the set–cue conjunction model for independent, compatible cues in the case of cue distraction only. b: The first task RT prediction of the set–cue conjunction model for compatible, independent cues when cue distraction activates a competing response from the second task. SOA = stimulus onset asynchronicity.

(see Rickard & Bajic, 2004, for more discussion of how dual-cue interference might be accommodated within the cue selection framework). Thus, if and only if there is cue distraction, there could be an interaction between SOA and compatibility, taking the form of a steeper negative SOA slope for the incompatible than for the compatible condition (see Figure 3b). Stated differently, performance in the compatible condition would suffer only relatively modest interference, due to cue distraction itself, whereas performance in the incompatible condition could suffer from the same base distraction effect, plus possible interference at the response level because of competition between two different activated responses.[4]

For Experiments 1 and 2, in which the cue–response associations are independent, the set–cue model cannot accommodate a positive SOA slope in the compatible condition (i.e., dual-cue facilitation). Thus, the set–cue model cannot accommodate either of the outcomes that seem most likely a priori on the basis of previous cross-talk data from related tasks and of the basic properties of potentially applicable parallel models (such as those developed to date for the Stroop task). For a flowchart summary of the model's predictions in the case of associative independence (as well as violation of associative independence; to be discussed later), see the Appendix.

Parallel Retrieval Models

A parallel retrieval model, on the other hand, is most consistent with cross-talk facilitation (a positive SOA slope) in the compatible condition. A race version of a parallel model (for discussions see Colonius & Ellermeier, 1997; Colonius & Vorberg, 1994; Logan, 1988; Miller, 1982; Townsend & Ashby, 1983) predicts cross-talk facilitation, at least in the 0-ms SOA condition, provided only that the RT distributions of the two cues overlap for at least some dual-cue pairs (the empirically derived race model predictions in the Rickard & Bajic, 2004, study support this assumption) and that the retrieval latencies for the two cues across trials do not have large positive correlations.[5] Because there must be some mechanism in a parallel retrieval model for accurately deciding which candidate responses to execute when more than one possible response is activated (Nosofsky & Palmeri, 1997), and because that decision process is likely to be time consuming, a viable race model would also appear to predict cross-talk interference in the incompatible condition, as indicated by a negative SOA slope. In this light, the null effect of SOA on mean RTs in the incompatible condition of the Logan and Schulkind (2000) experiments may not be easy to reconcile with a parallel retrieval model. We return to this point in the General Discussion.

Other varieties of parallel models, such as limited capacity parallel retrieval models, are not constrained to predict dual-cue facilitation in the compatible condition. Nevertheless, dual-cue facilitation has not been difficult to observe in other task domains, so a finding of no facilitation in the current case would suggest that there is something notably different about processing in the current tasks. Further, as discussed later, the cross-talk design affords several quantitative approaches to testing specific predictions of limited capacity models.

Response Grouping

The empirical predictions outlined above are predicated on the assumption that subjects will not adopt a strategy of grouping their task responses, that is, they will execute their Task 1 and Task 2 responses as each becomes available, instead of waiting until both responses have been retrieved before either is executed. There is always the possibility of response grouping in dual-task experiments. In investigations of two retrievals from a single cue, Rickard and Pashler (2004) and Nino and Rickard (2003) observed grouping effects for about one third of their subjects. However, in other unpublished work, we have found that subjects can usually control this tendency if instructed not to group. Following Logan and Schulkind (2000), we phrased subject instructions in a way that should discourage response grouping.

There is also a good diagnostic for response grouping in the cross-talk task design. Specifically, if the Task 1 SOA slope is positive in the incompatible condition, then some sort of response grouping is likely. According to a sequential retrieval model such as the set–cue model, neither SOA slope should be positive. According to a parallel retrieval model, the Task 1 SOA slope may well be positive in the compatible condition, reflecting cross-talk facilitation (e.g., Logan & Schulkind, 2000), but it should be negative (or at least not positive) in the incompatible condition, reflecting decreasing interference from the second task cue with increasing SOA. Therefore, preliminary subject-level analyses were conducted, and data from any subject that exhibits this pattern were not analyzed further.

Experiment 1

In this experiment we kept the stimulus–response set, the single-task training, and the response modality (vocal) nearly identical to those used in Rickard and Bajic's (2004) Experiment 1 and also adopted Logan and Schulkind's (2000) cross-talk dual-task design for the test phase.

Method

Subjects. Twenty University of California, San Diego undergraduate students participated for course credit.

Materials, design, and procedure. Test stimuli consisted of 12 capital letters (3 mm × 5 mm). Responses consisted of spoken digits, 1 through 6, with each digit serving as the response for 2 different letter stimuli. Twelve pairs of letters were generated from these stimuli, such that 6 of them were compatible (both letters having the same response) and 6 were incompatible. Incompatible pairings were selected randomly. We tested subjects individually using IBM-compatible personal computers, with each subject

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[4] Distraction could result in priming of the Task 2 response in the compatible condition as well. However, no RT facilitation would be expected, relative to RTs on compatible trials with no cue distraction (e.g., at long SOAs). In a sequential retrieval model such as the set–cue model, switching of attention from one set–cue node to another would take time and could only hamper the retrieval process, even if the two cues have the same response. The fastest performance is achieved when 100% of time and attention throughout the trial is focused on the target retrieval, a condition which obviously does not hold if there is cue distraction.

[5] A correlation of 1.0 represents a special case in which the race and efficient selection models make identical predictions. Given that dual-cue facilitation has been easily shown in other task domains, however, an absence of facilitation in the current experiments cannot plausibly be attributed to a strong positive correlation in dual-cue retrieval latencies (i.e., there is no reason to expect that such a strong correlation would be present in the current experiments but not in others).

seated approximately 50 cm from the computer screen and approximately 5 cm from a microphone. All experiments were programmed with Micro Experiment Laboratory software (Version 2.01; Micro Experimental Laboratory Professional, 1998) and the accompanying voice key apparatus (Model 200A, Psychology Software Tools, Pittsburgh, PA). Prior to each phase of the experiment, instructions were presented on the screen and were also read aloud by the experimenter.

The first phase of the experiment involved single-cue letter–digit learning. This phase proceeded in the following sequence: (a) Subjects studied half of the letter–digit associates, one at a time; (b) they received practice recalling the digits for this subset, 1 letter stimulus at a time, until learning criteria were met; (c) they studied the 6 remaining letter–digit associates, as before; (d) they performed the recall task for these 6 items, as before; and (e) they performed the recall task with all 12 single-letter stimuli mixed over trials until they again reached performance criteria. In our experience, this sequence of learning steps leads to faster mastery of the recall task than would initial study of all 12 letter stimuli. Further, in this design, 2 letter stimuli associated with the same digit response were never present in the same subgroup, minimizing opportunities for stimulus chunking.

During initial study, each trial included simultaneous visual presentation of one letter and one digit, along with instructions to "memorize the answer." After 5 s, these instructions were replaced with instructions to speak the correct response into the microphone. Subjects received three mandatory study blocks (with one block involving one randomized presentation of each item) and the option of a fourth such block.

Subjects then received the blocks in which they had to recall the answers from memory. Each trial consisted of a 500-ms fixation asterisk, followed by a 200-ms delay, followed by the presentation of the letter stimulus. After the subject responded and the voice key tripped, the experimenter entered the subject's response and recorded whether the voice key tripped properly. If the subject was in error, the correct response was presented for 500 ms. At the close of each block, the screen presented feedback on accuracy and mean RT. These blocks continued until the subject completed two consecutive blocks with 100% accuracy, achieved a mean RT no greater than 1 s for correct responses, and completed a minimum of 5 blocks total. This study and training sequence was then repeated for the second subset of six letter stimuli; the only change was the additional constraint that the mean RT for the last block had to be roughly equal to or less than that of the last recall block of the first stimulus subgroup.

At the close of this phase, each subject received the recall blocks (structured like those above) for the complete set of 12 individually presented letters. These concluded when the subject completed two consecutive blocks with 100% accuracy and achieved a mean RT (for correct responses) of no more than 1 s on the last block.

Phase 2 was the dual-task portion of the experiment. Instructions for this phase informed the subjects that each trial would involve the presentation of two letter stimuli, one above the other, and that the subjects should respond first to the top letter and then to the lower. Subjects were notified that the lower letter would sometimes appear after the higher one and were instructed to respond to the upper letter as soon as possible rather than waiting for both letters to be presented. They were instructed to respond as quickly as possible for both tasks while maintaining high accuracy.

Details of the dual-task phase matched those of the Logan and Schulkind (2000) study (Experiment 1) in nearly all respects. Each trial began with the presentation of a 500-ms fixation field in the center of the screen. This consisted of two hyphens separated by three spaces on one row near the middle of the screen and an identical configuration of two hyphens on the row immediately below. The central blank space on each row marked the location where each of the test stimuli would appear. On each trial, the first letter of each pair (the first task stimulus) would appear on the top row, followed by the second letter (second task stimulus) below, with SOAs of 0, 100, 300, or 900 ms. Both letters disappeared 1,000 ms after the appearance of the second letter. Each block of testing contained 12 trials, with each of the 12 possible compatible and incompatible letter pairs occurring once. In each block, three letter pairs appeared in each of the four SOA conditions. The top–bottom ordering of each pair was reversed from block to block, a manipulation that Rickard and Bajic (2004) found to preserve associative independence throughout multiple presentations of each cue pair, as noted earlier. Eight blocks (96 trials) were required for each letter pair and its reversal to occur in each of the four possible SOA conditions. Subject to the constraints above, assignment of each letter pair to its SOA condition in each block and the order in which the letter pairs were presented within each block were determined randomly. There were a total of 16 blocks in the testing phase of the experiment, with a brief break after the 8th block.

Because of the technical difficulty of obtaining two consecutive voice key latencies on a dual-cue trial, RTs in this experiment were collected only for the critical first task response. Second task RTs played a negligible role in theoretical conclusions reached by Hommel (1998) and Logan and Schulkind (2000) in their cross-talk designs. To better integrate notation in this experiment with that of Experiment 2, wherein RT is measured for both tasks, Task 1 RT is referred to as RT_1.

Results and Discussion

Voice key failures occurred on 2.2% of trials. These trials were removed from the error and mean RT_1 analyses. Error rates for the first task (computed for each subject and then averaged over subjects) at the 0-, 100-, 300-, and 900-ms SOA levels were, respectively, .044, .046, .045, and .050 for the compatible condition and .077, .080, .071, and .051 for the incompatible condition. There was no discernable effect of SOA in the compatible condition but a trend toward decreasing error rates with increasing SOA in the incompatible condition. Averaging over the SOA levels, we found fewer errors in the compatible condition than in the incompatible condition for 16 of 20 subjects ($p = .006$ in a sign test).

Of primary interest were the RT_1 results. In preliminary analyses, no subjects were observed to have a positive SOA slope in the incompatible condition. Thus, response grouping apparently did not occur for any subject. RT_1s of less than 300 ms were removed as outliers prior to analysis.

Mean correct RT_1s, computed for each subject and then averaged over subjects, are shown in Figure 4, separately for the two compatibility conditions and the four SOA levels. Also shown are 95% repeated measures confidence intervals for each mean (Loftus, 2002). A central result is that in the compatible condition, RT_1 did not increase with increasing SOA but rather decreased at the 900-ms level. Performance in the incompatible condition was

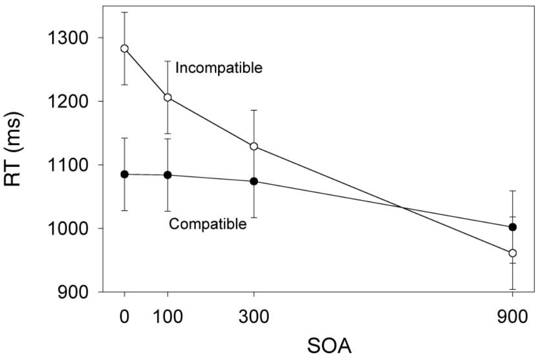

Figure 4. Mean response time (RT) in Experiment 1 as a function of task condition (compatible or incompatible) and stimulus onset asynchronicity (SOA; in milliseconds). Error bars represent 95% confidence intervals.

much slower than in the compatible condition, but this effect dissipated with increasing SOA, as expected.

A factorial within-subject analysis of variance (ANOVA) with factors of SOA (0, 100, 300, and 900 ms) and compatibility (compatible vs. incompatible) was performed on the subject-level mean RT_1 data. Here and elsewhere, the same ANOVAs were also performed on the log RT_1s. The patterns of significance for these two dependent variables were the same unless otherwise noted. The effects of compatibility, $F(1, 19) = 18.78$, $p < .001$, $MSE = 14{,}866$; SOA, $F(3, 57) = 14.90$, $p < .001$, $MSE = 20{,}647$; and their interaction, $F(3, 57) = 7.46$, $p < .001$, $MSE = 13{,}785$, were all highly significant. In an analysis limited to only the compatible condition, the effect of SOA was still significant, $F(3, 57) = 2.81$, $p = .048$, $MSE = 11{,}246$, suggesting, from the standpoint of the set–cue model, a cue distraction effect on at least some trials when the second cue was presented within the first 300 ms. Given the data suggest that cue distraction did occur, the steeper SOA slope for the incompatible condition can be accommodated by the set–cue model as a consequence of response competition following cue distraction on some percentage of distraction trials.

It appears that the Rickard and Bajic (2004) results were not due to some unique, unidentified property of their task design. Rather, it appears that cross-talk facilitation may not occur for retrieval from two independent cue–response associations under any task conditions. The current results are consistent with both the associative independence hypothesis and the set–cue model. Alternative accounts need to be considered, however. First, it is possible that subjects can retrieve from both cues in parallel but that the consequent RT_1 facilitation for the first task response was masked in the averaged data by response grouping on some fraction of trials. A pure grouping account, in which subjects always grouped responses, is easily rejected because of the fact that the mean RT_1s in the incompatible condition did not increase from the 0-ms to the 900-ms SOA levels. It remains possible, however, that response grouping occurred frequently at the 0-ms SOA level but became monotonically less frequent with increasing SOA. This scenario, if combined with a parallel retrieval process (such as a race) that can produce cross-talk facilitation when responses are not grouped, can in principle generate the patterns of mean RTs in the compatible condition seen in Figure 4.

The scenario is depicted in Figure 5, which shows hypothetical data patterns for the compatible task. The black circles represent the cumulative RT distribution quantiles (where increasing quantile values represent increasing cumulative frequency) of a hypothetical reference condition in which only a single cue is presented on each trial. The diamonds represent the distribution of RT_1 for the compatible condition at the 0-ms SOA level in the cross-talk task. On the low side of that distribution, RTs are faster than for the single-cue reference condition, reflecting the facilitation effect of the race on nongrouped trials. On the high side of that distribution, RT_1s are slower than for the single cue reference condition, reflecting the delay in first task responding induced by response grouping on those trials (here, RT_1 effectively reflects the time required to retrieve the answer from both cues in parallel). In this example, the effect of the response grouping more than offsets the facilitation when subjects do not group responses, resulting in a mean RT_1 that is slower than that for the single-cue reference condition. The open squares represent the distribution of RT_1 for the compatible condition at the 100-ms SOA level in the cross-talk task. On the low side of that distribution, RT_1s are again faster than for the single cue reference condition because of the parallel facilitation when the subject does not group responses, but the facilitation effect is smaller, reflecting the 100-ms delay in the onset of the second cue. On the high side of that distribution, RT_1s are again slower than for the single cue reference condition, reflecting the delay in first task responding induced by response grouping on those trials. If grouping is assumed to occur less often in the 100-ms than in the 0-ms SOA levels, then the net result for the 100-ms SOA level could be a mean RT_1 that is similar to that for the 0-ms SOA levels and again slower than that of the single cue reference condition. The same reasoning can be applied to the 300-ms SOA condition, represented by the triangles. In this overall scenario, mean RT_1s of the 0-, 100-, and 300-ms SOA levels are roughly equivalent and slower than in the hypothetical single-cue reference condition. This outcome would seem an unlikely coincidence, but in principle it cannot be ruled out on the basis of the observed mean RT_1s.

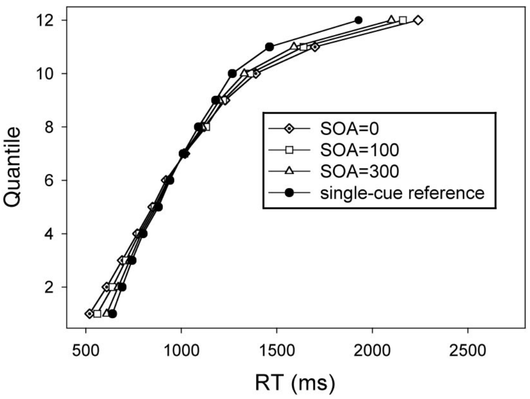

Figure 5. Hypothetical response time (RT) distribution data for the compatible task for the case in which subjects can retrieve in parallel, resulting in RT facilitation, but also can group their responses on some trials. SOA = stimulus onset asynchronicity (in milliseconds).

Although there was no pure single-cue reference condition in this experiment, the 900-ms SOA level provides a proxy for it. At that SOA level, the first task was likely completed, or nearly completed (probably in the motor output stage) on the majority of trials by the time the second cue was presented. Thus, the 900-ms condition can be treated as a close approximation to the ideal reference condition. The validity of this treatment is supported by the fact that the effect of compatibility was no longer significant in the 900-ms SOA condition (see Figure 4).

To test for, among other things, the possibility of a mixture of grouping and no-grouping trials combined with parallel retrieval resulting in facilitation, we computed cumulative distributions for each SOA level of the compatible condition using methods similar to those described in Rickard and Bajic (2004). There were 12 stimuli for each subject. Each of these stimuli was presented two times as the top stimulus in each of the four SOA levels of the compatible condition over the course of the experiment. For each subject, and separately for each of the four compatible SOA levels, the mean of the two RT_1s for each item was computed, and then those mean RT_1s were sorted, from smallest to largest, producing 12 quantiles of a distribution for each of the four SOA levels for each subject. Here and in subsequent distribution analyses, error trials were excluded. Because error rates were low and because each quantile estimate for each subject was based on two observations, this resulted in only seven missing values in the subject-level quantile estimates (0.7% of all estimates). Once these subject level distribution quantiles were computed, the values of each quantile were averaged over subjects to obtain an overall RT distribution for each SOA level with 12 quantiles. That is, the subject level means for the first quantile were averaged together to form a grand mean for the first quantile (at each SOA level), the subject level means for the second quantile were averaged together to form a grand mean for the second quantile, and so forth. Note that a stimulus item that happened to occupy a given quantile for one subject was not necessarily in the same quantile for another subject. The quantile ordering for each subject was done purely on the grounds of relative RT. Because an identical procedure for deriving the distribution quantiles was used for all SOA levels and because all items were represented in all SOA levels with counterbalancing, valid comparison of relative distribution shapes over conditions can be made.[6]

The results for each SOA level are shown in Figure 6. For reference, the mean of the 0-, 100-, and 300-ms SOA condition distribution estimates is also shown. For the 0-, 100-, and 300-ms SOA levels, the RT_1s were slower than in the 900-ms control condition across the entire distribution. This result rules out the possibility of a mixture of grouped and nongrouped trials in which the underlying retrieval process was parallel and yielded RT_1 facilitation on nongrouped trials. Matched *t* tests performed on each distribution quantile (for precedent and validating simulations see Miller, 1982, Footnote 3) comparing the 900-ms SOA level with each of the other three SOA levels revealed significant effects for 10, 10, and 9 of the 12 quantiles for the 0-ms, 100-ms, and 300-ms conditions, respectively. It should be kept in mind that these are nonindependent comparisons because the 900-ms reference condition was used in all three cases. Nevertheless, the general pattern seems clear, and there will be opportunities for replication.

The apparent absence of any interaction in the distribution shapes over SOA levels also speaks against at least some limited capacity parallel retrieval accounts in which there is no response grouping. Rickard and Bajic (2004), for example, discussed a straightforward, single-parameter limited capacity parallel retrieval model that predicts less skew in dual-cue data than in single-cue data. Further, it is not expected that the shape of a distribution involving any type of parallel retrieval would closely match that of a distribution known to reflect only a single retrieval (e.g., the 900-ms SOA condition). Rickard and Bajic also found highly similar distribution shapes when comparing single-cue performance with dual-cue performance in multiple distribution fits to five data sets. When there was good reason to believe that subjects were able to perform whatever process was available to them with maximum efficiency (as a result of practice), the match between the shapes and locations of the dual-cue and efficient selection (or efficient selection plus chunking) distributions was excellent, nearly exact in many cases. These close distribution matches are certainly not predicted by any current limited capacity model, and it seems unlikely that any future model could be developed that would be constrained to predict them, unless in a purely post hoc manner.

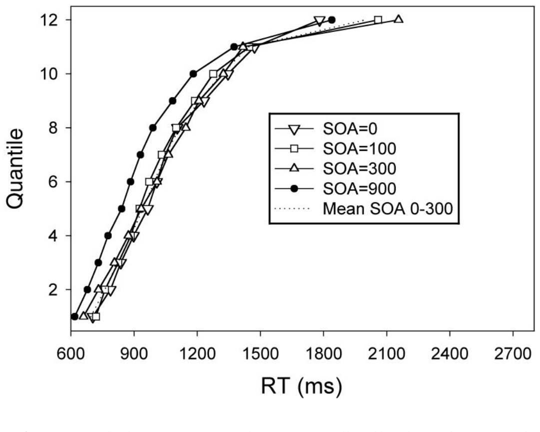

Figure 6. Cumulative response time (RT) distributions in Experiment 1 for each SOA level of the compatible condition. The mean of the 0–300-ms stimulus onset asynchronicity (SOA) conditions is overlaid.

On the basis of these patterns, we propose here a more detailed model of cue distraction and response interference within the set–cue framework. A basic assumption in the model is that the RT_1 distributions in the 0-, 100-, and 300-ms SOA conditions, without the cue distraction component, are identical to the idealized case in which no second cue appears until the first task is completed on all trials. As noted, the 900-ms SOA RT_1 distribution provides an approximation of this ideal. Second, we assume that there was unavoidable distraction caused by the onset of the second task cue up to at least the first 300 ms after the first task cue is presented. If this distraction is outside of the subject's control and occurs prior to the retrieval phase of processing, it is reasonable to assume that it would have roughly the same latency regardless of item difficulty (i.e., memory retrieval latency). Thus, it should result in an upward shifted RT_1 distribution for the 0-, 100-, and 300-ms levels of the compatible conditions, relative to the 900-ms control level, with minimal interaction with quantile (though it could result in a slight positive interaction with quantile if the variance of the distraction latency is nontrivial relative to that of the other components of task processing). This outcome holds to a reasonable approximation even if cue distraction does not occur on every trial.[7] The data in Figure 6 are generally consistent with this account.

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[6] To make valid inferences about relative performance in the different SOA levels (e.g., whether the distributions cross over), we do not require that the computed empirical distributions faithfully reproduce the distributions in the underlying populations. We only require that identical procedures are used to create the quantile values for all of the SOA levels, that each item and subject is represented at each SOA level, and that there is proper counterbalancing. If distortion in distribution shape (relative to the population distribution) is present because of averaging, it will be the same for all four SOA levels under the null hypothesis of no effect of SOA; for further discussion of this point, see Rickard and Bajic's (2004) study. We are not attempting to fit parametric models to these distribution data, and thus the very real concerns about shape bias and sample size, which should be heeded in parametric modeling (e.g., Van Zandt, 2000), do not apply.

[7] Simulations showed that if cue distraction happens on only a fraction of trials (say 50%) then there would be an interaction with quantile, such that the latency distribution for the 900-ms SOA level will converge with those of the other SOA levels at the lower tail and diverge from the other SOA levels at the upper tail. However, provided that the variability of the cue distraction latency is modest relative to the variance in the base retrieval RTs, then the model's prediction of a constant RT increment for the 0-, 100-, and 300-ms SOA levels, relative to the 900-ms SOA level, holds to a close approximation for all but the extreme lower and upper quantiles.

Because of the strong evidence that two letters can be perceived in parallel (Egeth & Dagenbach, 1991; Pashler & Badgio, 1985; Shiffrin & Gardner, 1972; Van der Heijden, 1975), this cue distraction effect presumably occurs after perception but before answer retrieval. The intermediate set–cue conjunction level of representation (see Figure 2a) is a natural candidate locus. We suggest that distraction to a nontarget (e.g., second task) cue only occurs when that cue has an independent association to its response and thus has an independent set–cue node. More specifically, we suggest that the process of activating the nontarget set–cue node when a nontarget cue is presented forces attention to that cue at least some percentage of the time, although Rickard and Bajic's (2004) results indicate that the distraction effect dissipates with dual-cue practice. We continue to refer to this effect as *cue distraction*, but from this theoretical perspective, it is occurring not at the cue level of representation but rather at the set–cue level of representation.

Experiment 2

In this experiment, we attempted to replicate the results of Experiment 1 while moving closer to the design of the Logan and Schulkind (2000) experiments in two respects. First, the response modality was switched from vocal to keypress. This change allowed us to evaluate the possibility that effects observed in Experiment 1 might be idiosyncratic to the vocal response modality. It also allowed us to record Task 2 RT (RT_2). Second, the stimulus–response mapping was changed to have the logical structure of two-choice categorization, just as in the Logan and Schulkind experiments. There were again 12 letter stimuli but in this case only two response possibilities: a "left" or a "right" keypress. In the subsequent dual-task phase, half of the trials involved either two left or two right responses (compatible trials), and the remaining trials involved a left and a right response.

The logic of the stimulus–response mapping in this case is consistent with a categorization task, but the actual learning trials were again a series of independent paired-associate cued-recall trials, just as in Experiment 1. According to the set–cue model, nothing of importance changed with respect to the underlying associative structure. Single-cue practice should have yielded an independent set–cue conjunction for each item, and thus no dual-cue facilitation should have been observed in the compatible condition at test. If this prediction holds, then the categorical logic of the Logan and Schulkind's (2000) task can be ruled out as a factor underlying their cross-talk facilitation effect. Such a result would instead suggest that the semantic categorization nature of Logan and Schulkind's task was the basis for the cross-talk facilitation.

Switching from a vocal to a key-press response modality introduces some added complexity. In Experiment 1, subjects probably retrieved their response first in a verbal form, so the vocal response modality was the most natural. The vocal responses were likely executed automatically, without need of any additional resource-demanding cognition. In the current experiment, it was less clear whether subjects would have a verbal, spatial, or motor level representation of the response. There was also the possibility that they would need to transcode their native response representation for response execution. For example, they may transcode a verbal response into a manual response in a postretrieval stage of processing.

The influence of these factors probably can be minimized simply by having subjects use the left-hand pointer finger to make a "left" keypress response (on the left side of the keyboard) and the right-hand pointer finger to make a "right" response (on the right side of the keyboard). However, in the compatible condition of a dual task, this design requires that the subject press the same key, with the same finger of the same hand, twice on each trial. Although this repetition should not bias first task performance, it could spuriously facilitate, or perhaps inhibit, second task responding.

An alternative design, similar to that used by Logan and Schulkind (2000), has subjects make their response to the first task by pressing one of two keys with one hand, and then make their response to the second task by pressing one of two keys with the other hand. For example, they might use the middle and pointer fingers of their left hand to make a "left" or "right" response (respectively) to the top stimulus and use the pointer and middle finger of their right hand to make a "left" or "right" response to the bottom stimulus. This design avoids the finger press repetition effect. However, it introduces somewhat greater complexity in the response mapping. There appears to be greater potential in this case for extraneous interference effects, especially if there is cue distraction or brief confusion about which hand to use at the beginning of a trial. Subjects must remember which hand to use for which task and which finger goes with which response (left or right) for each hand. Moreover, given that there are only two abstract responses, "left" and "right," and that the cues of each pair are top–bottom reversed on each block, it seems likely in this case that subjects would first retrieve the response in an abstract or verbal representation and then transcode it into the correct finger response for whichever hand is appropriate on a given trial.

As a general rule, it is reasonable to expect that the farther the response requirement is from the native response representation, the greater the possibility of a confound. This heuristic favors the simpler, two-finger response design. Nevertheless, because there seems to be no ideal design for translating responses from vocal to manual format in this case, we chose to run a separate set of subjects in each of the two keypress response designs outlined above. If similar patterns of results are obtained, then response requirements can be ruled out as a major factor underlying the results.

Method

Subjects. Twenty-seven University of California, San Diego undergraduate students participated for course credit. Twelve subjects were run in the two-finger response version, and 15 were run in the four-finger response version.

Materials, design, and procedure. The stimuli and design were the same as those in Experiment 1, with the exceptions listed below. For the 12 letter stimuli, there were only two possible responses: a "left" response and a "right" response. As in Experiment 1, the stimuli were divided into two independently trained subsets. Here, though, each subset contained three stimuli associated with a "left" response and three associated with "right." As in the previous experiment, no two stimuli from the same subset were combined in the dual-cue phase of the experiment. Each portion of the initial learning phase (individual stimuli from Subset 1, from Subset 2, and from both subsets combined) concluded when the subject completed two consecutive blocks with 100% accuracy and achieved a mean RT for correct responses that was less than 800 ms.

In the two-finger response condition, subjects pressed the *V* key with the index finger of their left hand to make a "left" response and the *M* key with the index finger of their right hand to make a "right" response. In the four-finger (one hand per task) response condition, subjects placed the middle and index fingers of their left hand on the *X* and *C* keys (corresponding to "left" and "right" responses, respectively) and the index and middle finger of their right hand on the "<" and ">" keys (also corresponding to "left" and "right"). Half of the subjects used the left hand to respond to the top stimulus in each trial of the dual-task phase, whereas the other subjects used the right hand to respond to the top stimulus. All 18 compatible cue pairs consisting of one cue from each of the six-stimulus subsets, as defined for the initial learning phase, were used in the test phase. Eighteen incompatible cues were also selected in an analogous manner. Each cue was present in three compatible and three incompatible cue pairs per block. There were eight test blocks, each with 36 trials. Over the course of those blocks, each of the 36 stimulus pairs was presented eight times (once with each of the two stimuli on top crossed with each of the four SOA conditions). RT and error data were collected for both Task 1 and Task 2.

Results: Two-Finger Response Subjects

The Task 1 error rates were .027, .023, .018, and .020 in the four (0, 100, 300, and 900 ms, respectively) SOA levels in the compatible condition and .047, .045, .016, and .039 in the same four SOA levels of the incompatible condition. The Task 2 error rates were .071, .080, .066, and .097 in the four (0, 100, 300, and 900 ms, respectively) SOA levels in the compatible condition and .043, .033, .039, and .035 in the same four SOA levels of the incompatible condition. For Task 1, 10 of 12 subjects had higher accuracy in the compatible condition ($p < .02$), but for Task 2 all 12 subjects had higher accuracy in the incompatible condition ($p < .0001$).

The crossover interaction, such that for Task 1 the error rates are higher in the incompatible condition whereas for Task 2 they are higher in the compatible condition, was not expected. The most obvious explanation is that the subjects had a bias to press the key for Task 2 that was opposite of that selected for Task 1. Perhaps there is a tendency toward inhibition of repetition, which in turn may bear some relation to inhibition of return (e.g., Pratt & Castel, 2001). There are two obvious candidate loci of this inhibition. First, it may occur at the motor stage of processing, at the level of the finger movement. Second, it may operate at a cognitive level, such as the verbal representation of "left" or "right" or a spatial representation of the two key locations. The four-finger response data set allows us to investigate these possibilities. If the locus of interference is in the motor stage or in a spatial representation stage, then the elimination of the finger and location repetition inherent to the two-finger response design should reverse the compatibility effect for Task 2. On the other hand, if the locus is at the stage of a generic verbal representation of "left" or "right," then the same reversed Task 2 error pattern should be observed in those data.

Preliminary analysis of the two-finger response data revealed no positive SOA slope for RT$_1$ in the incompatible condition for any subject, suggesting little or no response grouping. The mean correct RT$_1$s for these subjects are shown in Figure 7. The results for the compatible condition are quite similar to those of Experiment 1. RT$_1$s were roughly equivalent over the first three SOA levels but were substantially faster at the 900-ms level. In these data, however, the effect of compatibility observed in Experiment 1 was absent. In the within-subject ANOVA, there was no effect of compatibility, $F(1, 11) = 0.01$, $p > .20$, $MSE = 16{,}164$, and no Compatibility × SOA interaction, $F(3, 33) = 0.91$, $p > .20$, $MSE = 3{,}520$. There was a significant main effect of SOA, $F(3, 33) = 6.06$, $p < .01$. $MSE = 11{,}710$, reflecting the drop in RT$_1$s for the 900-ms SOA level for both compatible and incompatible items. These results were again consistent with cue distraction at the earlier SOA levels. Response modality and number of response alternatives were ruled out as factors underlying the results for the compatible condition in Experiment 1. A logical categorical structure among the items was also not sufficient to yield facilitation.

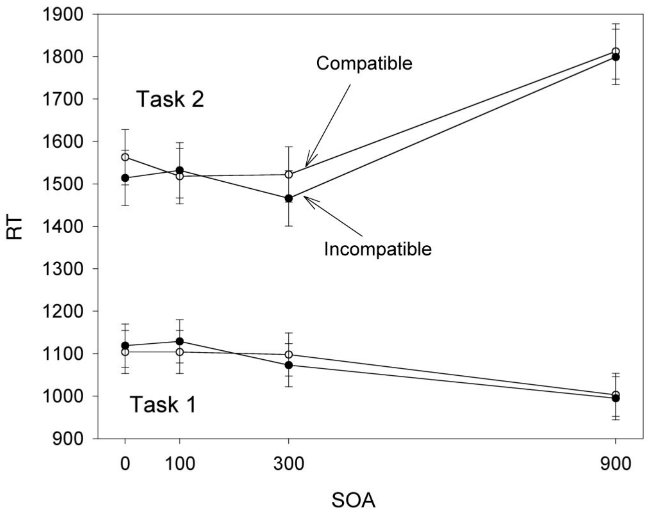

Figure 7. Mean response time (RT; in milliseconds) in Experiment 2 (two-finger response subjects) as a function of task condition (compatible or incompatible) and stimulus onset asynchronicity (SOA; in milliseconds). Error bars represent 95% confidence intervals.

Distribution analyses comparing the 900-ms SOA Task 1 compatible condition with the 0–300-ms conditions (identical to those conducted earlier) also yielded results reminiscent of those in Experiment 1 (see Figure 8). RTs in the 0–300-ms conditions were slower than those in the 900-ms condition throughout the distribution, and again there was no apparent interaction with quantile. In the quantile *t* tests, the 0-, 100-, and 300-ms conditions differed significantly from the 900-ms condition on 9, 8, and 7 of the 12 quantiles levels, respectively.

The total latency from onset of the first task stimulus to response execution for the second task is also shown in Figure 7, listed as Task 2 RTs. Hence, the difference between Task 2 and Task 1 latency constitutes the interresponse interval (IRI). The ANOVA on RT$_2$s again indicated no effect of compatibility, $F(1, 11) = 0.82$, $p > .20$, $MSE = 19{,}616$, or of the Compatibility × SOA interaction, $F(3, 33) = 0.81$, $p > .20$, $MSE = 7{,}871$, but a significant effect of SOA, $F(3, 33) = 33.89$, $p < .001$, $MSE = 14{,}741$.

As for RT$_1$, SOA had no effect on RT$_2$ for the first 300 ms. This finding is consistent with a bottleneck that precludes parallel retrieval because it implies that retrieval from the second cue had to wait in a holding queue until the retrieval for the first task was completed.[8] In other words, early presentation of the Task 2 cue was not helpful to subjects because they could only retrieve from that cue after they had completed retrieval for Task 1. RT$_2$ in-

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[8] Note that the finding of a flat SOA slope for the first 300 ms is equivalent to a finding of a slope of 1.0 in typical psychological refractory period studies, in which RT$_2$s are plotted as the latency from the onset of the second task cue to the second task response (for review, see Pashler, 1998).

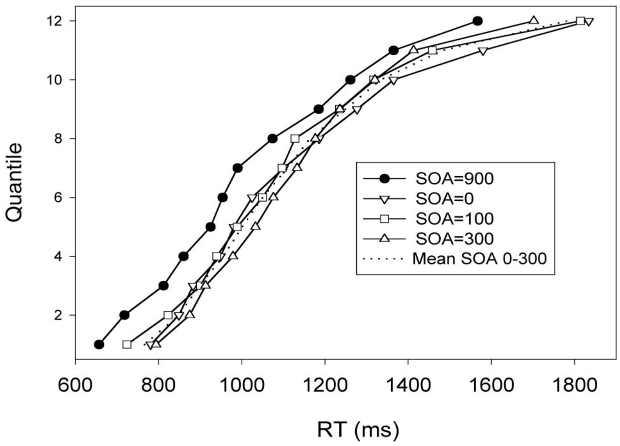

Figure 8. Cumulative response time (RT) distributions in Experiment 2 (two-finger response subjects) for each SOA level of the compatible condition. The mean of the 0–300-ms stimulus onset asynchronicity (SOA) conditions is overlaid.

creased significantly at the 900-ms SOA level, and the corresponding IRI increase was substantial, having a mean value of 432 ms for the first three SOA levels and increasing to about 740 ms at the 900-ms SOA level. Finally, note that the average RT_2 at the 0-ms SOA level was more than twice the mean latency to complete single-cue retrieval on the last five single-cue practice blocks immediately prior to the dual-task phase (720 ms). Thus, even for compatible stimulus pairs with a 0-ms SOA, there was no RT savings in performing both tasks on the same trial when compared with performing them on two independent trials.

Results: Four-Finger Response Subjects

Preliminary evaluation of the subject level data revealed large positive SOA slopes in the incompatible condition for three subjects, whereas all other subjects exhibited the expected negative SOA slope. For these three subjects, the average RT increase from the 0-ms to the 900-ms SOA level was 260 ms. As noted earlier, it is difficult to conceive how such a result could be obtained unless these subjects adopted a response grouping strategy on some percentage of trials. As such, data from these subjects were not analyzed. This elimination was based purely on data from the incompatible condition, regardless of what was obtained for the compatible condition. Thus, this procedure should not have biased the results for the crucial compatible condition. If cue processing is parallel to the response stage, this fact should be evident in the data from the remaining 12 subjects, who apparently did not group their responses.

The Task 1 error rates were .032, .029, .046, and .046 in the four (0, 100, 300, and 900 ms, respectively) SOA levels in the compatible condition and .047, .053, .037, and .029 in the same four SOA levels of the incompatible condition. A sign test indicated no main effect of compatibility in this case. The Task 2 error rates were .065, .074, .078, and .070 in the four (0, 100, 300, and 900 ms, respectively) SOA levels in the compatible condition and .052, .051, .039, and .036 in the same four SOA levels of the incompatible condition. Again, there was no main effect of compatibility. Nevertheless, as for the two-finger response subjects, for Task 2, overall errors were higher in the compatible than in the incompatible condition. The possibility of an interaction between compatibility and task in the error data, of the form observed for the two-finger response subjects, was tested by first computing the difference score (compatible minus incompatible error rate) separately for each task and subject, averaged over the four SOA levels. The difference score for Task 2 was then subtracted from the difference score for Task 1 for each subject. If there is no interaction, then roughly half of these differences of difference scores should be less than 0. If there is an interaction of the sort seen in the error data for the two-finger response subjects, then most of them should be less than 0. The difference of the difference scores was less than 0 for 10 of the 12 subjects ($p < .02$).

This interaction replicates the effect that was found for the two-finger response subjects and indicates that at least one locus of the apparent repetition inhibition is at an abstract, possibly verbal level of response representation. However, the effect size is smaller for the four-finger response subjects, raising the possibility that the effect may have more than one locus.

The RT results for correct trials are shown in Figure 9. The pattern of constant mean RT_1s across the first three SOA levels in the compatible condition, followed by decreased RT at the 900-ms SOA level, is almost identical to that of the previous two data sets. In the main ANOVA on RTs, there was a significant main effect of compatibility for both RT_1, $F(1, 11) = 17.69$, $p < .01$, $MSE = 5{,}765$, and RT_2, $F(1, 11) = 5.56$, $p < .05$, $MSE = 14{,}983$. There was also a main effect of SOA for both tasks: For RT_1, $F(3, 33) = 6.10$, $p < .01$, $MSE = 10{,}387$; for RT_2, $F(3, 33) = 65.40$, $p < .001$, $MSE = 7{,}638$. The interaction between compatibility and SOA was not significant for RT_1, $F(3, 33) = 1.87$, $p > .10$, $MSE = 5{,}359$, but it was significant for RT_2, $F(3, 33) = 5.07$, $p = .01$, $MSE = 9{,}026$. The simple effect of SOA for compatible items was not significant in this case for the raw RTs, but it was significant for the log RTs, $F(3, 33) = 3.96$, $p < .02$, $MSE = 0.001351$. This pattern of decreasing RT_1 as a function of SOA in the compatible condition is clearly a robust property of task performance.

Distribution analyses for the four SOA levels of the Task 1 compatible condition are plotted in Figure 10. RTs in the 0–300-ms conditions were again slower than those in the 900-ms condition throughout the distribution. In the quantile *t* tests, the 0- and 100-ms levels each differed significantly from the 900-ms

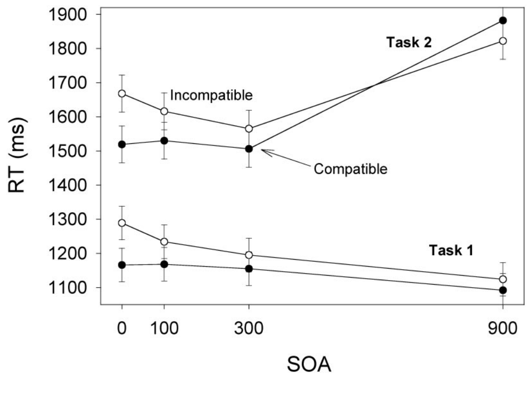

Figure 9. Mean response time (RT) in Experiment 2 (four-finger response subjects) as a function of task condition (compatible or incompatible) and stimulus onset asynchronicity (SOA; in milliseconds). Error bars represent 95% confidence intervals.

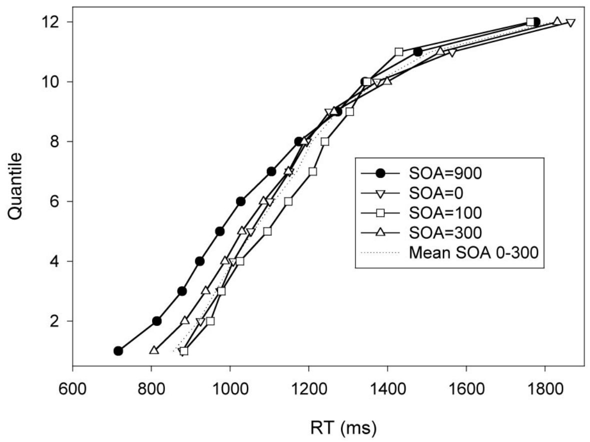

Figure 10. Cumulative response time (RT) distributions in Experiment 2 (four-finger response subjects) for each stimulus onset asynchronicity (SOA) level of the compatible condition. The mean of the 0–300-ms SOA conditions is overlaid.

level on the lower 4 quantiles. The 300-ms level differed from the 900-ms level on the lower 2 quantiles. Unlike the other fits, however, the RTs for the 0- through 300-ms SOA conditions bowed in somewhat toward those of the 900-ms SOA RTs in the middle portion of the distribution. This pattern is not predicted by the simple cue distraction account outlined earlier and may constitute a challenge to it. However, the pattern does not appear to be suggestive of any alternative account. We also believe that the effects of the postretrieval response mapping requirements are likely to be greatest in the four-finger response data (for reasons noted earlier), and this factor may be at play. It should be kept in mind that these experiments were not originally designed to yield fine grain detail on the relative quintile values of the RT distributions across SOA levels. To achieve this in future work, researchers will need to improve the stability of the quantile estimates across the entire distribution (stability of the estimates appears to have become increasingly poorer from the 1st to the 12th quantile). In any case, the simple cue distraction model proposed earlier did fit well to the first two data sets and cannot be conclusively rejected for this one. For now, it remains a viable default account.

Discussion

The results summarized above replicate and extend those of Experiment 1. There was no evidence of Task 1 cross-talk facilitation for either the two- or four-finger response subjects. The RT_2 data allows for additional analyses that bear on the question of parallel versus sequential retrieval. As a preliminary, note that mean RT_1s during testing in both data sets were substantially larger than the 720-ms and 652-ms mean RTs on the last five blocks of single task training in the two-response and four-response data sets, respectively (this was also the case in Experiment 1). When one considers the apparently ubiquitous preparation delay in dual-task responding (for discussion, see Pashler, 1998), along with cue distraction and the possibility of other performance inefficiencies, the slow RT_1s during the test phase are not surprising. Indeed, Logan and Schulkind (2000) also found RT_1s in the 1,100 ms range, even though their single task RTs were likely in the same range as ours.

The IRIs provide two ways to test for sequential retrieval that are not sensitive to preparation effects (which by definition should only affect Task 1), Task 1 cue distraction, or other Task 1 inefficiencies. First, if retrieval is sequential, then the IRIs should be large, in the neighborhood of several hundred ms, reflecting the execution of the second retrieval. The average IRI in the 0–300-ms SOA levels was 432 ms in the two-finger response data and 354 ms in the four-finger response data. These are substantial latencies that are roughly consistent with retrieval processes. However, they are smaller than the single cue latencies on the last five practice blocks in both cases (700 and 652 ms, respectively). This discrepancy can be understood within the sequential retrieval framework by noting that perceptual processing of the second task cue can take place in parallel (with negligible, if any, slowing) with retrieval for the first cue (for review, see Pashler, 1998). Similarly, motor processing for the first task can apparently take place in parallel with retrieval for the second task. The set–cue model applies only to the retrieval stage of processing, so parallel execution of perceptual and motor processes, along with one retrieval process, are not inconsistent with it. The sum of perceptual and motor processing latencies for a single retrieval (assuming here a simple additive factors model) can be reasonably approximated at around 200 ms (for discussion, see Nino & Rickard, 2003; Rickard & Pashler, 2004). Adding 200 ms to the 432 ms IRI of the two-response data set yields 632 ms, a modestly close match to single task mean RTs of 720 on the last five training blocks. For the four-finger response data set, adding 200 ms to 354 ms yields 554 ms, which is again close but still below the 640-ms RTs on the last five training blocks. However, during the test phase, the IRIs (along with RT_1 and RT_2) decreased. The mean IRI for the 0–300-ms SOA conditions, averaged over only the first two test blocks, was 558 ms for the two-finger response data and 492 ms for the four-finger response data. These values are more appropriate for comparison with the mean single-cue RTs over the last five training blocks. Adding 558 ms to 200 ms yields 758 ms, which is close to the 720-ms single-task mean for the two-finger response data. Adding 492 ms to 200 ms yields 692 ms, again close to the 652-ms single task mean for the four-finger response data. Note that the increase in RT_2 at the 900-ms SOA level is also consistent with the sequential retrieval account by this line of reasoning. If the second task cue does not appear until 900 ms after the first task cue, then the opportunity for RT_2 savings (i.e., absorption of its perceptual component into the RT_1) is decreased.

An additional test for sequential versus parallel retrieval can be performed by computing the correlation between RT_1 and the IRI. A sequential retrieval model predicts zero correlation because it assumes that the two retrievals are executed independently, one after the other. On the other hand a race model, as well as at least some limited capacity parallel retrieval models, predicts a negative correlation. Unusually slow (or fast) RT_1s will typically not co-occur with unusually slow (or fast) RT_2s (see Rohrer, Pashler, & Etchegaray, 1998). Thus, when RT_1 is unusually long on a given trial, the IRI will tend to be unusually short, and vice versa.

To test these predictions, we performed general linear model analyses on the data from the 0-ms SOA condition, separately for each subject, in which the IRI was predicted by RT_1 and by two categorical covariates of no interest: test block and the letter that was the Task 1 stimulus. Consistent with the sequential retrieval model, there was only one subject for whom the partial correlation between the IRI and RT_1 was significant (an event that might well occur by chance given the number of comparisons), and the mean *p* value over the 27 subjects was .42. This result replicates analogous correlation analyses performed by Rickard and Pashler (2004) and Nino and Rickard (2003). It is also consistent with earlier correlation results showing that alternating retrieval of exemplars from two different categories does not proceed in parallel (Rohrer et al., 1998; see also Maylor, Chater, & Jones, 2001).

The apparent absence of a compatibility effect in the two-finger response data set provides additional support for our theoretical perspective. Those results suggest that answer activation for the two tasks did not interact in any sense. In contrast, even a limited capacity version of a parallel model would generally predict cross-talk interference in the incompatible condition regardless of whether cross-talk facilitation was present. In a degenerate version of such a model, it could be argued that retrieval is parallel but that so little activation is leaking through from the nontarget (Task 2) cue that it has no detectable effect. However, such a model would be empirically identical to a sequential model, and the general class from which it would be drawn (all limited capacity parallel models) is less constrained.

Experiment 3

We have argued that the RT_1 slowing at short SOAs in the compatible conditions of Experiments 1 and 2 is due to associative independence and the accompanying cue distraction effect. The set–cue model implies that if associative independence is removed by way of prior dual-cue chunking for a particular cue pair, cue distraction for that pair will no longer occur. Indeed, if chunking has occurred for all items in the data set, then a positive SOA slope in the compatible condition similar to that in Logan and Schulkind (2000; see also Figure 1 of this article) should be observed.

Rickard and Bajic (2004) found clear evidence of dual-cue chunking—with accompanying dual-cue facilitation—when subjects were given extended dual-cue practice retrieving digits from letters pairs that were presented side by side, always in the same left–right order. In this experiment, we essentially replicate Rickard and Bajic's Experiment 2 as the first phase for one group of subjects. In the second phase, these subjects performed a cross-talk task similar to that of Experiment 1 of the current study. According to the set–cue model (with its chunking component), the effect of SOA in the compatible condition should be substantially diminished or even reversed if all cue pairs had been chunked in Phase 1 (a result that cannot be guaranteed).

A second, control group of subjects was given only single-cue practice during the first phase and were then given the same cross-talk task as was the experimental group. According to the set–cue model, associative independence should still hold for this group following single-cue practice, so the SOA slope in the compatible condition of the cross-talk task should be negative, just as in the previous experiments. This result would buttress the associative independence account by showing that moderate practice on the single cue–response associations alone cannot produce a dual-cue facilitation effect (see Rickard & Bajic, 2004, for related findings in their dual-cue retrieval experiments).

Method

Subjects. Forty undergraduate students from the University of California, San Diego participated for course credit, 20 in the control group and 20 in the experimental group.

Materials, design, and procedure. For the experimental group, the design of the single- and dual-cue practice phase was identical to that described in the Method section of Rickard and Bajic (2004, Experiment 2). Dual-cue stimuli were always in the same left–right configuration to promote chunking. Each subject received exactly 20 blocks of retrieval practice on each single- and dual-cue item. The control group received the same practice phase design, but for that group only single-cue items were presented.

The design and responses (spoken digits) for the cross-talk task were the same as those in Experiment 1 of the current study, with the following exceptions. The fixation field was replaced with a single fixation asterisk. The first task stimulus appeared just to the right of the location of the preceding fixation, rather than above it, and the second task stimulus appeared on the same line just to the right of the preceding fixation, rather than below it (as in the preceding practice phase). Subjects were therefore instructed to respond first to the leftmost stimulus and then to the rightmost. For the control subjects and in the incompatible condition for the experimental subjects, the left–right ordering of the letters in each pair were reversed from block to block, in a manner equivalent to the upper–lower reversals in Experiment 1. This helped to preserve associative independence for the dual-cue items throughout the task. For the compatible pairs of the experimental group, however, the left–right ordering of letters on each trial was always the same as those encountered in the earlier portion of the experiment, to promote access to the chunked letter representations. As in Experiment 1, this phase concluded after 16 blocks.

Results and Discussion

As expected for the dual-cue practice (experimental) group, performance in the first phase replicated that of Rickard and Bajic (2004, Experiment 2), yielding faster RTs on dual-cue than on single-cue trials by the end of practice and setting the stage for the possible observance of cross-talk facilitation in the compatible condition.

For the control group, error rates in the cross-talk task were .035, .033, .050, and .037 in 0-, 100-, 300-, and 900-ms SOA levels, respectively, of the compatible condition and .084, .066, .056, and .060 in the same four SOA levels of the incompatible condition. Nineteen of 20 subjects had higher error rates in the incompatible condition, $p < 001$. For the experimental group, error rates were .010, .028, .016, and .038 in the 0-, 100-, 300-, and 900-ms SOA levels, respectively, of the compatible condition and .061, .066, .035, and .050 in the same four SOA levels of the incompatible condition. Fifteen of 19 subjects who made any errors had higher error rates in the incompatible condition ($p < .001$).

Mean RT_1s for correct responses in the cross-talk task are shown separately for the control (single-cue practice only) and experimental (single- and dual-cue practice) groups in Figure 11. For the control group (see Figure 11a), the RT_1 patterns are quite similar to those of the first two experiments. In the same ANOVAs as performed earlier, the effects of task, $F(1, 19) = 36.04$, $p < .001$, $MSE = 10{,}876$; SOA, $F(3, 57) = 15.50$, $p < .001$, $MSE = 13{,}338$; and their interaction, $F(3, 57) = 10.10$, $p < .001$, $MSE = 6{,}868.27$, were all highly significant. One notable difference in this experiment, however, is that the mean RT_1 at the 300-ms SOA level of the compatible condition dropped to a level similar to that for the 900-ms SOA level. Because of their prior single-cue practice and consequent speeded RT_1s, subjects in this experiment may have been far enough along in the retrieval process for Task 1 to be relatively immune to cue distraction at the 300 SOA level.

Mean RT_1s in the cross-talk task for the experimental group are shown in Figure 11b. Once again, the ANOVA revealed signifi-

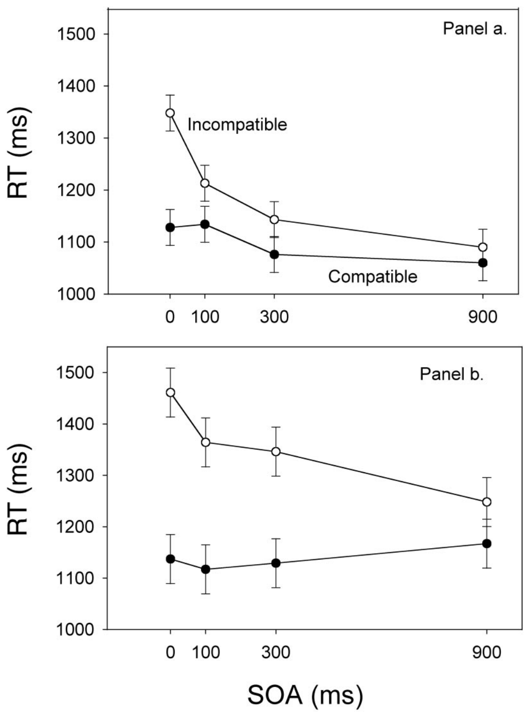

Figure 11. a: Mean response time (RT) in Experiment 3 for the control group as a function of task condition (compatible or incompatible) and SOA. b: Mean RT in Experiment 3 for the experimental group as a function of task condition (compatible or incompatible) and stimulus onset asynchronicity (SOA). Error bars represent 95% confidence intervals.

cant effects of task, $F(1, 20) = 37.78$, $p < .001$, $MSE = 52{,}554.67$; SOA, $F(3, 60) = 2.84$, $p = .045$, $MSE = 21{,}580.28$; and their interaction, $F(3, 60) = 9.10$, $p < .001$, $MSE = 11{,}910.67$. As predicted by the set–cue model, however, the pattern of results in the compatible condition differed between the two groups. For the experimental group there was a slight positive SOA slope, similar to that observed by Logan and Schulkind (2000). To test for the significance of this Group × SOA interaction, a mixed ANOVA on mean RT_1s in the compatible condition, with factors of group (control vs. experimental), SOA, and their interaction, was performed. There were no main effects of either group, $F(1, 39) = 0.19$, $p = .66$, or SOA, $F(3, 117) = 0.87$, $p = .46$. There was, however, a significant interaction between these two factors, $F(3, 117) = 3.72$, $p = .014$, confirming the performance impact of the prior dual-cue practice for the experimental group.

The set–cue model makes the related prediction that for the 0-ms SOA level at least, there should be an interaction between group and compatibility, such that the compatibility effect for the experimental group is larger than that for the control group (because of the faster RT_1s in the compatible condition for the experimental group). This effect was in fact significant at the 0-ms, $F(1, 39) = 3.75$, $p = .03$; 100-ms, $F(1, 39) = 10.58$, $p = .0012$; and 300-ms, $F(1, 39) = 6.45$, $p = .0076$, SOA levels, but not at the 900-ms SOA level, $F(1, 39) = 0.92$, $p = .17$ (all p values for one-tailed tests).

Cumulative distribution analysis of SOA effects in the compatible condition mirrored the results for the means, as in the previous experiments. For neither the control nor the experimental group were there systematic crossover effects among the distributions for the different SOA levels.

In summary, these findings reinforce the evidence favoring the associative independence hypothesis and the set–cue model. They demonstrate that the slowed RT_1s at short SOA levels in the compatible conditions in Experiments 1 and 2 resulted from the fact that those cue pairs had not been seen together before and thus presumably had independent associations to their common response. In both this study and in Rickard and Bajic's (2004) study, cue distraction could be overcome, and dual-cue facilitation could be observed only when associative independence was violated through prior dual-cue practice.

General Discussion

The results are as predicted by the associative independence principle and, more specifically, by the set–cue model. Provided that the cue–response associations were learned on independent single-cue trials, there was no evidence of cross-talk facilitation in the compatible condition at any point on the RT_1 distribution. Instead, there was a consistent decrease in RT_1 for compatible items at the 900-ms SOA level (and also at the 300-ms level for the control group in Experiment 3) relative to the other SOA levels, consistent with a cue distraction effect at the earlier SOA levels. Only for the experimental group of Experiment 3, where associative independence had been violated due to prior dual-cue practice, was the cue distraction effect completely eliminated.

A simple race version of a parallel recall model can be rejected for these tasks, as can any model that combines response grouping and parallel retrieval. A limited capacity parallel retrieval model might account for the slowed RTs in the compatible cue conditions at short SOAs in Experiments 1 and 2 (and in the control condition of Experiment 3), as well as the increased slowing at short SOAs in the incompatible condition. However, as noted in the *Discussion* section of Experiment 2, a number of patterns in the data speak against that class of models: (a) the lack of SOA × Quantile interactions in the RT distribution data, (b) the lack of any compatibility effects for the two-finger response subjects in Experiment 2, (c) the lack of a negative correlation between RT_1 and the IRI in Experiment 2, and (d) the evidence for additive retrieval stage latencies in Experiment 2. It appears that these effects could only be accommodated by a degenerate version of a limited capacity model in which each retrieval requires all available capacity. This special case is isomorphic with a sequential model, however. It is also a member of a larger class of limited capacity models that have more flexibility than does the sequential model.

It remains to be seen whether any future limited capacity parallel retrieval model can account for the constellation of results in these experiments. Even if such a model can be developed, however, it seems highly unlikely that it could be constrained, in anything other than a post hoc manner, to predict both this set of results and the results of Rickard and Bajic (2004).

The concept of cue distraction seems out of place within a parallel retrieval framework. If retrieval can run to completion in parallel from two independent cues, with or without capacity limitation, why would there be cue distraction? At what stage of processing would such an effect occur? How could a distraction mechanism be added to a parallel model while still allowing that model to account for the Logan and Schulkind (2000) cross-talk facilitation effects? How could that be done without appealing to the very same associative independence principle that largely defines the set–cue model? It is also unclear at present what purpose a cue distraction mechanism would serve in a parallel model, other than to support cue distraction itself. In contrast, in a cue selection model such as the set–cue model, a mechanism that is fundamental to the model for other reasons also serves as a natural basis for the distraction effect; the very process that selects a cue for retrieval also generates cue distraction when that selection process goes temporarily awry.

Prospects for Extension of the Set–Cue Model

As currently developed, the set–cue model is not directly applicable to semantic categorization tasks, such as the letter and digit categorization task studied by Logan and Schulkind (2000). However, there is a potential analog to the set–cue model in that task domain that may hold promise as an integrative account. In the categorization task, the functional equivalents of the set–cue nodes are the category nodes representing "letter" and "digit." Presumably, the subject's task set keeps these two category representations primed throughout the experiment. When the two cues are presented on a trial, activation from them flows to these two active category nodes. Therefore, there is a convergence of activation from both the task set and the cues at the level of the category representations. These representations, or "nodes," are, functionally speaking, the set–cue conjunction nodes for this task.

Viewing the Logan and Schulkind (2000) results from this perspective has interesting consequences. According to the set–cue model and the cue distraction hypothesis, cue distraction would not be expected for their task in the compatible condition. If two digits (or letters) are presented, activation from both of them flows to the same set–cue (category) node. Only one set–cue node is activated on these compatible trials, so there is no mechanism to generate cue distraction. Instead, the positive SOA slope in the compatible condition that Logan and Schulkind observed might occur. This category representation can be viewed as a type of chunked representation and might be represented for current purposes as shown in Figure 3c. This chunked representation is similar to that proposed for the dual-cue chunking in the novel cued-recall task, as depicted in Figure 3b. In the cued-recall task, the chunking is assumed to occur at a perceptual or other relatively early stage of representation, as motivated by the specificity of transfer effects observed by Rickard and Bajic (2004). In the case of semantic categories (see Figure 3c), a more central locus of activation convergence from the cues, the category representation node, is motivated.

There was no evidence of cross-talk interference in the Logan and Schulkind (2000) data, despite clear evidence of cross-talk facilitation. Instead, the SOA slope for incompatible condition was flat. The cue distraction dynamics of the set–cue model may provide a natural account of that surprising result. We hypothesized that cue distraction occurs when a nontarget set–cue node becomes activated while the subject is attempting to perform the target task. It is the onset of nontarget set–cue activation that triggers the attention shift to that node. This aspect of the model is appealing because it is the process of change that results in distraction, not simply static activation of a nontarget set–cue node at the outset of a trial. In the Logan and Schulkind experiments, there were presumably only two possible set–cue nodes that could be activated on any trial (one for each of the two response categories, letter or digit). Because each was in use once per trial on average, it is reasonable to assume that both nodes were continuously primed. Thus, presentation of a nontarget cue (i.e., the second task cue during first task performance) could not have resulted in the onset of activation of its corresponding set–cue node, as it was already activated, and there should be no cue distraction. Because there was no cue distraction, there could be no subsequent cross-talk interference, resulting in the observed SOA slope of 0 for the incompatible condition. In contrast, in the current experiments, there were multiple set–cue nodes (one for each of the 12 cues), and it would be far less likely, if not impossible, for all of them to be continuously active during each trial. Hence, when the second task cue (compatible or incompatible) was presented, a new set–cue node was activated, resulting in cue distraction on at least some trials.

One way to conceptualize the idea above is in terms of working memory activation. In the semantic categorization task, both set–cue nodes (i.e., category nodes) may be continuously active in working memory. Presentation of a nontarget cue produces no novelty effect for the subject in terms of set–cue activity, so the subject does not shift attention to it. From an evolutionary perspective, resistance to distraction in this case would seem to be optimal. If an event is anticipated, then its potential for harm or benefit could already have been evaluated and distraction as a consequence of its occurrence cannot be productive (provided that the event was evaluated as innocuous). It matches intuition that distraction would be reduced for expected and innocuous events.

In another recent cross-talk experiment involving long-term memory, Logan and Delheimer (2001, Experiment 1) had subjects first study a list of words. During the subsequent dual task, subjects were presented with either two words from the list, one word from the list and one distracter word, or two distracter words. Subjects pressed one key if a word was from the list, and another if it was not. First task responding was faster when both words were from the list. However, close inspection of the results from their Experiment 1 (the one most closely analogous to ours) reveals a negative SOA slope for both the compatible and incompatible conditions in four of the six data sets. Essentially, there was no effect of SOA for either condition in one of the data sets and, in the remaining data set, a positive SOA slope for the compatible condition, combined with a flat slope for the incompatible condition. Overall, these results are more consistent with the set–cue model. The generally negative slope for the Task 1 compatible condition suggests cue distraction, and the steeper negative slope for the incompatible condition indicates response interference resulting from cue distraction.

The dominant finding of no Task 1 facilitation at short SOAs in the Logan and Delheimer (2001, Experiment 1) implies that the nature of the underlying representations was not the same as the semantic categorization structure of the Logan and Schulkind (2000) experiments. More likely, subjects coded many of the words independently as being from the list, yielding something more similar to the paired associate structure of our Experiment 2. Word-to-word associations may well have formed during list study as well, as the authors suggested, but a true semantic-type category apparently did not (nor did the authors suggest that it did).

In Experiments 2 and 3 of Logan and Delheimer's (2001) study, clear Task 1 cross-talk facilitation was observed in the compatible cues condition. However, a similar positive SOA slope was also present for the incompatible conditions. As we stated in the introduction, that pattern indicates that at least some subjects used a response grouping strategy.[9] The positive slope for the compatible condition is thus also expected without recourse to an independent, parallel response activation account.

Logan and Gordon (2001) recently proposed a computational model of executive control that, like the set–cue model, assumes that the task set plays a central role in determining task performance. In Logan and Gordon's model, the role of the task set is more complex and does not specify a role for cue–response independence, as is pivotal in the set–cue model. Their model is broad in scope, but at present it is quite flexible, allowing for either parallel or serial processing in most situations. Their model does not make strong a priori predictions for the current experiments as currently formulated.

The set–cue model and its parent skill model now provide a reasonably well-supported account of performance across a range of tasks and phenomena, from strategy shifts and transfer effects in some skill learning tasks (Rickard, 1997, 1999, 2004), to recall of two responses from a single cue (Nino & Rickard, 2003; Rickard & Pashler, 2004), to retrieval of a single response from two redundant cues (Rickard & Bajic, 2004), to practice effects in those tasks (see citations above), to cross-talk effects in cued recall. The set–cue model is a central bottleneck model, but is unique in that it places a bottleneck at the level of selecting a set–cue node (i.e., preretrieval) instead of at the level of selecting a response (i.e., postretrieval). A response selection account assumes that response signals from both cues make it to the response level in parallel but that the system can select only one response at a time for execution. In some conceptions, the unselected response is inhibited, and retrieval through its corresponding cue must be reinitiated from the start to complete the second task.

The set–cue and response selection models make contrasting predictions for the current experiments and for the dual-cue experiments of Rickard and Bajic (2004). The response selection model, conceived as the sole bottleneck, predicts dual-cue facilitation for first task responding when the cues are compatible (or at least a limited capacity form of parallel processing up to the response level of representation) even when associative independence holds. There is only one response to select in such tasks (considering only first task performance for the case of the cross-talk task), so the bottleneck should not come into play. Our findings are not consistent with that model. It may be, however, that both cue (or set–cue) selection and response selection bottlenecks are present in the case of cued recall. Because cue selection guarantees that there will be only one retrieved response per retrieval attempt, the response selection bottleneck would play no role in our tasks. More research is needed to differentiate between, and gain a better understanding of, these proposed loci of the bottleneck.

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[9] In those experiments, words were presented for study in pairs. Some of the time during testing, the two presented words were from the same word pair. This design change may explain why subjects might be more likely to group responses in that experiment. The presence of a word pair that was associated during training introduces an extra cue, namely, the word pair association, indicating that the words were from the study list. Thus, subjects could increase (or decrease) their confidence that the first word was from the list by waiting for the second word to be presented and testing for an association before making either response. Some subjects may have been tempted to do this, especially when their confidence for the first word was low.

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Appendix

A Flowchart Outlining Predictions of the Set–Cue Model Under Various Task Conditions

QUESTION: Does associative independence hold?

1. Have the two cue–response items been seen together before under conditions that are conducive to dual-cue chunking (e.g., constant left–right spatial location as in Rickard & Bajic, 2004, Experiment 2)?
2. Are the cues semantically related in a way that is directly relevant to task performance?

If "yes" to either or both of the questions above, proceed to Predictions When Associative Independence May Not Hold. Else, proceed to Predictions Under Associative Independence.

Predictions Under Associative Independence

1. Dual-cue facilitation will not be observed in the compatible condition (the SOA slope must be 0 or negative).
2. Cue distraction may occur, resulting in a negative SOA slope in the compatible condition.

QUESTION: Is there a negative SOA slope for the compatible condition?

If "yes" then there should be a negative SOA slope in the incompatible condition of equal, or more likely greater, magnitude (Experiments 1 and 2 and the control condition of Experiment 3, in this article).

If "no" then there should be no effects of compatibility, SOA, or their interaction.

Predictions When Associative Independence May Not Hold

1. There may be cross-talk facilitation in the compatible condition if there has been sufficient dual-cue chunking.

QUESTION: How many set–cue nodes should, according to the model, be involved in performing the task as a whole?

If only 2 set–cue nodes are involved in performing the task, then there should be no cross-talk interference in the incompatible condition (i.e., a flat SOA slope is expected), as hypothesized for the Logan and Schulkind (2000) data.

If more than 2 set–cue nodes are involved in performing the task; then cross-talk interference may be observed in the incompatible condition (the experimental condition of Experiment 3 in this article).

Glossary of Terms

Positive SOA slope:	Monotonic increases in RT with increasing SOA.
Negative SOA slope:	Monotonic decreases in RT with increasing SOA.
Cross-talk facilitation:	A positive SOA slope for the compatible cues condition.
Cross-talk interference:	A negative SOA slope for either the compatible or incompatible cues condition.
Cue distraction:	The hypothesis that there is frequent, uncontrollable distraction to the nontarget cue, slowing Task 1 performance. Extensive dual-cue practice appears to eliminate this slowing effect even when dual-cue chunking does not occur (Rickard & Bajic, 2004).
Associative independence:	The condition under which the associative links between two cues and their respective responses are independent (i.e., the condition of no convergence of activation at an intermediate stage of representation prior to the response stage of representation).
Dual-cue chunking:	Convergence of activation from two cues at an intermediate, preresponse stage of representation.
Set–cue node:	An intermediate level of representation in the set–cue model at which activation from the cue(s) and the task set converges.
Efficient cue selection:	A special case of associative independence and of the set–cue model in which the cue that yields the faster response on average is always selected for retrieval (see Rickard & Bajic, 2004).

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