Incidentally Encoded Temporal Associations Produce Priming in Implicit Memory

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Abstract

Remembering one event tends to trigger retrieval of other events previously experienced nearby in time (temporal contiguity effect). The retrieved context framework attributes this effect to automatic encoding and retrieval processes, predicting temporal contiguity even with incidental encoding and implicit retrieval. There is strong evidence of temporal contiguity following incidental encoding, but does the prediction hold for implicit retrieval? In this experiment, we tested the framework's predictions for recall and repetition priming. Across 30 trials, undergraduates read a series of words aloud. In each trial, two words were repeated (cue and target), initially separated by $|lag| = 1, 2$, or 5. On their second presentation, the cue was presented first, immediately followed by the target. Temporal contiguity occurred in surprise final free recall, replicating previous work. Repeating a cue enhanced repetition priming for its associated target, and this effect varied with initial lag, demonstrating temporal contiguity in implicit retrieval.

Statement of Relevance

A key assumption of some leading memory theories is that information about the relative order of events (temporal information) is automatically encoded whenever memories are formed and also automatically retrieved. These theories naturally predict that temporal information affects memory search even when encoding is unintentional and retrieval is implicit because memories that occurred nearby in time should cue one another automatically. We tested this critical prediction with both recall and repetition priming. Subjects read a list of words, some of which were repeated, before a surprise recall test. Some repeated words were primed by another word previously experienced nearby in the list (targets), while others were not (cues). Temporal information influenced recall order, and repetition priming was greater for targets than cues. Moreover, repetition priming for targets varied with the initial distance between the cue and target. These results support theories that assume temporal information is encoded *and* retrieved automatically.

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Information about the relative order of events is a powerful force in guiding deliberate memory search. When subjects study a list of words and are asked to recall the words in any order, recalling one item tends to lead to next recalling another item originally studied nearby in time (Kahana, 1996). This temporal contiguity effect (TCE) has greatly influenced memory theory development, giving rise to theories with diverging predictions about the conditions under which a TCE should occur. This makes the TCE a useful tool for theory testing (Healey et al., 2019; Mundorf et al., 2022). Whereas some theories assume the TCE is a result of strategic control processes (e.g., Hintzman, 2016), others emphasize automatic TCE-generating processes (e.g., Davelaar et al., 2005; Howard et al., 2015; Lehman & Malmberg, 2013). The retrieved context framework is one such account which attributes the TCE to the automatic formation of temporal associations during encoding and the automatic reinstatement of those associations when items are retrieved (see Howard & Kahana, 2002; Howard et al., 2015; Polyn et al., 2009). The framework naturally predicts a TCE even under conditions of incidental encoding or implicit retrieval.

Consistent with this prediction, recent work has found a small but significant TCE in free recall following incidental encoding, indicating the TCE is due, at least in part, to automatic encoding of new temporal associations (Diamond & Levine, 2020; Healey, 2018; Mundorf et al., 2021). That is, merely presenting items nearby in a list is sufficient for new temporal associations to form, even when subjects are prevented from using order-based strategies (although subjects may not be aware temporal order information is available; see Bradley & Glenberg, 1983). Temporal information may also be automatically retrieved. Even when order-based strategies hurt performance or subjects adopt an alternate retrieval strategy that should reduce the TCE, temporal information guides memory search (Davis et al., 2008; Healey & Uitvlugt, 2019; Polyn et al., 2011). For example, when subjects are instructed to recall semantically related items together in a list with semantic structure, the TCE is eliminated; yet *within* a semantic cluster, subjects still tend to transition between words originally studied closer in time (Healey & Uitvlugt, 2019; Polyn et al., 2011). However, these findings come from tests of explicit memory, which inherently involve intentional retrieval. To test if temporal information is retrieved automatically *whenever* an item is retrieved, we must consider tasks where retrieval is unintentional.

Implicit memory tests measure the effect of previous experience on current responses in the absence of intentional retrieval or even awareness that information is being retrieved. Implicit memory can be inferred when responses to a repeated item are faster on its second presentation (repetition priming; Graf & Schacter, 1985). Repetition priming may be enhanced when a repeated target is preceded by a cue previously experienced nearby in the list (associative repetition priming). When words are studied in cue-target pairs, responses to a repeated target tend to be faster if it was preceded by its associated cue than if it was preceded by an unrelated item, even if the cue and target are not semantically related (McKoon & Ratcliff, 1979, 1986; Spieler & Balota, 1996). Some have suggested this associative repetition priming occurs because the cue and target form new associations during their first presentation; those associations are re-activated when the cue is repeated, facilitating responses to the target (Ratcliff & McKoon, 1988; Zeelenberg et al., 2003).

However, there are mixed findings on when, and if, associative repetition priming occurs (for a review, see Zeelenberg et al., 2003). Associative repetition priming is greatest when the cue and target are presented in the same order across presentations and at longer delays between the repetition of the cue and repetition of the target (Raaijmakers, 2005; Zeelenberg et al., 2003). Associative repetition priming may even be eliminated if the presentation order is reversed, leading some to suggest this priming is due not to reinstatement of newly formed temporal associations, but rather to perceptual priming (Goshen-Gottstein & Moscovitch, 1995; Poldrack & Cohen, 1997) or unitization (encoding the pair as a single item; Graf & Schacter, 1989). Others attribute associative repetition priming to intentional retrieval strategies, since the effect is largest when subjects have more time between the repetition of the cue and repetition of the target (Carroll & Kirsner, 1982; Dew et al., 2007; Durgunoğlu & Neely, 1987; but see McKoon & Ratcliff, 1986). One challenge in evaluating these accounts is that associative repetition priming has been investigated primarily in a paired associates paradigm. Little work has examined repetition priming among items not explicitly paired together (but see Smith et al., 1989). Therefore, it is not obvious if associative repetition priming occurs between *any* items merely experienced nearby in time or only between items explicitly paired together, and it is unclear if these associations are automatically retrieved.

Theoretical Predictions

Insofar as its mechanisms operate automatically, the retrieved context framework makes clear, testable predictions for how temporal information should influence not only recall, but also repetition priming. For recall, the framework clearly predicts temporal contiguity regardless of encoding intentionality (Mundorf et al., 2021). This framework assumes that at encoding, items automatically form reciprocal associations with the current state of mental context. Context changes during encoding as each item is studied while still retaining a record of the recent past, such that items studied relatively closer in time form associations with more similar states of context. When an item is retrieved, it reinstates its associated context from encoding. Because items studied closer together in time are associated with more similar states of context, the reinstated context tends to be a better cue for closer, relative to farther, temporal associates. In this way, temporal associates indirectly cue one another. Thus, the retrieved context framework naturally predicts a TCE.

If we assume that the same context reinstatement occurs in implicit retrieval, this framework clearly predicts associative repetition priming for paired associates. Further, we can make two novel predictions regarding the conditions under which associative repetition priming should occur beyond a paired associates task. First, associative repetition priming should occur for items not explicitly paired together, even if they were originally separated by other list items, because the context associated with each item during encoding contains a record of the recent past. Second, because context changes with each item studied, the degree of priming should vary with initial *lag* (distance between cue and target on their first presentation). Current quantitative implementations of this framework specifically predict more priming at shorter initial lags. In contrast, accounts which attribute associative repetition priming to perceptual priming, unitization, or intentional strategies predict associative repetition priming *only* for items explicitly paired together and always presented in the same order (initial *lag* = +1).

In the present experiment, subjects read a series of words aloud, unaware that some would later be repeated or that their memory for the words would be tested. To avoid explicitly pairing words together, we presented words individually at regular intervals. Only a small proportion of words were repeated, and we varied the initial lag between repeated words so subjects could not predict which words would later be repeated together. This also allowed us to test if the degree of associative repetition priming varied with initial lag.

Open Practices Statement

This experiment was not preregistered prior to data collection. De-identified data along with data analysis scripts are available at: https://osf.io/392cs/?view_only=b7610fcf7d86422b87393107c1f28927.

Methods

Subjects read 505 words aloud into a microphone as each word appeared one at a time on the screen. Most words were presented once, but the stimuli of interest were 30 pairs of words which were each presented twice (60 unique repeated words total). Each pair was composed of a cue word and a target word. After completing the reading task, subjects were given 3 minutes for a surprise free recall test on all of the words they had read. The task took approximately 22 minutes to complete.

Subjects

Because of the novel design of the current experiment, setting sample size through a precise a priori power calculation was not possible. However, as a general guideline we used Healey's (2018) finding that achieving 95% power to detect a TCE in *deliberate* memory search following incidental encoding requires a sample size of 510 subjects per condition. We thus aimed to collect data from at least 500 subjects. To do so we opted to collect data from as many Michigan State University undergraduate students as possible within two academic semesters, a sample of convenience. This resulted in a final sample size of 723 subjects who completed the experiment for course credit. Due to a technical error, demographic information was only recorded for 714 subjects. Of these, 562 (78.7%) identified their gender as female, and the mean age was 19.7 years (SD = 1.9).

Data exclusions

To eliminate the potential influence of intentional study strategies, data were excluded for subjects who indicated on a post-task questionnaire that they suspected their memory would be tested after the reading task. After making these exclusions, 603 subjects (83.4%) remained.

Materials

Subjects read 505 words, 385 of which were presented only once. The remaining 120 words were composed of 60 unique words each presented twice. These 60 words were divided into 30 pairs, where one member of each pair was designated as a cue word and the other as a target word.

The words were presented to subjects as one long, continuous list. However, the experiment was in fact divided into 30 sections, or pseudo-lists, each composed of 10 to 25 words. Example pseudo-lists are presented in Figure 1. Each pseudo-list was composed of two words each presented twice (the cue and the target) and some number of once-presented filler words (represented with an X in Figure 1).

So that subjects would not be able to anticipate, even unconsciously, when cue or target words would appear, each pseudo-list began with a jittered number of filler words (between 0 and 9). On their first presentation, we manipulated the initial lag between the cue and target—the distance in serial positions between the first presentation of the target word and the first presentation of the cue word (*lag* = *target*−*cue*). There were 6 possible initial lags: −5, −2, −1, +1, +2, or +5. Positive initial lags occurred when the cue was presented before the target; negative initial lags occurred when the target was presented before the cue. For example, if the cue was presented in serial position 1 and the target in serial position 2, the initial lag between them would be 2 − 1 = +1 (Figure 1A). If instead the target was presented first in serial position 1, and the cue was presented in serial position 6, the initial lag between them would be 1 − 6 = −5 (Figure 1B). Any serial positions between the first presentations of the cue and target were filled with once-presented items; in this example, the target is followed by four filler items (serial positions 2, 3, 4, and 5) before the first presentation of the cue. Each subject experienced each possible initial lag exactly five times.

On their second presentation, the cue was always presented first, immediately followed by the target (*lag* = +1). Filler words intervened between repetitions such that there was always an inter-presentation *lag* = +10 between the first and second presentation of the target. Given that priming effects tend to be smaller at longer inter-presentation lags (Bentin & Moscovitch, 1988), we held the inter-presentation lag constant for the target words, which were our key stimuli of interest. This allowed us to examine the effect of the initial *target* − *cue* lag on repetition priming for target items free from potential confounding effects of the target's inter-presentation lag. The inter-presentation lag for the cue word necessarily varied depending on the initial *target* − *cue* lag.

For each subject, the 385 filler words were randomly drawn without replacement from a pool of 1,198 one- or two- syllable nouns containing between 2 and 9 letters, a subset of a larger word pool developed for the Penn Electrophysiology of Encoding and Retrieval Study

(PEERS; Healey & Kahana, 2014; Siegel & Kahana, 2014). The repeated words were selected from a pool of 60 target words used by Healey et al. (2014) for a similar naming time task. These words were also one- or two-syllable nouns with between 2 and 9 letters. The cue and target words for each list were randomly selected without replacement from this pool for each subject. Thus, across subjects, each word was equally likely to be chosen as a cue or target word.

Procedure

Subjects completed the experiment individually in sound-insulated testing booths. Instructions appearing onscreen stated the experimenters were interested in developing a list of words for a future experiment that were neither too easy nor too difficult to process, and how quickly a person can initiate reading a word can be a measure of how difficult it is to process. Subjects were therefore asked to read each word aloud *as soon as it appeared.* Subjects were *not* informed that some words would be repeated or that they would be tested on the words at the end of the experiment. They were asked to avoid movement and making extraneous noise during the session (such as tapping their feet or coughing) because clear audio recordings were important for the experiment. Vocal responses were recorded for each word using a microphone placed in front of the computer. Subjects were provided with two short breaks: one after the tenth pseudo-list and another after the twentieth pseudo-list. During these breaks, they could make noise and move around the booth if desired. Aside from these breaks, subjects experienced the task as one continuous list.

In the reading time task, each word was presented individually on the screen for 1.5 s followed by a 500 ms inter-stimulus interval. Therefore, the stimulus onset asynchrony between any two words was 2,000 ms. After reading all 505 words, subjects were given 3 min for a surprise free recall task. They were asked to type any words they could remember in whatever order they came to mind. Recalls were typed into an onscreen text box and submitted by pressing ENTER after each word. After pressing ENTER, the word they had just typed disappeared, leaving a blank text box for subjects to type their next recall. Finally, subjects were asked “At any point while reading the words, did you suspect you would be asked to remember the words later?” Subjects were then debriefed and asked not to share the details of the incidental memory test with anyone else.

Data Scoring

Naming time detection and reliability

To measure implicit memory, we compared naming time (i.e., how long it took subjects to begin reading the word aloud once it appeared onscreen) for the first versus the second presentation of each repeated word. We used Chronset to detect speech initiation for each word (Roux et al., 2017). Chronset is designed to distinguish noise from speech by analyzing recordings on the basis of multiple acoustic features and has been successful in detecting speech onset at rates similar to those of human raters (Roux et al., 2017). We used Chronset to score both the first and second presentations of all target and cue words: 4 words per trial, 120 words per subject.

To verify that Chronset was accurately classifying speech onset in our recordings, four human raters manually marked naming times for the first 41 subjects. Each rater determined naming time for the second presentation of each target word using Audacity® recording and editing software (Version 2.3.0; Audacity Team, 2018). For any word where it was difficult to determine naming time (for example, due to poor recording quality), the human raters marked their ratings as low-confidence, and these low-confidence ratings were excluded from the reliability analysis. Only 1.5% of ratings were low-confidence.

We calculated intraclass correlation (ICC) estimates and their 95% confidence intervals using a two-way mixed effects model to calculate variability among human raters. An ICC value of 0 indicates no agreement among raters, while an ICC value of 1 indicates perfect agreement (Shrout & Fleiss, 1979). Reliability was high among the human raters (ICC = 0.956 [0.952, 0.960]). Chronset ratings were highly correlated with each of the human raters (range:

0.872–0.903; see Table 1).

Naming time exclusions

Differences in response times tend to be quite sensitive to any fast or slow outlying data points (Ratcliff, 1979). Given that our measure of implicit memory relies on differences in naming times, we utilized a set of exclusion criteria similar to that adopted by Healey et al. (2014) to remove outlying naming times. We first eliminated any responses faster than 200 ms or slower than 2,000 ms. This step excluded responses on 0.6% of trials. After excluding these extreme outliers, we made additional exclusions for each subject based on their distribution of reaction times. Any value more than 2.5 standard deviations from the mean for each subject was replaced with a value equal to the subject's mean response time plus 2.5 standard deviations (if the original value was above the mean) or minus 2.5 standard deviations (if the original value was below the mean). The mean and standard deviations were calculated separately for each subject for each of the four response types (first presentation of the cue, first presentation of the target, second presentation of the cue, second presentation of the target). In total, 8.9% of all trials were affected, with no more than 20% of trials excluded from a single subject.[1]

Table 1
Correlations for Human Raters and Chronset Ratings

	Rater 1	Rater 2	Rater 3	Rater 4	Chronset
Rater 1	–				
Rater 2	0.972	–			
Rater 3	0.983	0.965	–		
Rater 4	0.933	0.941	0.927	–	
Chronset	0.903	0.877	0.882	0.872	–

[a] Note: Correlations reported here are Pearson's r. All correlations were significant, $p < .001$.

[1] We considered two other approaches to exclusions. In the first approach, we excluded extreme outliers (as defined above) and then made exclusions based on the mean and standard deviation across subjects for each item type, rather than the mean and standard deviation for *each* subject. The second method was to make no exclusions. Neither method changed the direction or significance of our results.

Table 2
Average Naming Times for Cue and Target Items

Item Type	Mean Naming Time (SD)	
	First Presentation	Second Presentation
Cue	519.11(63.02)	510.75(63.66)
Target	519.37(64.17)	498.34(61.90)

[a] Note: All naming times are in milliseconds. For each item type, we first calculated the mean naming time for each each subject and then calculated the mean and standard deviation (SD) across subjects.

Results

Measures of Implicit Memory

We examined repetition priming for both cue and target words to test the predictions that 1) associative repetition priming should occur even when items are not explicitly paired and 2) the degree of associative repetition priming should be affected by the initial lag between the cue and target. Average naming times are presented in Table 2. Repetition priming was measured for each repeated item by subtracting naming time on the first presentation from naming time on the second presentation, with negative values indicating faster naming on the item's second presentation (i.e., repetition priming).

As expected, basic repetition priming occurred for both cue and target items (Figure 2A). Importantly, however, the size of this priming effect was strongly influenced by item type. Repetition priming was greater for target than cue items, $t(602) = 10.87$, $p < .001$, $d = 0.442$, indicating significant *associative* repetition priming. Consistent with the retrieved context framework, cuing the target with another word previously presented nearby in time resulted in greater repetition priming, even when the words were not explicitly paired.

Temporal contiguity effects on priming

To test the retrieved context framework's prediction regarding the effect of lag on associative repetition priming, we examined priming of target items for each initial lag (Figure

2B). Repetition priming occurred at all initial lags, even when the cue and target were initially separated by other items ($|lag| = 2$ or 5) or their presentation order changed from the first to second presentation (negative initial lags).

We were also interested in the effect of initial lag. The by-lag analyses are based on 602 subjects who contributed data for all 6 possible lags (one subject was excluded for missing data for initial $lag = -2$). There was an effect of initial lag (−5, −2, −1, +1, +2, or +5) on repetition priming using the Greenhouse-Geisser correction to account for a violation of the sphericity assumption, $F(4.92, 2956.59) = 3.86$, $p = .002$, $\eta^2 = .005$. As displayed in Figure 2B, this difference was driven primarily by a *smaller* repetition priming effect at $lag = +1$, when the cue and target appeared in the same order on both presentations. Planned contrasts revealed that repetition priming was reduced at $lag = +1$ relative to all other lags, $t(601) = -3.87$, $p < .001$. Most current implementations of the retrieved context framework assume that retrieving one item tends to facilitate retrieval of other items studied closer, relative to farther, in time. If the same mechanisms are responsible for repetition priming we would expect greater, not reduced, repetition priming at $lag = +1$. We consider potential explanations for the lag effects in the Discussion.

Measures of Explicit Memory

Although the main focus of this experiment was to test the retrieved context framework's predictions for associative repetition priming, the free recall test is also of interest. If similar mechanisms underly explicit and implicit retrieval, then similar patterns should emerge in both memory tests. Analyzing temporal contiguity in recall also serves as an important test of the retrieved context framework, which predicts a TCE in almost any circumstance (see Healey et al., 2019). Since the TCE tends to be smaller for longer lists (Healey et al., 2019; Hong et al., 2019), it is possible that the small TCE previously observed in incidental encoding (Mundorf et al., 2021) may disappear altogether in a list of 505 items.

Repetition effects on recall

Our primary measure of explicit memory is recall probability, the average percentage of list items recalled. Recall probabilities for the three item types (cue, target, and filler) are displayed in Figure 3. There was a significant effect of item type using the Greenhouse-Gesisser correction to account for a violation of the sphericity assumption, $F(1.67, 1002.78) = 246.36$, $p < .001$, $\eta^2 = .182$. Recall was higher for repeated items relative to once-presented filler items with a Bonferroni adjusted $\alpha = .05/3 = 0.017$ (cue: $t(602) = 20.17$, $p < .001$, $d = 0.821$, target: $t(602) = 23.00$, $p < .001$, $d = .937$). Although we do not base any strong conclusions on these contrasts because the cues and targets were selected from a different (albeit similar) word pool than filler items, these results are consistent with previous findings that repeated items tend to be better remembered (e.g., Glanzer, 1969). Target items were also slightly more likely to be recalled than cue items, $t(602) = 2.56$, $p = .011$, $d = 0.104$. In both recall and repetition priming, memory was better for target than cue items.

Recall dynamics

A major goal of these analyses was to compare patterns of recall following incidental encoding of a very long list to previous work with shorter lists. However, the present task differed from standard free recall in that some words were presented twice. To facilitate comparisons between the current results and previous work, we restricted the detailed analyses of recall dynamics to the once-presented filler items.

Serial position curves (SPCs), which plot the probability of recalling an item from each position in the full list of 505 items, provide a measure of *which* items tend to be recalled. Figure 4 displays both the full SPC and a binned version. The full SPC plots recall probability for each serial position. Given the long length of the list, we also calculated a binned SPC to better visualize general trends, like primacy or recency. Each point on the binned SPC represents average recall probability for a bin of 10 consecutive serial positions (except the last bin, which is an average of the final 15 serial positions). For example, the first point on the binned SPC represents average recall probability for serial positions 1–10, the second represents average recall probability for serial positions 11–20, etc. Both SPCs display fairly low recall across serial positions (see also Figure 3) with a strong recency effect, as is typical in immediate free recall of shorter lists (Glanzer & Cunitz, 1966; Ward et al., 2010).

Temporal contiguity effects on recall

We utilized temporal bias scores to measure temporal contiguity in free recall. Temporal bias scores, introduced by Uitvlugt and Healey (2019), are similar to lag-conditional response probabilities (lag-CRPs; Kahana, 1996). However, temporal bias scores are designed to remove potential confounds between serial position effects, such as recency, and temporal contiguity that may influence the lag-CRP (for a discussion and simulations demonstrating the importance of considering these confounds, see Mundorf et al., 2021). They correct for these potential confounds by comparing the number of times a transition of a given lag was actually made to the number of times a transition of that lag would be expected if the same items were recalled in random order. Here, lag refers to the distance in serial positions between the just-recalled item and the next recall. For example, recalling the item from serial position 3 followed by the item from serial position 5 would be a $lag = 5 - 3 = +2$. As presented in Figure 5, temporal bias scores revealed bias was greatest for near lags, particularly $|lag| = 1$. This replicates previous findings of a symmetrical TCE following incidental encoding and is consistent with the predictions of the retrieved context framework (Mundorf et al., 2021).

Discussion

The aim of this experiment was to test the predictions of the retrieved context framework, which assumes temporal information is encoded and retrieved automatically. Under this framework, items automatically form associations with the current state of mental context. This mental context changes as each item is studied, retaining a record of the recent past. During memory search, retrieving an item automatically reinstates its associated context, which then serves as a good cue for other items originally experienced nearby in time. The framework predicts a TCE in free recall regardless of encoding intentionality; because temporal associations are encoded automatically, temporal contiguity should be observed even if subjects are not intentionally studying. Consistent with this prediction, we found a TCE in recall following incidental encoding.

If we assume context reinstatement is automatic even when items are not intentionally retrieved, the retrieved context framework also makes clear predictions for associative repetition priming. We tested two specific predictions. First, associative repetition priming should occur even when items are not presented as a pair, and second, this effect should vary with initial lag. Our results are clearly consistent with the first prediction. Associative repetition priming occurred even when subjects incidentally encoded words without knowing which items would be repeated together later, indicating new temporal associations were encoded automatically. Associative repetition priming also occurred among cue-target pairs originally separated by filler items or whose presentation order was reversed. This supports the framework's assumption that during encoding, mental context retains a record of the recent past, so items separated by a few serial positions may still be associated with somewhat similar contexts and thus cue one another. Consistent with the second prediction, we found a small yet significant effect of initial lag on priming. This difference was primarily driven by reduced repetition priming when the cue and target were presented in the same order at both presentations (initial $lag = +1$).

Although our results are generally consistent with the retrieved context framework, additional mechanisms not implemented in current recall-oriented models may contribute to the pattern of results. Current computational implementations of the framework assume items studied closer in time become associated with more similar states of context. A natural prediction is that a cue and target should provide better cues for each other when they are initially presented in adjacent serial positions. However, we found the opposite pattern. Why might this be? Repetition priming may have been reduced for initial $lag = +1$ because subjects consciously recognized words were being repeated in the 2 s between stimulus onsets. Given that conscious recollection may be more time-consuming than implicit retrieval, (e.g., Dew & Cabeza, 2011; Jacoby, 1991), responses may have been slower when the cue triggered conscious retrieval of the target. Subjects may have also been surprised or confused upon detecting a repetition, further delaying their response. We suggest that conscious recollection was more likely on trials with an initial *lag* = +1 because the cue and target were presented in the same order on both presentations, providing the strongest possible retrieval cue for the repeated target. Even if this occurred only on a few trials, average naming time at *lag* = +1 would be slower, as observed here. Implementations of the retrieved context framework assume that the more accessible an item is, the faster responses to that item will be. It is possible that, instead, activation increases items' accessibility up to a point (resulting in greater priming). But when activation is high, an additional process such as episodic or pre-episodic recollection may be engaged (Smith et al., 2013), slowing responses. We also note that the present experiment examined a limited number of lags with a presentation rate that allowed for episodic recollection. Further work can test if this pattern occurs at faster presentation rates and with greater temporal distances between items.

Our results are, however, inconsistent with several alternate explanations of associative repetition priming. If associative repetition priming is due to priming of items' perceptual features or unitization alone, repetition priming should be enhanced only if the cue and target were presented in the same order at both presentations (initial *lag* = +1). Similarly, if associative repetition priming is a result of intentional strategies, priming should be enhanced primarily for cue-target pairs consistently presented at *lag* = +1. Our design made it unlikely that subjects could enhance repetition priming through encoding strategies, although items were presented slowly enough that retrieval strategies could have influenced priming. However, our results reveal the opposite pattern; associative repetition priming occurred at all initial lags and was *reduced* at initial *lag* = +1.

Conclusions

In this experiment examining the effect of temporal distance between items on associative repetition priming, we found results partially consistent with the assumption that the same automatic mechanisms underly both explicit and implicit retrieval. Specifically, we found evidence supporting the retrieved context framework's prediction of temporal contiguity in free recall and associative repetition priming among items not explicitly presented as a pair. However, priming was *reduced* if the cue and target were presented close in time and in the same order on both presentations, contrary to specific models' predictions. These results demonstrate that new associations are automatically formed during encoding, allowing items studied nearby in time to later cue one another automatically, even when retrieval is implicit, and prompt new questions about the influences of temporal proximity and awareness on repetition priming.

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Example Trials

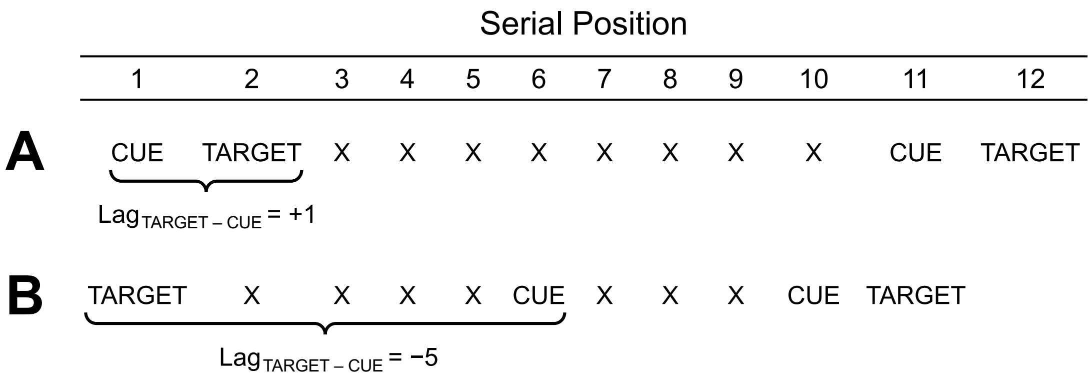

Figure 1

In these example trials each X represents a filler word, and repeated words are labelled as either CUE or TARGET. For the purpose of manipulating initial lags between target and cue words, the words were arranged into pseudo-lists, where each psuedo-list contained between 10 and 25 words. Each list began with a jittered number of filler words (between 0 and 9). There were 6 possible initial lags between the first presentation of the target word and the first presentation of the cue word: -5, -2, -1, $+1$, $+2$, *or* $+5$. *On their second presentation, the cue was always presented first, immediately followed by the target (*$\text{lag} = +1$*). (A) An example psuedo-list. The cue is presented in serial position 1 immediately followed by the target in serial position 2. Here, the initial* $\text{lag} = 2 - 1 = +1$. *The inter-presentation lag between the first and second presentation of the cue* $= 11 - 1 = +10$. *(B) An example psuedo-list where the initial* $\text{target} - \text{cue lag} = 1 - 6 = -5$ *and the inter-presentation lag for the cue word* $= 10 - 6 = +4$. *In all pseudo-lists the inter-presentation lag for the target* $= +10$.

Repetition Priming for Cue and Target Items

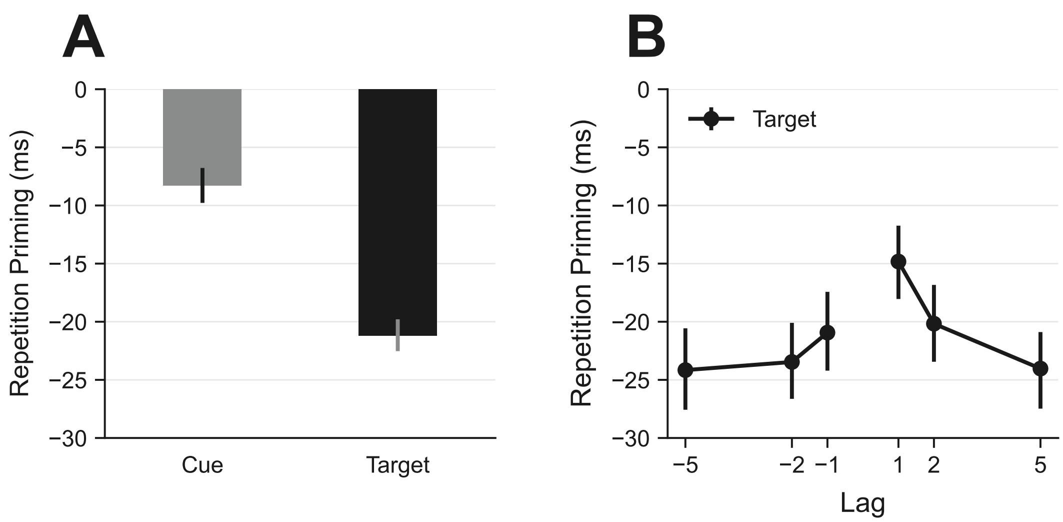

Figure 2

(A) Repetition priming for both cue and target items, on average, and (B) Repetition priming of target words plotted by the initial target minus cue lag. Repetition priming was calculated for each subject for each item as naming time on the item's second presentation minus naming time on the item's first presentation. Negative values indicate a repetition priming effect, and more negative values indicate a larger repetition priming effect. Error bars are bootstrapped 95% confidence intervals.

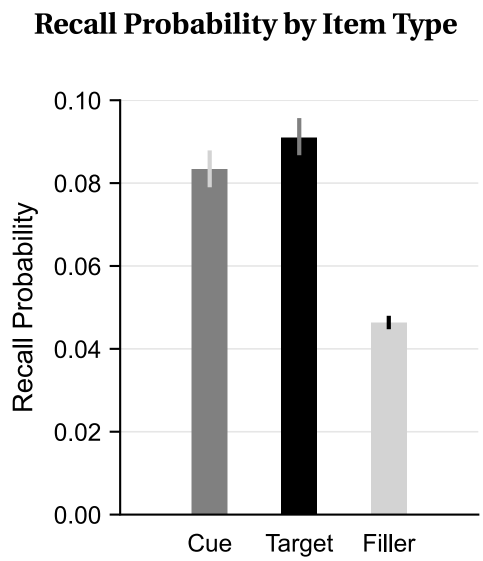

Figure 3

Recall probability for cue, target, and once-presented filler items on the final free recall test. For cue and target items, recall probability was calculated by dividing the number of cue or target items recalled by the number of unique cue or target items viewed during the naming task (30). For filler items, recall probability was calculated for each subject by dividing the number of filler items recalled by the total number of filler items viewed during the naming task (385). Error bars are bootstrapped 95% confidence intervals.

Serial Position Curves for Once-presented Items

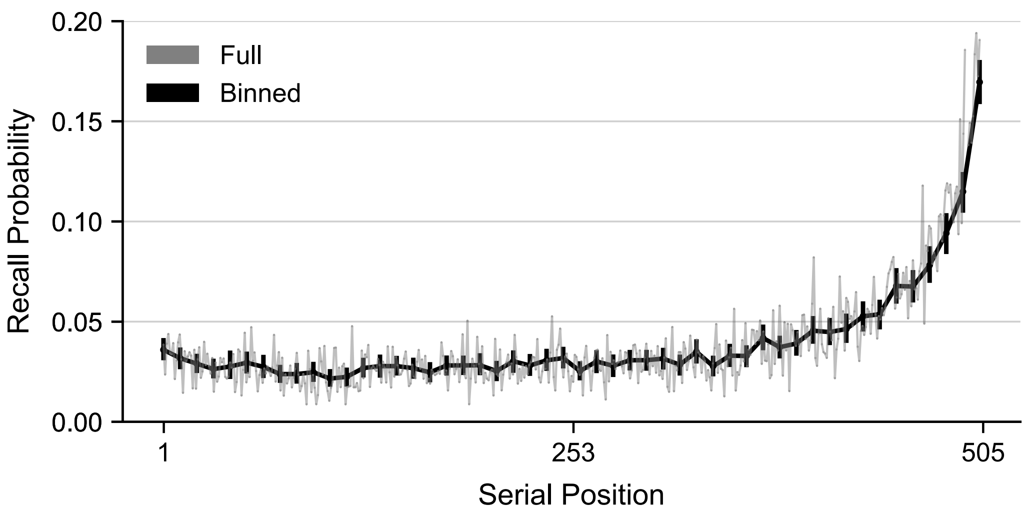

Figure 4

Full (gray) and binned (black) serial position curves for recall of once-presented filler items. These serial position curves (SPCs) represent the probability that a filler item from each serial position would be recalled, given a filler item was actually presented in that serial position. The four serial positions which were only ever occupied by a repeated item (495, 504, and 505), were treated as missing values. Each point on the binned SPC represents the average recall probability for each bin of 10 serial positions, except the last bin, which is an average of the final 15 serial positions. For example, the first point on the binned SPC represents the average recall probability for serial positions 1–10, and the second point represents the average recall probability for serial positions 11–20. Error bars are bootstrapped 95% confidence intervals.

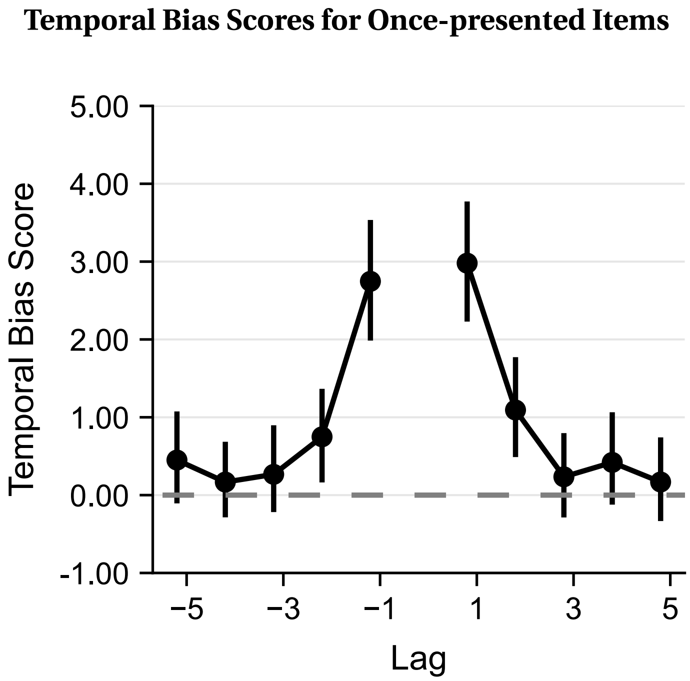

Figure 5

Temporal bias scores for recall of once-presented filler items, from lag = −5 *to* +5*. Here, lag refers to the distance in serial positions between the just-recalled item and the next recall. Temporal bias scores for each lag were calculated by comparing the number of times a transition of that lag was actually made to the number of times it would be expected to occur by chance. Chance (expected count) was calculated by permuting the order of recalls for each list 500,000 times, counting the number of times a transition of each lag was made across permutations, and dividing by the number of permutations to get the number of times a transition of that lag would be expected to occur if the items were recalled in random order. For each subject and for each lag, the temporal bias score was (actual count − expected count) / expected count. The dotted line indicates a score of zero (no bias). Error bars are bootstrapped 95% confidence intervals.*