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Two Sources of Information in Reconstructing Event Sequence

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Reconstructing memory for sequences is a complex process, likely involving multiple sources of information. In 3 experiments, we examined the source(s) of information that might underlie the ability to accurately place an event within a temporal context. The task was to estimate, after studying each list, the temporal position of a single test word within that list. In the first 2 experiments, we demonstrated that memory for temporal location was better following semantic encoding than silent reading of the list, which in turn was better than orthographic encoding of the list. Although other measures of sequence retention have revealed impaired memory for order with greater item-level encoding, these experiments demonstrated that item-level encoding improved memory for temporal-location. A 3rd experiment extended these findings by measuring interitem associations in addition to item memory, demonstrating that memory for temporal location within a list was more closely related to item information than to interitem relational information. It is now clear that reconstructing an event sequence can involve at least 2 distinct sources of information—both item and relational encoding can play important roles, depending on the nature of the test for order.

Keywords: memory for order, interitem associations, sequence

Memory for contextual features, including placing an event orderly in time, is a hallmark of episodic memory (Tulving, 2002). Yet recalling how an event unfolded over time is a complex process, and memory for *when* an event occurred could potentially be produced using multiple approaches or strategies. For example, imagine that you ran three errands yesterday—first you got groceries, then you went to the gym, and finally you took your cat to the veterinarian. Now you are trying to recall when you went to the gym. To remember when this event took place, one approach that you could take would involve remembering the events that preceded and succeeded it. By remembering that you got groceries before driving to the gym and that you planned your route to the veterinarian from the gym parking lot, you could reconstruct the timeline to deduce when you went to the gym. A second approach could involve contrasting the relative strengths of two of the memories and concluding that the weaker memory is the older one. That is, if going to the gym feels like an older and weaker memory than your memory for going to the veterinarian, you could conclude that your visit to the gym occurred earlier in time. Still a third approach could involve remembering the time at which you went to the gym. If you can remember the time of day, such as that it was early afternoon, then you do not have to rely on memory for any other events. Although not exhaustive, this list demonstrates that various approaches could be used to retrieve when an event occurred, highlighting the complexity of understanding how people represent memories in time.

Currently, one dominant theoretical framework holds that memory for sequences of events occurs as the result of encoding interitem associations. An example of an interitem association involves remembering that you planned your route to the veterinarian from the gym parking lot, resulting in an association between two events that occurred sequentially. The *item-order account* (see McDaniel & Bugg, 2008) postulates that in remembering the order of events, one uses these interitem associations to reconstruct sequence. Work aimed at examining the role of interitem associations in order reconstruction has focused on how different learning tasks emphasize relational encoding to differing degrees, with some resulting in better order reconstruction than others. This body of work includes examinations of memory for order following various encoding tasks, such as generation, enactment, and production. To test memory for order, one typically uses an order-reconstruction test in which participants sort scrambled sequences of studied items into their originally studied order (Engelkamp & Dehn, 2000; Jonker, Levene, & MacLeod, 2014; Jonker & MacLeod, 2015; Nairne, Riegler, & Serra, 1991; Serra & Nairne, 1993). The order-reconstruction test is thought to rely on interitem associations, and indeed, performance on this task typically is superior following relational encoding (e.g., reading silently, relational judgments; Jonker & MacLeod, 2015, 2017) as opposed to tasks that emphasize item-specific elaborative information (e.g., reading aloud, semantic judgments; Jonker et al., 2014; for a review, see McDaniel &

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Bugg, 2008). These order reconstruction results converge with findings found in free recall.: When freely recalling lists of words, participants more frequently output adjacent items sequentially following relational encoding than when following item-specific elaborative encoding (Jonker et al., 2014; McDaniel & Bugg, 2008; Nairne et al., 1991; see also Howard & Kahana, 2002; Kahana, 1996). Thus, a considerable body of literature provides support for the role of interitem associations in the reconstruction of sequences of events.

Although there have been many other ideas about how we remember order—such as item-to-context associations (Ebenholtz, 1972; Howard & Kahana, 2002; Mensink & Raaijmakers, 1988; Polyn, Norman, & Kahana, 2009) and hierarchical organization (Lashley, 1951)—many of these approaches have mainly focused on *relations among items*. And yet, in recent work, we found that item-specific information itself plays a role in temporal memory (Jonker & MacLeod, 2017). Specifically, we had participants encode lists of words by making a semantic judgment about each word, which should limit relational encoding, or by silently reading each word. After a short retention period, participants then completed one of two tests. Both tests emphasized order information and therefore—based on the item-order account literature—we predicted that participants would perform best after silent reading on both tests. This was indeed true for a test of interitem associations (e.g., remembering that A and B occurred sequentially; see Jonker & MacLeod, 2017, and Experiment 3 of the present article). However, contrary to our prediction, our second test produced the reverse pattern: Item information led to better performance. For this second test, participants were shown two items from different parts of the list and were to indicate whether the words had occurred during study in the order shown on the test or in the reverse order (e.g., remembering that A was learned before B). We found that these relative judgments of order were more accurate following semantic judgments than following silent reading, emphasizing the use of item-specific (rather than relational) information even on a sequence-based memory test. Both tests certainly probed memory for order, yet they produced opposing patterns. This finding led us to speculate, based on previous research, that some testing conditions prompt participants to assess the strength of each item individually and to use this information to estimate relative order such that the weaker item is deemed the older item (e.g., see Yonelinas & Levy, 2002). This outcome highlights the need for a more nuanced view of temporal and sequence memory.

In the present work, we sought to expand our understanding of temporal and sequence memory by determining whether individuals do indeed rely on item information when making temporal judgments. To restrict the possible role of relational information during the test, we had participants make *single-item* temporal judgments. To this end, in a series of experiments, we manipulated the encoding of item-specific and relational information using various encoding tasks (i.e., semantic judgments, relational judgments, and silent reading) and followed each study list with a test of memory for the temporal occurrence of a single item in that list (see Figure 1). Based on our above-mentioned work, we predicted that these temporal-location estimates would be more accurate following stronger item-specific encoding, perhaps because the strength of the item memory can be used to place the item in time. However, an alternative outcome, one suggested by the item-order account, is that serial encoding is superior during passive encoding tasks (i.e., silent reading), which could lead to more accurate temporal-location estimates. In other words, one possible outcome is that relational information reflects not only interitem associations, but also item–context associations—or, more specifically, item–serial-positions associations (for a discussion of absolute-order memory, see McDaniel & Bugg, 2008, p. 251). Thus, our series of experiments was designed to determine whether temporal-location estimates are based on the strength of item-specific information rather than on relational binding between pairs of items and/or between item and context. These experiments served to enhance our understanding of the many facets of temporal and sequence memory.

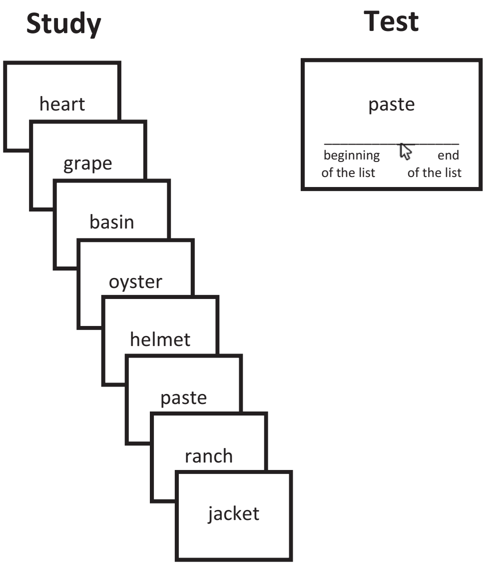

Figure 1. A sample sequence of study and test trials for all experiments. Font color of words during study was used to indicate encoding task, which was constant within a list.

Experiment 1

The first experiment contrasted a semantic-judgment task with a silent-reading task. A wealth of research on these encoding tasks has revealed that the former increases item information (Craik & Lockhart, 1972) and decreases relational information, relative to the latter (Einstein & Hunt, 1980; Jonker & MacLeod, 2015). Relational information is thought to be stronger following silent reading than semantic judgment because an elaborative task, such as semantic judgment, disrupts the encoding of interitem associations (McDaniel & Bugg, 2008). Thus, passive-encoding tasks, such as silent reading, are thought to provide a type of baseline for relational encoding, and elaborative tasks show impaired relational encoding relative to this baseline. It is worth noting that an alternate possibility is that silent reading allows for more covert rehearsal and thereby increases the encoding of interitem associations between list items beyond that of many other tasks. This point highlights the difficulty of selecting a "true" baseline with which to compare elaborative encoding tasks. However, this issue is not problematic for the present studies because our interest is in relative differences in item and order information and in how these differences influence the accuracy of single-item temporal estimates. Furthermore, in Experiment 3, we corroborate our findings using a different type of relational encoding to ensure generalizability beyond silent reading. Thus, a comparison of silent reading versus semantic judgment was ideal for this purpose because it is known that the former results in better relational memory and poorer item memory relative to the latter, allowing us to determine whether temporal judgments rely primarily on item or relational information.

Our test was one of temporal location: One word was selected at random from the study list and participants were to indicate where in the list that one word had appeared. The test was not one of exact serial position; rather, participants had to estimate the test item's temporal location in a list by selecting a point on a line that represented the entire list.

As set out in the introduction, we predicted that temporal-location estimates would be more accurate following semantic judgment than following silent reading based on a prior finding that stronger item-specific information resulted in better performance on a relative judgment of temporal order (Jonker & MacLeod, 2017). The alternate possibility is that single-item temporal estimates will be driven by relational information, in which case these estimates should be better following silent reading.

Method

Participants. Thirty-five students (16 women, $M_{\text{age}} = 21.3$) from the University of Waterloo participated in exchange for partial course credit. Participants in this and in all subsequent experiments were eligible to take part only if they had normal or corrected-to-normal vision and reported fluency in written and spoken English. All experiments reported in this paper were approved by an institutional ethics review board.

Materials. A large set of 276 common nouns was selected from the MRC psycholinguistic database (Coltheart, 1981). To homogenize word length, we selected words that were 5 or 6 letters long. For each participant, 32 lists of eight items each were randomly selected without replacement from the set of nouns. Stimuli were presented on a computer using E-Prime software (Psychology Software Tools, Sharpsburg, PA).

Procedure. Participants completed 32 blocks of tasks, each consisting of a study phase, a distractor task, and a test. During each study phase, participants were shown a list of eight words. Each word was presented for 2 s with a 500-ms interstimulus interval. All eight items in a list were studied under the same encoding task (i.e., there were no mixed lists). When a list appeared in blue, participants were to indicate with key presses whether they found each item pleasant or unpleasant; when a list appeared in white, participants were to read each item silently. Following study, participants performed a self-paced distractor task for 15 s during which they were to indicate with key presses whether single digits were odd or even. They were then given a single test trial with one word from the study list presented at the center of the screen. Below the word, a line appeared with the left end labeled "beginning of the list" and the right end labeled "end of the list" (see Figure 1). Participants were instructed to click on the line to indicate the approximate position of that item in the study list; the trial advanced as soon as a selection was made. We refer to this as temporal-location estimation. After making their responses, participants were shown the next study list.

For each participant, a random half of the 32 blocks involved a semantic judgment and the other half involved silent reading. Of the 16 blocks for each encoding type, each of the eight serial positions was tested in two separate blocks. Prior to beginning the 32 blocks, under the guidance of a research assistant, participants completed a practice block involving the study, distractor, and temporal-location tasks.

Following completion of the final block, participants performed a 4-min distractor task during which they were to generate as many countries as possible. They then performed a surprise recognition test consisting of words from the six most recently studied lists (three semantic and three silent lists, totaling 48 old words) randomly intermingled with 20 new words. For each word, participants were to indicate whether that word had been studied at some point during the experiment or was new. The recognition test served two purposes. First, it served as a manipulation check for the levels-of-processing manipulation. If memory was not better following semantic encoding, this would suggest that participants perhaps shifted their encoding strategies, which would complicate interpretation of the temporal-location results. Second, it provided a measure of item memory with which to correlate temporal-location estimation to allow us to assess whether estimation accuracy was related to item-specific information.

Results and Discussion

As expected, the surprise recognition test revealed a strong levels-of-processing effect: Participants recognized considerably more semantically judged words ($M_{d'} = 2.65$, $SD = 0.97$) than silently read words ($M_{d'} = 1.36$, $SD = 0.85$), $t(34) = 9.63$, $SE = .13$, $p < .001$, $d = 1.64$[1], demonstrating that the encoding manipulation was successful. This and all subsequent analyses on recognition performance used d' as a measure of memory sensitivity. Hit and false alarm rates are reported separately in Table 1.

Temporal-Location Estimation

To assess accuracy of temporal-location estimates, the test line was segmented into 80 portions and 10 portions were devoted to each serial position. For example, Serial Position 1 was represented by Points 1 to 10, Position 2 by Points 11 to 20, and so forth. Thus, perfect performance would involve a score of 5.5 for Serial Position 1, 15.5 for Serial Position 2, and so on. An average score (out of the 80 segments) was computed for each serial position for each participant, and these scores were used to produce a slope for each participant for each of the two encoding conditions (semantic, silent reading).

A paired-samples *t* test on the slopes revealed that performance on the estimation test was more accurate following semantic encoding ($M_{\text{slope}} = 6.37$, $SD = 2.53$) than following silent reading ($M_{\text{slope}} = 5.29$, $SD = 3.16$), $t(34) = 2.08$, $SE = .52$, $p = .045$, $d = 0.35$, which can be seen in Figure 2A. The slope for the semantic condition (dotted gray line) more closely approaches optimal performance (solid gray line) than does the slope for the silent-reading

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[1] All estimates of Cohen's *d* were computed using the method proposed by Morris and Deshon (2002).

Table 1
Hit and False-Alarm Rates for Each Condition From Each Experiment

Experiment	Condition	Hits	False alarms
1	Semantic	.94 (.08)	.24 (.16)
	Silent	.65 (.21)	
2	Silent	.75 (.18)	.26 (.19)
	Shallow	.78 (.17)	
3	Independent	.92 (.08)	.23 (.12)
	Relational	.93 (.10)	

condition (solid black line). Thus, participants were more likely to correctly estimate the temporal location for an item that had been encoded semantically than for an item that had been encoded silently.

This pattern of results closely resembles the levels-of-processing effect, suggesting that encoding tasks that foster relational encoding (e.g., silent reading) do not generally improve memory for temporal information. Instead, an encoding task that improves item-specific information (i.e., semantic judgment) also enhanced memory on a test that probed memory for a single item's temporal location.

To supplement the slope analysis, we also examined individual differences in recognition and temporal-location estimation. Specifically, we conducted two analyses. The first correlated slope and recognition d' for each item type (silent, semantic) to determine whether individual differences in item memory on the recognition test were related to individual differences in temporal-location estimates between participants. Slope and d' correlated with marginal significance both for semantic lists, $r = .32$, $p = .06$ (see Figure 3, Panel A), and for silent lists, $r = .29$, $p = .09$ (see Figure 3, Panel B), suggesting that differences in recognition across participants might be related to memory for temporal location for both types of encoding, and that accuracy of temporal-location estimation is closely linked to item memory.

Our second analysis assessed the correlation between difference scores (semantic - silent) for slopes and d'. This method removes individual differences in overall performance on the tests, instead emphasizing only individual differences in the encoding benefit offered by semantic judgment over and above silent reading. These difference scores also correlated with marginal significance, $r = .28$, $p = .10$ (see Figure 4A), suggesting that individual differences in the benefit of semantic encoding relative to silent reading for recognition memory might be related to similar benefits on the temporal-location task. In other words, a larger levels-of-processing effect on the recognition test might also mean a larger levels-of-processing effect on the temporal-location task. Of course, our correlational effects should be interpreted with caution because they are associative (not causal) and they are not statistically significant. However, they correspond with our main analysis (shown in Figure 2A) and the pattern is replicated in Experiments 2 and 3, suggesting a consistent link between item information and temporal-location estimation.

Together, the results of Experiment 1 suggest that encoding tasks that have been shown to strengthen interitem associations, such as silent reading (Jonker et al., 2014; Jonker & MacLeod, 2015, 2017; McDaniel & Bugg, 2008), do not generally improve all types of temporal memory. Instead, temporal-location estimation is improved when item information is strong, as measured by an item recognition test.

One alternative explanation for the present results is that temporal-location estimates benefited not from item encoding, but instead from making an overt response. That is, perhaps the response task (key presses for pleasant vs. unpleasant) resulted in a more distinct temporal code for each item, possibly creating

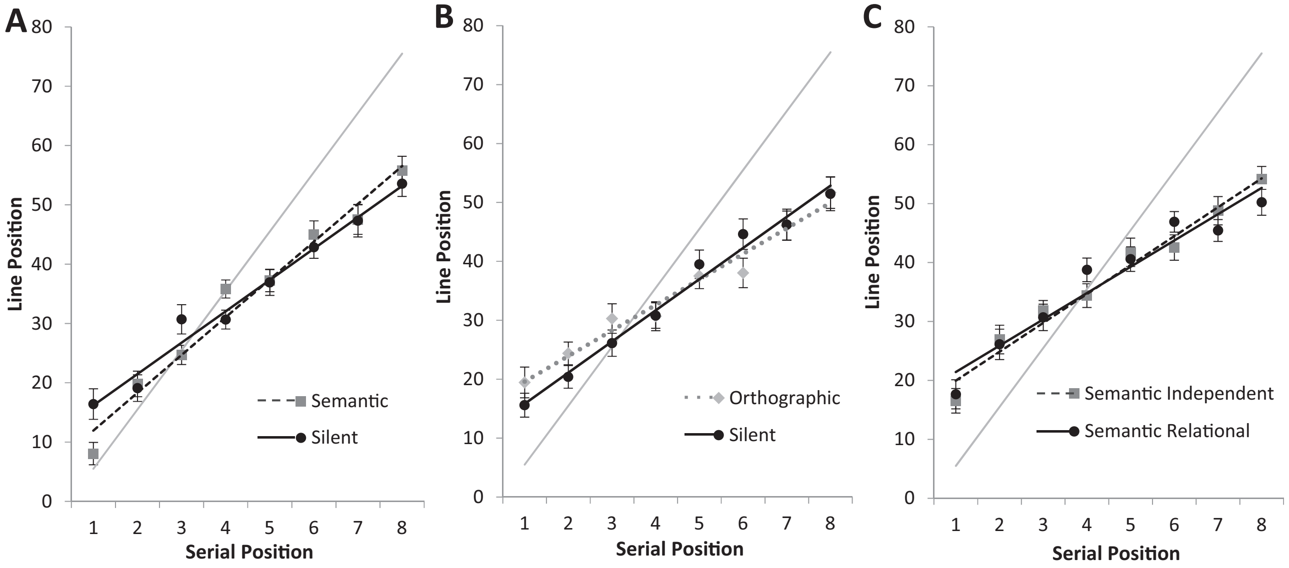

Figure 2. Temporal-location estimates for (A) Experiment 1, (B) Experiment 2, and (C) Experiment 3. The solid gray line represents optimal performance; the solid black and gray dotted lines show the mean slopes for the two encoding tasks. The points are group means at each serial position in the eight-item study list, and the error bars represent 1 *SE* of the corresponding mean.

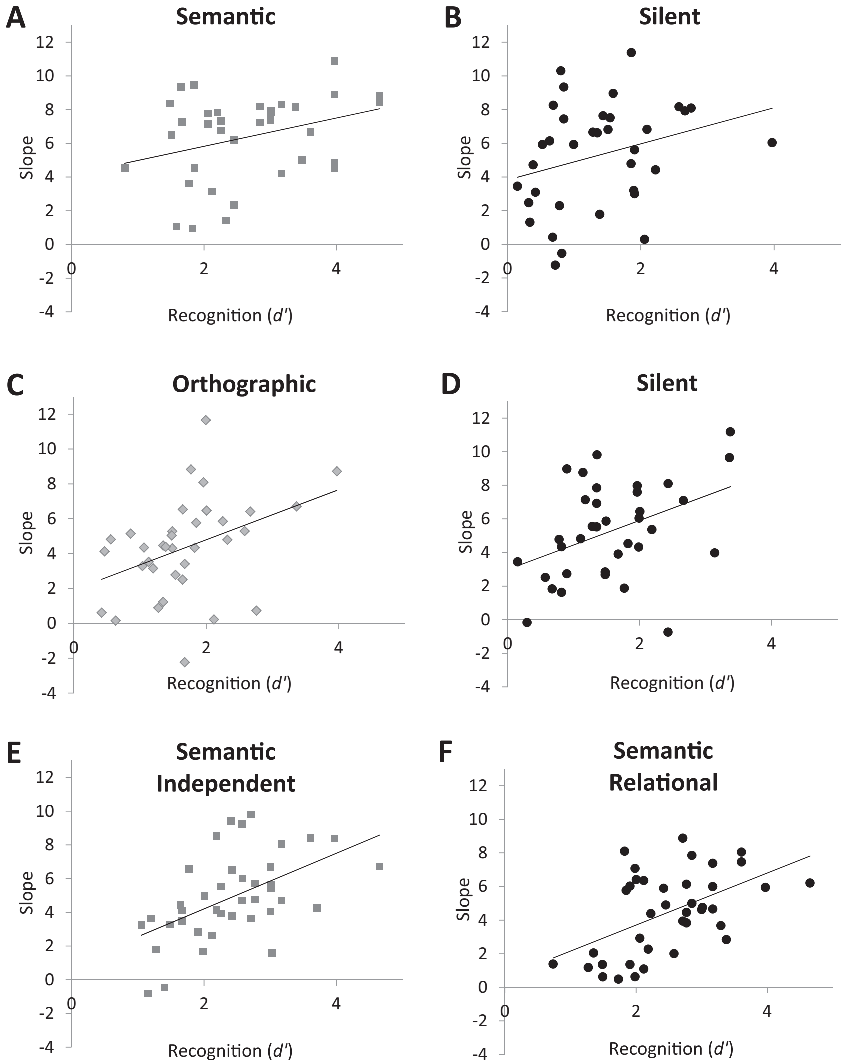

Figure 3. Scatter plots showing each individual's temporal location slope score on the *y* axis and recognition performance on the *x* axis, each with a fitted trend line. Panels A and B display data from Experiment 1; Panels C and D display data from Experiment 2; Panels E and F display data from Experiment 3. Panels A and E display conceptually similar encoding tasks (i.e., item-specific semantic judgments).

a strong association between the item and context because the decision or response-production process was strongly linked to temporal-location information (no such key press was made for the silently read items). In other words, perhaps the act of producing a response created a strong "time stamp" for that experience. Under this explanation, superior performance on the temporal-location task would be due not to increased item information, but to the increased item-temporal binding that resulted from making an overt response. Experiment 2 was designed to address this possibility.

Experiment 2

In Experiment 2, we sought to determine whether the temporal-location estimates in Experiment 1 benefited from item encoding or from making overt responses. To dissociate these two possibilities, we replaced the semantic-judgment task with a response task that is well-known to produce relatively poor item memory in comparison. Specifically, we replaced the semantic judgment with an orthographic judgment, which has been found to produce poorer memory (Hyde & Jenkins, 1969; as summarized by Craik & Lockhart, 1972). This change allowed us to contrast temporal-location estimates following silent reading to those following a response task with impoverished—as opposed to heightened—item information. If temporal-location estimates benefit from greater item information, then performance on our temporal-location task should be equivalent or better following silent reading compared with orthographic judgment. Alternatively, if temporal-location estimates benefit from response production, then performance on our temporal-location task should be better following orthographic judgment than silent reading.

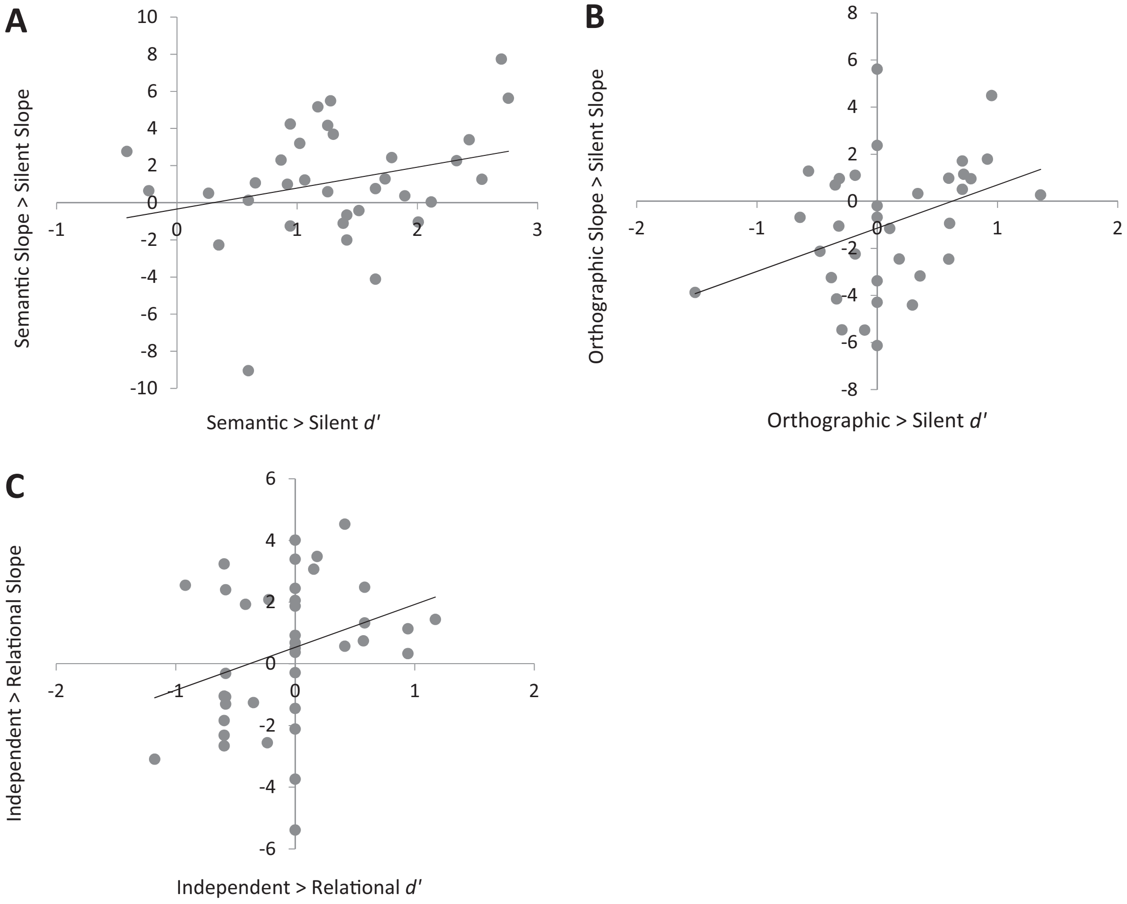

Figure 4. Scatter plots showing each individual's difference score for slope on the *y* axis and recognition performance on the *x* axis, each with a fitted trend line. Panel A displays data from Experiment 1; Panel B displays data from Experiment 2; Panel C displays data from Experiment 3.

Method

Participants. Thirty-five students (26 women, $M_{\text{age}} = 20.0$) from the University of Waterloo participated in exchange for partial course credit.

Materials and procedure. Experiment 2 differed from Experiment 1 in only one respect: The semantic-judgment encoding task was replaced with an orthographic judgment in which participants were to indicate with a key press whether each word contained the letter "a."

Results and Discussion

The surprise recognition test revealed no differences in memory strength following orthographic judgments ($M_{d'} = 1.68$, $SD = 0.77$) compared with silent reading ($M_{d'} = 1.58$, $SD = 0.80$), $t(34) = 1.06$, $SE = .10$, $p = .30$, $d = 0.18$. Notably, recognition following orthographic judgments here was poorer than that following the semantic judgments in Experiment 1, $t(64.89\,^{2}) = 4.67$, $SE = .21$, $p < .001$, $d = 1.12$, demonstrating that the goal of decreasing item memory in the overt response-task condition was met.

A paired-samples *t* test assessed whether slopes for orthographic lists differed from slopes for silently read lists. Performance on the temporal-location test was more accurate following silent reading ($M_{\text{slope}} = 5.29$, $SD = 2.86$) than following orthographic judgment ($M_{\text{slope}} = 4.36$, $SD = 2.82$), $t(34) = 2.02$, $SE = .47$, $p = .05$, $d = 0.34$, which can be seen in Figure 2B: The slope for silent reading more closely approaches optimal performance than does the slope for orthographic judgment. This result is surprising, given that recognition performance did not differ significantly and, in fact, trended in the opposite direction (orthographic judgment > silent reading). However, this result could be driven by the fact that temporal estimation is facilitated by semantic information, which might be higher in the silent-reading condition. The recognition test, on the other hand, could be performed using semantic information or orthography. In other words, our estimates of item memory (d') for the orthographic condition might be enhanced by the fact that the recognition test could be performed well enough

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[2] Levene's test for equality of variances revealed that the assumption of homogeneity of variances was not met. Therefore, a correction to degrees of freedom was used.

by relying on recognition of word orthography, thus artificially inflating estimates of item memory. It is unlikely that temporal-location estimates would similarly benefit from recognition of orthography. Therefore, our recognition test might be probing memory for orthography and/or semantic information, whereas the temporal-location test might be probing semantic information only. Despite this open question, the purpose of the present experiment was to rule out the possibility that temporal-location estimation is linked to the decision-making and/or response production required to perform the semantic and orthographic judgment tasks, which was achieved here. Response production is not the key factor.

We also examined individual differences in recognition and temporal-location estimation. Slope and d' correlated both for orthographic lists, $r = .39$, $p = .02$, and for silent lists, $r = .41$, $p = .02$ (see Figures 3C and 3D), a pattern consistent with that of Experiment 1. Furthermore, individual differences in the relative benefit of silent reading over orthographic judgments were also consistent with the results of Experiment 1: The levels-of-processing effect for temporal-location estimation and d' correlated across individuals, $r = .37$, $p = .03$ (see Figure 4B). Therefore, even though there was no observed difference in recognition performance between the two encoding tasks, we observed a consistent relation between task-related differences in item memory and estimates on our temporal-location task. Thus, this experiment provides a conceptual replication of the results found in Experiment 1 and also demonstrates that superior temporal memory is not due to the presence of an overt response task. Instead, the results support the explanation that item strength underlies temporal estimation.

Experiment 3

The results of Experiments 1 and 2 make a case for the critical role of item information in temporal-location estimation. However, to bolster this claim, it would be ideal to demonstrate that temporal estimation is not also affected by relational information. To achieve this goal, in Experiment 3, we also tested memory for relational information. Specifically, after completing an estimate of temporal location, we probed participants' memory for interitem associations as well, using a method we introduced in earlier work (Jonker & MacLeod, 2017). If temporal estimation is driven by item information only, then temporal-location slopes should not correlate with memory for interitem associations.

Experiment 3 achieved a second goal of generalizing our findings beyond silent reading, which is a relatively unconstrained encoding task. To this end, we used a relational encoding task that we have employed in the past: relational semantic judgment (Jonker & MacLeod, 2015, 2017). For this task, participants were asked to indicate whether the object corresponding to the current word was larger or smaller than that corresponding to the previously presented word. In other words, using the example stimuli in Figure 1, for the second item, the participant would have to indicate whether a *grape* is larger or smaller than a *heart*. This can be contrasted with an independent semantic judgment, where participants were asked to indicate whether the object was larger or smaller than a constant (a *microwave*). The benefit of this manipulation is that the probed information is highly similar for both judgments; in both cases, participants make a size judgment. The main difference is whether that judgment is based on the list-independent constant or a list-dependent and variable item.

In previous work, these encoding tasks produced equivalent recognition performance (Jonker & MacLeod, 2017) but the relational semantic judgment resulted in superior performance both on an order reconstruction test (Jonker & MacLeod, 2015) and on a test of interitem associations (Jonker & MacLeod, 2017) when compared to the independent semantic judgment.

Method

Participants. Thirty-nine students (29 women, $M_{\text{age}} = 19.6$) from the University of Waterloo participated in exchange for partial course credit.

Materials and procedure. Experiment 3 was modeled after Experiment 1 with two main changes. First, both encoding tasks were semantic in nature; however, the encoding was either an independent semantic judgment ("Is this object larger or smaller than the size of a microwave?" with word presented in red font) or a relational semantic judgment ("Is this object larger or smaller than the previous object?" with word presented in blue font). The second change was that a second test trial was added to most blocks. That is, after participants completed the temporal-location estimate, their memory for an interitem association was tested. For this test, participants were shown the same word in the center of the screen along with two other words from the study list, one in each of the bottom corners of the screen. Of these two words, one had occurred immediately after the target during study and the other had occurred two serial positions later. Participants were to indicate which of the two items had immediately followed the target during study. The location of the correct response on the screen was randomly assigned on each trial. This test was not included if the target item was from Serial Positions 7 or 8.

Results and Discussion

The surprise recognition test revealed no differences in d' following independent ($M_{d'} = 2.42$, $SD = 0.81$) compared with relational ($M_{d'} = 2.49$, $SD = 0.81$) semantic judgments, $t(38) = 0.82$, $SE = .08$, $p = .42$, $d = 0.13$, replicating our previous work (Jonker & MacLeod, 2017).

A paired-samples t test assessed whether slopes for independent compared with relational semantic judgments differed. Unlike in Experiments 1 and 2, performance on the temporal-location test did not differ by encoding task (independent: $M_{\text{slope}} = 4.90$, $SD = 2.53$; relational: $M_{\text{slope}} = 4.46$, $SD = 2.43$), $t(38) = 1.18$, $SE = .37$, $p = .25$, $d = 0.19$, which can be seen in Figure 2C: The slopes are approximately equivalent. This result demonstrates that when item information is approximately equivalent, as measured by recognition performance, slopes do not differ.

In contrast, performance on the interitem-association test did differ; participants were more accurate following the relational judgment ($M_{\text{IIA}} = .75$, $SD = .16$) compared with the independent one ($M_{\text{IIA}} = .60$, $SD = .19$), $t(38) = 5.28$, $SE = .03$, $p < .001$, $d = 0.85$, again replicating our previous work (Jonker & MacLeod, 2017) and demonstrating that, relative to independent semantic-judgment, the relational semantic-judgment was effective at increasing associations among list items.

To determine whether temporal-location estimates rely on relational as well as item-specific information, we examined individual differences in recognition and temporal-location estimation. Slope and *d′* correlated both for independent semantic lists, $r = .53$, $p = .001$, and for relational semantic lists, $r = .51$, $p = .001$ (see Figures 3E and 3F), and the processing differences for the temporal-location estimates and *d′* were marginally correlated across individuals, $r = .31$, $p = .06$ (see Figure 4C). These patterns are consistent with those of Experiments 1 and 2.

In contrast, the correlations with interitem association performance were mixed: Slopes were marginally correlated with memory for interitem associations in the independent semantic condition, $r = .27$, $p = .10$, but the relation fell below the marginal range in the relational semantic condition, $r = .25$, $p = .12$ (see Figures 5A and 5B). However, as shown in Figures 5C and 5D, neither temporal estimation slopes nor *d′* correlated with processing differences on the interitem association test (slope: $r = -.02$, $p = .93$; d': $r = -.15$, $p = .36$).

Even though no recognition differences were observed in the present experiment, we found a consistent relation between individual differences in item memory and estimates on our temporal-location task. This pattern cannot be attributed to memory for interitem associations, which did not correlate consistently with temporal-location estimates (the strongest relation was one marginally significant correlation). These results confirm the conclusion that temporal-location estimates are closely linked to item information rather than to relational information.

General Discussion

Many sources of information can inform the reconstruction of a sequence of events. Previous research has emphasized the importance of relational information for order memory (e.g., Jonker & MacLeod, 2017; McDaniel & Bugg, 2008). However, it is unclear whether all types of temporal and sequence memory are reconstructed using relational information, particularly when that reconstruction involves remembering an individual item within a defined temporal context (i.e., a list).

In the present work, we examined whether interitem associations or item-specific information guides estimates of temporal occurrence. To accomplish this goal, we drew on previous work demonstrating that interitem associations are encoded particularly well during silent reading, whereas item information is encoded well during semantic judgment (Jonker et al., 2014). In Experiment 1, we found that, compared with semantic judgment, silent reading resulted in less accurate estimates of tem-

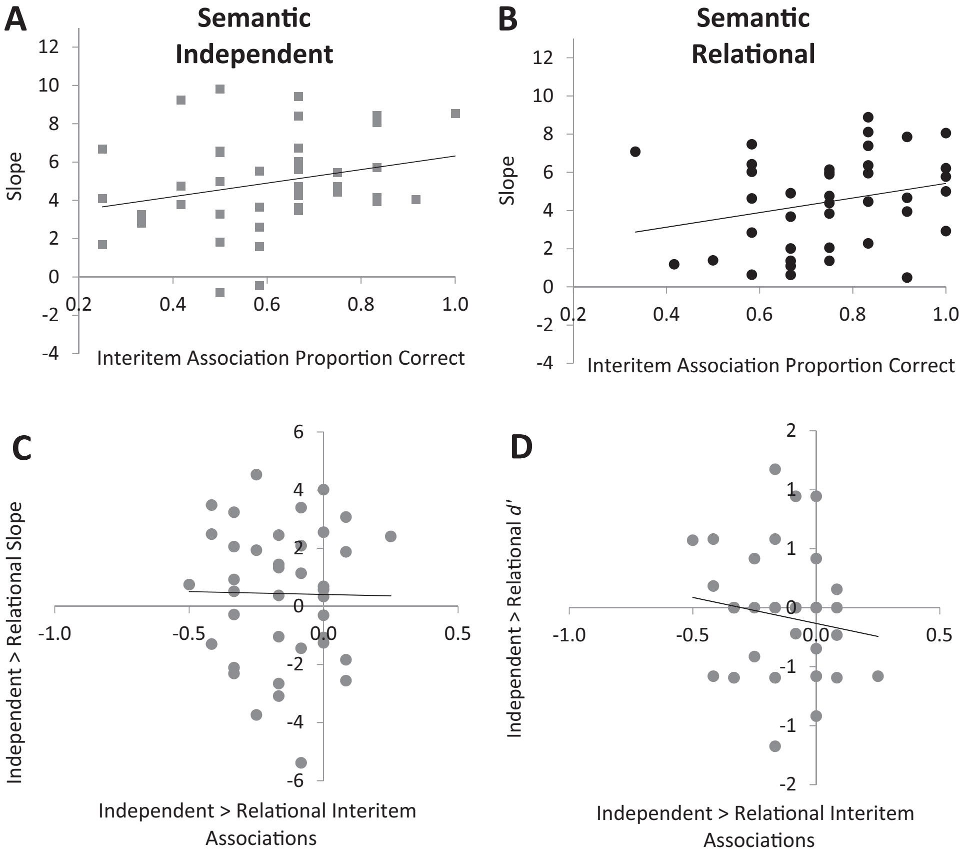

Figure 5. Scatter plots showing relations with performance on the interitem association test. Panels A and B show correlations between performance on the interitem association test with each individual's temporal location slope score for both the independent (Panel A) and relational (Panel B) semantic judgments, with a fitted trend line. Panels C and D show correlations between each individual's difference score on the interitem-association test with slope (Panel C) and *d′* (Panel D), with a fitted trend line.

poral location, which suggests that memory for temporal location relies more heavily on item information than on interitem associations.

In Experiment 2, we considered the possibility that temporal-estimation performance was better following semantic judgment because making those judgments required an overt response. That is, we reasoned that perhaps the decision and/or the response-production components of the semantic task result in stronger item–context binding, such that an item becomes associated with temporal-location information by virtue of making a judgment and producing a response. To rule out this possibility, we replaced the strong item encoding of a semantic judgment with a weaker response task: an orthographic judgment. Similar to the semantic task, the orthographic task involved both decision and response production, but it involved weaker item information. Despite this similarity, we found poorer temporal-location accuracy for the orthographic task than for silent reading, demonstrating that temporal-location estimates were more closely linked to item memory than to decision-making or response production. The conclusion that temporal-location estimates are related to item memory was further bolstered by correlational assessments. We found correspondence between item recognition and temporal-location estimates across individuals, and we also found that individual differences in the size of the levels-of-processing effect on the recognition test correlated with a similar index on the temporal-location task.

In a final experiment, we generalized the findings beyond silent reading to another relational task. This relational semantic judgment resulted in recognition performance equivalent to that of an independent semantic judgment, but the relational task increased memory for interitem associations, as we have previously found (Jonker & MacLeod, 2017). We correlated performance on the temporal-location task with our separate metrics of item memory and interitem associations, and found that temporal-location estimation was closely tied to recognition performance, but not to relational memory. Overall, the pattern of results demonstrates that estimates of temporal location within a defined list context are driven by item information and not by relational information.

This outcome can be linked back to the example we posed in our introduction. In this example, we postulated how one might remember the order of a series of errands completed during a day. When trying to remember when one went to the gym, memory for when this event occurred is likely best if the person encoded a strong memory of being at the gym (i.e., item-specific information) rather than a strong memory of planning the route to the veterinarian from the gym parking lot (i.e., interitem association). In other words, item information is likely more useful when trying to place an independent event in time.

There is precedence in the literature to suspect a different pattern of results than the one we observed, which we found interesting. Studies of judgments of recency (JOR), which are judgments of how long ago an item was presented, suggest that stronger items are perceived as having occurred more recently (e.g., Hintzman, 2004, 2005). Therefore, a plausible hypothesis for the present experiments could have been that stronger encoding tasks, such as the independent semantic judgment, would result in a bias to place items toward the end of the list, rather than an increase in temporal-location accuracy. This was not the case. Instead, the reverse was true, with stronger item information resulting in earlier and more accurate temporal estimates. This result is especially apparent in Serial Positions 1, 2, and 3 of Figure 2A. The discrepancy between previous work on JORs and our present work may be because our temporal-location estimates involved anchors in time; that is, participants were presented with a beginning and an end of a specific list context and they were to place the item between these two anchors. This method can be contrasted with the JOR method, which involves a continuous stream of items in which participants must indicate how far back an item occurred. In the absence of strong context anchors, as with JORs, participants might rely only on item strength; however, when presented with clear context cues, as with our temporal-location estimates, stronger items might more easily be tied to specific context cues (e.g., the beginning of the list). This observation highlights an important unexplored area ripe for future investigation. Much of our world involves anchors in time rather than a continuous context-free stream of information. In our example of remembering a series of errands, there are clear anchors for the memory search, such as the beginning and end of the day, as well as many other discrete context markers throughout the day. Thus, our short lists, with a clear beginning and end, provide a convenient paradigm for further investigation of the roles that interitem associations and item–context associations play in temporal estimates.

The results reported in this article demonstrate that all types of temporal memory are not equal. Instead, it seems to be the case that memory for the order of events can be informed by at least two sources of information. One of these sources—as found repeatedly in the literature—is relational information (Hunt & Einstein, 1981; McDaniel & Bugg, 2008), and this information is well-encoded when the task is relatively common. The other source is independent temporal-location information, and here we demonstrated that this information is linked to item-specific encoding. These findings highlight the importance of checking assumptions when using complex tests of memory for sequence information. Indeed, tests such as the order-reconstruction test (Nairne et al., 1991) and sequence-learning tasks (Hsieh, Gruber, Jenkins, & Ranganath, 2014; Ranganath & Hsieh, 2016) make assumptions about the nature of the associations they are probing. Often, those who use the order-reconstruction test assume that interitem associations drive performance; however, it is plausible that temporal estimation could play a role in order reconstruction as well. Similarly, those who use the sequence-learning paradigm often assume that performance reflects item–context associations, but it is plausible that interitem associations could be driving the observed results. Even more likely, different sources of information might be interacting during performance of these complex tests to collectively produce behavior. That is, together, interitem associations, item strength, and item–context associations could all contribute to produce temporal memory. Depending on how temporal memory is measured, then, these factors may well be differentially influential. Thus, careful experimentation should be done prior to making claims about the type(s) of association driving performance on a test.

In summary, although sequence and temporal memory have sometimes been referred to interchangeably, there is good reason to believe that reconstruction of a sequence of events can be informed by at least two distinct sources of information. Further research in this domain will uncover the nuances of temporal memory and ideally lead to a comprehensive model that predicts memory for temporal order based on different task demands.

References

Coltheart, M. (1981). The MRC psycholinguistic database. *The Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology, 33,* 497–505. http://dx.doi.org/10.1080/14640748108400805

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning & Verbal Behavior, 11,* 671–684. http://dx.doi.org/10.1016/S0022-5371(72)80001-X

Ebenholtz, S. M. (1972). Serial learning and dimensional organization. In G. H. Bower (Ed.), *The psychology of learning and motivation* (pp. 267–314). New York, NY: Academic Press.

Einstein, G. O., & Hunt, R. R. (1980). Levels of processing and organization: Additive effects of individual-item and relational processing. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 588–598.

Engelkamp, J., & Dehn, D. M. (2000). Item and order information in subject-performed tasks and experimenter-performed tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 671–682. http://dx.doi.org/10.1037/0278-7393.26.3.671

Hintzman, D. L. (2004). Time versus items in judgment of recency. *Mem. Cognit*., *32,* 1298–1304.

Hintzman, D. L. (2005). Memory strength and recency judgments. *Psychon. Bull. Rev*., *12,* 858–864.

Howard, M. W., & Kahana, M. J. (2002). A distributed representation of temporal context. *Journal of Mathematical Psychology, 46,* 269–299. http://dx.doi.org/10.1006/jmps.2001.1388

Hsieh, L.-T., Gruber, M. J., Jenkins, L. J., & Ranganath, C. (2014). Hippocampal activity patterns carry information about objects in temporal context. *Neuron, 81,* 1165–1178. http://dx.doi.org/10.1016/j.neuron.2014.01.015

Hunt, R. R., & Einstein, G. O. (1981). Relational and item-specific information in memory. *Journal of Verbal Learning & Verbal Behavior, 20,* 497–514. http://dx.doi.org/10.1016/S0022-5371(81)90138-9

Hyde, T. S., & Jenkins, J. J. (1969). Differential effects of incidental tasks on the organization of recall of a list of highly associated words. *Journal of Experimental Psychology, 82,* 472–481. http://dx.doi.org/10.1037/h0028372

Jonker, T. R., Levene, M., & MacLeod, C. M. (2014). Testing the item-order account of design effects using the production effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40,* 441–448. http://dx.doi.org/10.1037/a0034977

Jonker, T. R., & MacLeod, C. M. (2015). Disruption of relational processing underlies poor memory for order. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41,* 831–840. http://dx.doi.org/10.1037/xlm0000069

Jonker, T. R., & MacLeod, C. M. (2017). Not all order memory is equal: Test demands reveal dissociations in memory for sequence information. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 43,* 177–188. http://dx.doi.org/10.1037/xlm0000301

Kahana, M. J. (1996). Associative retrieval processes in free recall. *Memory & Cognition, 24,* 103–109. http://dx.doi.org/10.3758/BF03197276

Lashley, K. S. (1951). The problem of serial order in behavior. In A. Jeffress (Ed.), *Cerebral mechanisms in behavior* (pp. 112–136). New York, NY: Wiley.

McDaniel, M. A., & Bugg, J. M. (2008). Instability in memory phenomena: A common puzzle and a unifying explanation. *Psychonomic Bulletin & Review, 15,* 237–255. http://dx.doi.org/10.3758/PBR.15.2.237

Mensink, G.-J., & Raaijmakers, J. G. (1988). A model for interference and forgetting. *Psychological Review, 95,* 434–455. http://dx.doi.org/10.1037/0033-295X.95.4.434

Morris, S. B., & DeShon, R. P. (2002). Combining effect size estimates in meta-analysis with repeated measures and independent-groups designs. *Psychol. Methods, 7,* 105–125.

Nairne, J. S., Riegler, G. L., & Serra, M. (1991). Dissociative effects of generation on item and order retention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 702–709. http://dx.doi.org/10.1037/0278-7393.17.4.702

Polyn, S. M., Norman, K. A., & Kahana, M. J. (2009). A context maintenance and retrieval model of organizational processes in free recall. *Psychological Review, 116,* 129–156. http://dx.doi.org/10.1037/a0014420

Ranganath, C., & Hsieh, L.-T. (2016). The hippocampus: A special place for time. *Annals of the New York Academy of Sciences, 1369,* 93–110. http://dx.doi.org/10.1111/nyas.13043

Serra, M., & Nairne, J. S. (1993). Design controversies and the generation effect: Support for an item-order hypothesis. *Memory & Cognition, 21,* 34–40. http://dx.doi.org/10.3758/BF03211162

Tulving, E. (2002). Episodic Memory: From Mind to Brain. *Annu. Rev. Psychol*. *53,* 1–25.

Yonelinas, A. P., & Levy, B. J. (2002). Dissociating familiarity from recollection in human recognition memory: Different rates of forgetting over short retention intervals. *Psychonomic Bulletin & Review, 9,* 575–582. http://dx.doi.org/10.3758/BF03196315

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