Memory-Based Similar Lure Rejections Promote Subsequent Memory for Relative Recency

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Abstract

Memory updating requires detecting changes between similar events and preserving information about their relative order. Two experiments examined whether memory-based rejection of similar lures in the Mnemonic Similarity Task supports subsequent temporal memory. Participants studied objects, completed a modified recognition test including repeated targets, similar lures, and novel foils, and then performed a relative recency test in which they selected which of two versions of the same object appeared during the previous recognition test. Recency judgments for lures were most accurate when they were correctly rejected as "similar," suggesting that retrieval-based comparison processes during recognition supported subsequent memory updating. Conditional analyses showed that this benefit was enhanced when participants also reported the subjective experience of remembering that both objects had appeared in the experiment, indexing memory for change. Subjective reports of retrieving studied objects before seeing lures were associated with more accurate lure decisions, and clearer subjective retrieval was associated with more frequent reports indicating memory for change. Together, these findings suggest that retrieval and comparison processes engaged during mnemonic discrimination encode information that supports distinguishing earlier and later events. This study provides a step toward integrating cognitive accounts of temporal memory with complementary neural accounts of episodic memory updating.

Keywords: mnemonic discrimination, temporal order memory, episodic memory updating, proactive interference and facilitation, memory for change

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A key component of episodic memory is the ability to distinguish between similar events and flexibly represent overlapping experiences. For example, imagine meeting a friend at the same local café for lunch two weeks in a row. Many details are shared across the two occasions, such as your friend, the café, and even their order, but the content of your discussion changes, creating multiple related event representations that may be differentially accessible. During the first lunch, you might plan to attend a local hockey game together on a specific date, whereas during the second lunch that plan is revised because a wintry mix is now highly likely on the original date, resulting in a new date. Later, when recalling the discussion, remembering that the plan changed can help you retrieve the date that is appropriate for the current context while also retaining access to the original date. However, such remembering depends on encoding the change itself, which may require conscious consideration of both the original and updated event features. Importantly, the processes illustrated by this example generalize beyond social interactions and apply broadly to changes in objects, actions, and environments.

To simulate these experiences, studies have examined change detection and memory updating across episodes using a wide range of stimuli, including word pairs, objects, scenes, and movies. A common approach to studying change detection, defined as detecting changed features through comparisons with long-term memory representations, is the use of mnemonic discrimination tasks. These tasks employ modified recognition protocols in which participants study items and then complete a recognition test comprising repetitions of studied items, novel foils, and lures that share identities with studied items but differ in specific features. In these tasks, change detection is reflected in the ability to reject lures because they are not identical to studied items. The cognitive and neural mechanisms supporting lure rejection have been examined extensively using a variant known as the Mnemonic Similarity Task (MST; Stark et al., 2019), which characterizes how the memory system distinguishes similar experiences to reduce interference during retrieval. However, MST studies that use two-phase protocols to rigorously examine change detection do not directly assess the consequences of lure rejection for later retrieval of recent events. The present study addresses this gap by reporting two experiments that use modified variants of the canonical object-based MST, incorporating a third phase that measures memory for the relative order of studied objects and corresponding lures.

By characterizing change detection, the MST provides a foundation for examining how lure rejections affect subsequent memory for object order. The task builds on earlier work on the retrieval dynamics involved in lure recognition using highly similar words and word-like stimuli (Hintzman & Curran, 1994; Rotello & Heit, 1999), which showed that lure rejections can reflect a recall-to-reject process involving retrieval and comparison with studied items, whereas false alarms more often reflect familiarity-based responding. Although the MST has been interpreted as indexing pattern separation processes associated with the dentate gyrus (Kirwan & Stark, 2007), lure decisions are not process-pure. Discrimination can engage broader medial temporal lobe circuitry supporting retrieval and comparison (Stark et al., 2019), along with cortical regions involved in cognitive control and sensory representation (Amer & Davachi, 2023). Critically, when lure rejections involve retrieving and comparing memories with perceptual inputs, these processes may mitigate interference and support memory for relative order by linking previously studied items with their more recent counterparts.

To clarify how retrieval supports lure rejections, MSTs have incorporated measures of retrieval quality during these decisions. In one study, participants made Remember/Know judgments (Tulving, 1985) following lure rejections and false alarms, indicating whether decisions were supported by recollection of studied features or familiarity-based signals (J. Kim & Yassa, 2013). Lure rejections were more often accompanied by recollection, implicating retrieval and comparison of diagnostic features, even though recollection also occurred when discrimination failed. In contrast, another study found that lure rejections were more often associated with familiarity-based responding (Szőllősi et al., 2020). This mixed evidence suggested that the retrieval processes supporting these decisions varied with task constraints, with recent work implicating attentional states during study (Wahlheim et al., 2024). Converging evidence for recollection-based lure rejections has also been obtained without Remember/Know judgments. For example, machine learning classification of verbal reports revealed that lure rejections were primarily accompanied by language implicating recollection and feature-level comparison (Wahlheim et al., 2026). In other work, complementary modeling using old/new confidence judgments and receiver operating characteristics (ROCs) indicated that recollection rejection reflects a dissociable component that varies independently from familiarity-based processes (Parks et al., 2026). Collectively, this work indicates that recollection-based retrieval enables feature-level comparisons that support detecting changes between prior memories and current experiences.

The findings from MST studies motivate examining how memory-based change detection during lure decisions affects later memory for the order of studied items and corresponding lures. Prior work shows that memory for relative order depends on retrieval and comparison processes engaged during encoding. Early studies showed more accurate temporal order judgments for related than for unrelated item pairs despite comparable familiarity, suggesting that study-phase retrieval supports order memory (Hintzman et al., 1975; Tzeng & Cotton, 1980). Subsequent work confirmed that order memory improves specifically for item pairs that elicit retrieval during study (Winograd & Soloway, 1985). Extending this approach, Hintzman (2001) used Remember/Know judgments during item recognition and showed that accurate recency judgments were associated with items later endorsed as “Remember,” whereas “Know” responses supported recognition but not memory for temporal order. These findings support accounts in which temporal order memory depends on recollection-based retrieval rather than familiarity alone, consistent with theoretical proposals that retrieval processes associate events during encoding (Friedman, 1993; Hintzman, 2011, 2016), including recursive remindings that preserve temporal structure and, by extension, reduce interference between similar events (Hintzman, 2004, 2010). Collectively, this work suggests that retrieval of prior events during encoding supports relational information that distinguishes earlier from later occurrences, paralleling memory-based lure rejections in the MST.

This logic extends to mnemonic discrimination tasks in which features of similar lures trigger retrieval of studied items, enabling detection of changes that can later be recollected. Under these conditions, discrimination decisions should support temporal order memory and reduce interference. Consistent with this proposal, one study used an A–B, A–D paradigm in which cues repeated and responses changed across lists, and participants made judgments indicating whether pairs were the same or changed, followed by tests of list membership and change recollection (Jacoby et al., 2013). Temporal discrimination was enhanced for changed pairs when changes were detected and recollected, but impaired when changes were not recollected, indicating proactive facilitation and interference, respectively. These findings suggest that retrieval and comparison during study support encoding of temporal information that enables later recollection-based retrieval and reduces interference.

This approach to conditionalizing memory performance on tests of temporal memory has yielded consistent patterns across paradigms that vary in procedural details and in the naturalism of their materials (Putnam et al., 2014; Wahlheim et al., 2020, 2022). This generality suggests that similar principles should apply when examining the mnemonic consequences of lure rejections in the MST. Critically, this literature shows that: manipulations produce parallel effects on change detection and change recollection, participants rarely recollect changes without prior detection via study-phase retrieval, and change recollection measures are more valid when they assess subjective awareness and original-event retrieval (for reviews, see Wahlheim et al., 2021; Wahlheim & Zacks, 2025). This combined subjective and objective approach improves on Hintzman's (2001) conditional analytic method for assessing the role of recollection in temporal memory, in which item recognition was tested for all items before temporal memory for the same items, introducing a dependency between measures. The present study uses this improved methodology by asking participants to first report memory for the recent stimulus and then to report subjective recollection of change by indicating whether they remember that both stimuli appeared earlier. We next describe how this procedure was implemented and present hypotheses derived from theoretical and empirical considerations in the literature on temporal memory and memory for change.

Two unsupervised online experiments used variants of an object-based MST that examined mnemonic discrimination and the consequences of lure rejections for subsequent memory for relative order. Both experiments used a three-phase procedure (see Figure 1) comprising an initial study phase (Phase 1), a recognition phase including repeated targets, similar lures, and novel foils (Phase 2), and a final test assessing memory for relative recency and Phase 1 object occurrence (Phase 3). In Phase 1, participants viewed individual objects and made semantic judgments. In Phase 2, participants viewed objects and classified each as “old,” “similar,” or “new” based on whether it exactly matched (repeated targets), was similar-but-not-identical (similar lures), or never appeared (novel foils). Lure rejections (i.e., lures called “similar”) indexed change detection, which we assumed was accomplished primarily via retrieval and comparison with studied objects. In Phase 3, participants completed a relative recency test in which two versions of an object appeared side-by-side; participants first selected the object from Phase 2 and then indicated whether the other object had appeared earlier in Phase 1. This final phase allowed us to test whether retrieval-based lure decisions during Phase 2 supported subsequent temporal memory by assessing memory for relative order and recollection of prior object occurrence within the same trial.

Experiment 1 established this basic paradigm and tested the hypothesis that, if lure rejections engage retrieval and comparison processes, then memory for relative order will be enhanced following such rejections relative to trials in which lures were not identified as such. Experiment 1 also tested the hypothesis that, if temporal memory is preserved by retrieval and comparison processes that promote change recollection, then lures classified as “similar” in Phase 2 will lead to enhanced temporal memory in Phase 3, but only when in Phase 3 participants indicate that they remember both objects appearing earlier, by responding that the initially unchosen object appeared in Phase 1. Experiment 2 extended this approach in two critical ways. First, it increased the number of lures to improve sensitivity for conditional subsequent memory analyses following lure rejections. Second, it incorporated a retrieval-quality probe prior to each Phase 2 decision, in which participants rated the clarity of their memory for the studied object based on a verbal label presented before the image. “Clear” responses were intended to capture cases in which participants could retrieve detailed representations of the earlier object, whereas “fuzzy” and “no memory” responses indexed progressively poorer retrieval states. This approach was adopted in place of Remember/Know judgments, which have been shown to be sensitive to instructional framing and participant interpretation, making them difficult to standardize in unsupervised online testing contexts (Umanath & Coane, 2020). Together, these experiments test the hypothesis that memory-based lure rejections that promote subsequent recollection-based retrieval will support recency judgments to the extent that discrimination decisions are preceded by higher-quality retrieval of studied objects.

Results

Because Experiments 1 and 2 used highly similar procedures and yielded similar results, we report the results jointly to streamline exposition, highlighting experiment-specific effects where relevant.

Phase 2: Recognition Responses

The overall patterns of Phase 2 recognition responses were consistent with prior MST studies (Table 1). In each experiment, we compared recognition accuracy across item types using a model with item type as a fixed effect. The Experiment 1 model yielded a significant effect, $\chi^2(2) = 451.67$, $p < .001$, showing significantly higher recognition accuracy for targets and foils than lures, smallest $OR = 3.55$, z ratio = 17.66, $p < .001$, and for foils than targets, $OR = 1.28$, z ratio = 4.13, $p < .001$. Replicating this pattern, the Experiment 2 model yielded a significant effect, $\chi^2(2) = 798.18$, $p < .001$, showing significantly higher recognition accuracy for target and foils than lures, smallest $OR = 1.57$, z ratio = 8.55, $p < .001$, and for foils than targets, $OR = 4.05$, z ratio = 19.40, $p < .001$. Note that target recognition accuracy was lower in Experiment 2, which likely reflected the Phase 2 list comprising half similar lures, as compared to a third similar lures in Experiment 1. This increased demand to respond “similar” may have biased participants to respond “similar” more than “old” when uncertain. Regardless, lure rejections occurred for about half the trials, thus providing suitable distributions of lures called “similar” versus “old” or “new” for subsequent memory analyses.

Phase 2: Lure Rejections Conditionalized on Retrieval Quality Reports (Experiment 2 Only)

In Phase 2 of Experiment 2, when provided with verbal labels of Phase 1 objects, participants nearly always reported retrieving studied objects (Table 2). If lure rejections were based on memory for studied objects, then “similar” responses to lures will occur more following responses implying memory for Phase 1 objects. This was examined using a model of “similar” responses to lures with a fixed effect of retrieval quality (Figure 2). The model yielded a significant effect, $\chi^2(2) = 40.53$, $p < .001$, showing no significant difference in lure rejections following clear and fuzzy subjective memories of Phase 1 objects, $OR = 1.09$, z ratio = 0.92, $p = .63$. However, lure rejections were significantly higher following both of those reports than reports of no memory of Phase 1 objects, smallest *OR* = 2.24, *z* ratio = 5.22, $p < .001$. These results showed that lure rejections are based on memories of varying qualities.

Phase 3: Temporal Memory Task

Relative Recency Judgments (Phase 2 Object Selection)

Each trial showed two versions of an object; participants first attempted to choose the Phase 2 object. The correct choice differed across item types: For targets, it was the object that repeated from Phase 1 to 2; for lures, it was the similar version of a Phase 1 object that appeared in Phase 2; for foils, it was the novel object that only appeared in Phase 2. Relative recency accuracy (Figure 3, black points) was examined using models with a fixed effect of item type. The Experiment 1 model yielded a significant effect, $\chi^2(2) = 180.42$, $p < .001$, showing significantly higher accuracy for targets than foils, *OR* = 1.77, *z* ratio = 8.58, $p < .001$, and significantly higher accuracy for foils than lures, *OR* = 1.65, *z* ratio = 6.59, $p < .001$ (Figure 3A). Replicating this pattern, the Experiment 2 model yielded a significant effect, $\chi^2(2) = 128.54$, $p < .001$, showing significantly higher accuracy for targets than foils, *OR* = 1.57, *z* ratio = 5.33, $p < .001$, and significantly higher accuracy for foils than lures, *OR* = 1.43, *z* ratio = 5.41, $p < .001$ (Figure 3B). Thus, repeating targets improved accuracy, and changing features created interference.

Memory-for-Change Reports (Phase 1 Occurrence Probe)

After choosing a Phase 2 object, the unchosen object remained visible; participants indicated if they remembered seeing that object in Phase 1 by responding “yes” or “no.” When a lure was recognized just before, the correct response here was “yes.” When a target or foil was recognized just before, the correct response here was “no.” We compared correct and incorrect responses by testing for differences among “yes” responses (Table 3) using models with a fixed effect of item type. The Experiment 1 model yielded a significant effect, $\chi^2(2) = 1903.20$, $p < .001$, showing significantly higher correct recognition for lures than incorrect recognition for targets, *OR* = 10.31, *z* ratio = 36.17, $p < .001$, that was significantly higher than incorrect recognition for foils, *OR* = 1.59, *z* ratio = 7.32, $p < .001$. Replicating this pattern, the Experiment 2 model yielded a significant effect, $\chi^2(2) = 1645.20$, $p < .001$, showing significantly higher correct recognition for lures than incorrect recognition for targets, *OR* = 5.59, *z* ratio = 29.22, $p < .001$, that was significantly higher than incorrect recognition for foils, *OR* = 1.96, *z* ratio = 8.62, $p < .001$. These results suggest that participants were reasonably able to remember noticing that lure features changed.

Conditional Analyses of Relative Recency Judgments for Similar Lures

To test the hypothesis that lure rejections can support subsequent memory for temporal order, we conducted subsequent memory analyses of recognition accuracy for similar lures in Phase 3 (Figure 3). Specifically, we first conditionalized lure recency accuracy on the three recognition responses made in Phase 2 (old / similar / new), isolating trials in which lures were rejected as “similar,” consistent with change detection via retrieval and comparison. We then further conditionalized recency accuracy for lures correctly called “similar” on Phase 3 reports of whether the unselected object had appeared in Phase 1 (yes / no), which were intended to capture reports of memory for change, defined here as the subjective sense that the object had appeared earlier, whether accurate or inaccurate. Recollection-based accounts predict that relative recency accuracy should be enhanced when such memory for change is present because these trials should more often reflect recollective experiences that preserved order information.

Importantly, novel foils served as control items for assessing proactive interference and facilitation effects. Because foils were not preceded by exposure to objects of the same identity in Phase 1, they provided a baseline against which to evaluate the consequences of retrieval processes engaged during lure decisions. Relative to this baseline, enhanced recency accuracy for lures would indicate proactive facilitation, consistent with the proposal that retrieval during change detection supports the encoding of order information. In contrast, reduced recency accuracy relative to foils would indicate proactive interference, suggesting that prior exposure strengthened competing representations that were left unopposed on the recency test in the absence of memory for change. These comparisons, highlighted by dashed lines in Figure 3, therefore allowed us to determine whether memory-based lure rejections and subsequent memory for change yielded facilitation, interference, or no net effect on temporal memory.

Recency Accuracy for Lures Conditionalized on Phase 2 Decisions. We first examined whether Phase 3 recency accuracy for lures depended on how those lures were classified in Phase 2. In both experiments, models with a fixed effect of lure classification yielded significant effects (Experiment

1: $\chi^2(2) = 52.50$, $p < .001$; Experiment 2: $\chi^2(2) = 25.08$, $p < .001$). In Experiment 1, recency accuracy was significantly higher for lures classified as “similar” than misclassified as “old” or “new,” smallest *OR* = 1.68, *z* ratio = 4.30, $p < .001$, and was not significantly different between misclassified lures, *OR* = 1.10, z ratio = 0.73, $p = .74$. Experiment 2 replicated the central pattern from Experiment 1, showing significantly higher recency accuracy following “similar” classifications than misclassifications as “old,” *OR* = 1.61, *z* ratio = 4.96, $p < .001$. However, unlike Experiment 1, recency accuracy was also significantly higher for “new” than “old” misclassifications, *OR* = 1.43, *z* ratio = 3.13, $p < .01$, and was not significantly different between “similar” classifications and “new” misclassifications, *OR* = 1.12, *z* ratio = 1.11, $p = .51$. Collectively, these results suggest that retrieval processes engaged during accurate lure discrimination in Phase 2 promoted subsequent temporal memory for lures. However, in Experiment 2, the retrieval demands introduced by overt Phase 1 memory reports prior to lure decisions may have enhanced encoding of the temporal context of lures even for those later misclassified as “new.”

Recency Accuracy for Rejected Lures Conditionalized on Phase 3 Memory for Change. We next examined, for lures classified as “similar” in Phase 2, whether Phase 3 recency accuracy depended on reports of memory for change, indexed by whether participants responded “yes” or “no” to the question of whether the unselected object had appeared in Phase 1; “yes” responses indicated memory for change and “no” responses indicated no memory for change. In both experiments, models including three levels (lures with “yes” responses, lures with “no” responses, and novel foils) yielded significant effects (Experiment 1: $\chi^2(2) = 83.53$, $p < .001$; Experiment 2: $\chi^2(2) = 95.71$, p < .001). In Experiment 1, recency accuracy for lures was significantly higher when participants reported memory for change than when they did not, *OR* = 3.30, *z* ratio = 8.77, $p < .001$. Recency accuracy was not significantly different between lures with memory for change and foils, *OR* = 1.15, *z* ratio = 1.42, $p = .33$, whereas recency accuracy was significantly higher for foils than lures without memory for change, *OR* = 2.86, *z* ratio = 8.03, $p < .001$, indicating proactive interference. Experiment 2 replicated the central pattern in showing significantly higher recency accuracy when memory for change was reported than when it was not, *OR* = 3.42, *z* ratio = 9.47, $p < .001$. However, unlike Experiment 1, recency accuracy was significantly higher for lures with memory for change than for foils, *OR* = 1.35, z ratio = 2.91, *p* = .01, indicating proactive facilitation, while recency accuracy was significantly higher for foils than lures without memory for change, *OR* = 2.53, *z* ratio = 8.05, *p* < .001, indicating proactive interference. Collectively, these results suggest that lure rejections were associated with enhanced temporal memory when accompanied by memory for change and with impaired temporal memory when such memory was absent, with facilitation emerging under the additional retrieval demands present immediately before lure decisions in Phase 2 of Experiment 2.

Conditional Analysis of Phase 1 Object Occurrence for Similar Lures in Phase 3 (Experiment 2 Only)

Finally, we examined whether the Phase 1 memory judgments made before recognition decisions in Phase 2 of Experiment 2 provided converging evidence that retrieval processes engaged during lure decisions had consequences for subsequent temporal memory. As noted earlier, we used a "clear / fuzzy / no memory" distinction instead of Remember/Know judgments because the experiment was conducted in an unsupervised online context, where subjective reports can be sensitive to instructional framing and interpretation. We therefore treated these judgments as a coarse index of subjective retrieval quality rather than a process-pure measure of recollection. Although one could further conditionalize Phase 3 recency accuracy on Phase 2 lure decisions, Phase 3 memory-for-change reports, and Phase 2 retrieval-quality judgments simultaneously, such triple conditionalization would result in very small cell counts and substantially reduced power. The present approach instead provides the most sensitive test of whether clearer subjective retrieval during lure decisions predicted more accurate subsequent memory for those objects. Because recollection-based memory for change has been implicated as a marker of preserved temporal order, this predicted pattern offers converging support for the role of retrieval during lure decisions in subsequent temporal memory.

A model with the Phase 2 memory judgment about Phase 1 objects as a fixed effect yielded a significant effect, $\chi^2(2) = 16.43$, *p* < .001. Because we had a priori directional expectations that Phase 1 object recognition would increase as a function of subjective retrieval quality during lure decisions, we conducted planned ordered contrasts comparing clear, fuzzy, and no-memory reports. These contrasts confirmed a graded pattern. Phase 1 object recognition in Phase 3 was highest for objects accompanied by clear memory reports, intermediate following fuzzy reports, and lowest when participants had reported no memory (Figure 4). Clear reports were associated with significantly higher recognition than fuzzy reports, $OR = 1.41$, z ratio = 6.85, $p < .001$. Fuzzy reports were associated with significantly higher recognition than no-memory reports, $OR = 1.81$, z ratio = 3.66, $p < .001$. Taken together with the proactive facilitation observed for lures accompanied by memory for change, this graded pattern provides converging evidence that clearer subjective retrieval during lure decisions was associated with stronger subsequent temporal memory. Although the clear/fuzzy distinction cannot isolate specific retrieval processes, the differences in Phase 1 object recognition across report categories is consistent with the proposal that variability in subjective retrieval during lure discrimination carries forward to subsequent temporal order judgments.

Discussion

The present study examined whether memory-based lure rejections in the MST support subsequent memory for relative temporal order. Two experiments tested the hypothesis that when similar lures evoke retrieval and comparison with studied objects, order information is encoded that can later be expressed in recency judgments. Consistent with this prediction, relative recency accuracy for lures was enhanced when lures were initially rejected as “similar” rather than misclassified, indicating that retrieval processes engaged during recognition were associated with later temporal memory. Critically, conditional analyses showed that recency accuracy was highest when lure rejections were accompanied by memory for change and lowest when such memory was absent, revealing proactive facilitation and proactive interference, respectively. Experiment 2 further showed that when lure decisions were preceded by clearer subjective retrieval reports, subsequent memory for the original objects was graded and more accurate, providing converging evidence that variability in retrieval during lure decisions was associated with later temporal memory. Collectively, these findings extend prior work by showing that memory-based lure rejections reorganize representations of similar memories in ways that affect subsequent memory for relative order.

To interpret why lure decisions had downstream effects on temporal memory, it is useful to situate the present results in evidence that lure rejections can be supported by retrieval processes of varying quality. Such rejections can reflect retrieval of studied features, especially when time or diagnostic information is available (Hintzman & Curran, 1994; Rotello & Heit, 1999; Stark et al., 2019). Complementing this work, studies using Remember/Know judgments and verbal reports have provided evidence for recollection-based lure discrimination (Kim & Yassa, 2013; Szőllősi et al., 2020; Wahlheim et al., 2026), and ROC modeling has shown that recollection rejection is dissociable from false familiarity and false recollection (Parks et al., 2026). The present findings replicate this heterogeneity in retrieval during lure decision. In Experiment 2, participants reported both clear and fuzzy memories of Phase 1 objects prior to lure decisions, and rejection rates were reduced when no memory was reported, indicating that decisions were grounded in retrieval rather than response bias. Although the clear/fuzzy/no-memory distinction was a coarse index of retrieval quality, Phase 3 analyses provided construct validation: Phase 1 occurrence responses showed a graded pattern across these reports, indicating that they tracked meaningful differences. Consistent with this interpretation, lures classified as “similar” were more likely to support accurate recency judgments than lures that were misclassified. Because memory for change following rejected lures was associated with enhanced recency accuracy, the correspondence between Phase 1 recognition and recency performance is compatible with the proposal that retrieval quality during lure decisions was associated with temporal memory through its association with memory for change.

One way to interpret this conditional pattern is from the perspectives of the recursive remindings hypothesis (Hintzman, 2011) and the MFC framework (Wahlheim & Jacoby, 2013). The present findings are compatible with an account in which lure features in Phase 2 evoke retrievals of the corresponding Phase 1 objects, and those retrievals support encoding of information about the relationship between the earlier and later object versions. This would occur here when the lure’s identity reinstates features of the studied object enough to support a “similar” decision, thereby providing an opportunity to compare retrieved Phase 1 features with the perceived lure and to encode a representation that links the two objects. Accordingly, the Phase 3 “memory for change” report can be treated as one marker that such relationship information was more likely to be accessible at test. Regarding the observed proactive memory effects, this framework posits that when temporal relationship information was accessible, recency judgments were enhanced, leading to proactive facilitation. Conversely, when relationship information was not accessible, prior exposure to same-identity objects may have strengthened competing memories that were left unopposed at test, leading to proactive interference. Although a familiarity-only account could attribute recency judgments to relative strength for the two alternatives, that view does not parsimoniously predict the conditional dissociation between facilitation and interference.

Extending the cognitive account offered above, retrieval-based lure decisions can also be situated within neural mechanisms. One candidate mechanism is neural integration, in which reactivated content is bound with currently perceived features to form an associative representation that spans similar memories (Schlichting & Preston, 2015). This process may be supported by hippocampal interactions with dopaminergic midbrain systems (Shohamy & Wagner, 2008). Related accounts propose that hippocampal interactions with mPFC can prioritize reactivation of relevant memories during new learning episodes, which provides one route by which overlap could yield integrative encoding (Preston & Eichenbaum, 2013; van Kesteren et al., 2012). On this view, lure rejections and subsequent memory for change may index trials on which reactivation preserved relational information about the two object versions and their temporal relationship. Moreover, studies of neural integration often pair study-phase measures of reactivation with later associative inference judgments that index cross-episode representations including constituents of paired associates linked by a common element (Zeithamova & Preston, 2017). Because the stimulus structure in the MST showing only individual objects does not support associative inference judgments, a relative recency test may serve a similar purpose by assessing whether lure decisions promote integrative encoding that can later be used to distinguish object versions.

A complementary possibility is that retrieval-based lure decisions may engage neural differentiation processes that reduce representational overlap among similar memories (Hulbert & Norman, 2015). Differentiation studies have used paradigms like those examining neural integration, in which participants learn overlapping paired associates. In a key experiment, participants learned overlapping scene-face associations, and pattern similarity analyses showed that hippocampal representations of highly similar scenes became less overlapping with learning, in some cases exhibiting repulsion that extended beyond orthogonality (Favila et al., 2016). Critically, lower hippocampal similarity predicted fewer errors during subsequent learning, indicating that differentiation reduced interference. Applied to the present context, retrieval of studied objects during lure decisions may similarly decrease overlap between object versions, thereby mitigating interference and supporting memory for relative order. Indeed, high similarity can trigger distortions in which competing features are remembered as more distinct than they were (Chanales et al., 2021), suggesting that differentiation of perceptual features may coincide with shifts in temporal contextual information. Prediction-error accounts further propose that misprediction of expected items, followed by restudy, can lead to differentiation from the prior context (Kim et al., 2017), raising the possibility that the sequential structure of Experiment 2, in which labels preceded lure images, created conditions conducive to similar effects. This may explain why lure decisions following overt retrieval attempts promoted subsequent recency accuracy both when lures had been called “similar” and “new.” In both cases, the subjective experience that the lures were unstudied, regardless of whether the object identity was recognized from study, likely evoked a prediction error. Future work using a two-stage MST, hippocampal pattern-similarity analyses, and subsequent recency judgments could test whether retrieval before lure decisions leads to reduced representational overlap that preserves temporal information.

The present results can also be considered from the perspective of the MST’s original use as a behavioral assay of hippocampal pattern separation, with lure rejections reflecting the assignment of distinct representations to highly similar inputs, particularly via DG and CA3 circuitry (Leal & Yassa, 2018). At the same time, the explicit nature of standard “old/similar/new” instructions used in the present experiments encourages a recall-to-reject strategy, such that correctly rejecting a lure may depend on retrieving the original target for comparison, and this activity reflecting pattern completion may rise above signals more directly reflecting pattern separation (Stark et al., 2019). From this view, the present finding that temporal memory was most accurate following lure rejections that promoted memory for change is compatible with the general view that lure rejections reflect conditions under which competing representations are more distinct, regardless of whether that distinctiveness reflects separation-like computations, retrieval-based comparison, or some combination of both. Future studies could leverage the subsequent temporal memory test introduced here to sort lure decision trials based on recency judgment success and examine how neural signatures in hippocampal subfields commonly associated with pattern separation and pattern completion relate to temporal memory that is associated with memory for change.

Limitations and Directions

Several limitations qualify the present findings and suggest directions for future work. First, our assessment of memory for change was subjective and inferential, grounded in prior literature linking such reports to recollection-based retrieval (for a review, see Wahlheim et al., 2021). Stronger construct validation could be obtained by manipulating variables known to affect change detection, such as attention or elaboration during encoding, which were not controlled here. Although the conditional pattern of relative recency accuracy is compatible with retrieval-based comparison accounts, recency judgments may also reflect differences in unidimensional familiarity between object versions. Second, we did not a priori sample stimuli across a broad continuum of lure similarity, as in prior work selecting from low-to-high similarity bins (Stark et al., 2013). Although limited variability in similarity was present, the absence of systematic sampling constrained our ability to evaluate graded effects. A design using lures spanning the full similarity range would clarify whether downstream relative recency accuracy depends on the degree of feature overlap and would provide leverage on how pattern separation- and completion-dominant processing during lure decisions relate to subsequent order memory. Finally, our assessment of retrieval variability during lure decisions was simplified to ensure clarity in unsupervised online testing. However, these reports may capture confidence or individual differences in addition to discrete retrieval processes. Future studies incorporating similarity manipulations and more process-sensitive measures will provide stronger assays of the mechanistic links between lure rejections and temporal memory.

Conclusion

In the present study, we modified the object-based MST, which has been widely used to assess hippocampal function supporting mnemonic discrimination, by adding a subsequent test of memory for relative temporal order. This provides a method for assessing the downstream consequences of lure rejection for later memory for new events, rather than treating lure decisions as an endpoint measure. The results show that temporal memory for object versions can vary systematically as a function of lure rejection and later memory for studied objects, consistent with the long-standing idea that retrieval-based discriminations have downstream consequences for temporal memory. The present findings motivate mechanisms emphasized in both cognitive and neural accounts, including integrative encoding that links overlapping events and differentiation processes that reduce overlap among competing representations. The three-phase procedure introduced here therefore offers a method for connecting mnemonic discrimination to theories of memory updating and interference, and it motivates future work combining this approach with neuroimaging measures of activation change and representational similarity to clarify when lure discrimination reflects different learning operations and how these relate to hippocampal and broader cortical activity in supporting memory for recent events.

Materials and Methods

All procedures were approved by the Stony Brook University and UNC Greensboro Institutional Review Boards.

Participants

All participants were recruited from the Stony Brook University Department of Psychology Participant Pool and received partial course credit. Inclusion criteria were English fluency, normal or corrected-to-normal vision, and task comprehension. In Experiment 1, we planned to obtain usable data from at least 48 participants and continued recruitment until this target was met; additional enrolled participants were tested. Usable data were obtained from 53 adults (24 female, 27 male, 2 unknown; M_{age} = 20.29 years, SD_{age} = 3.02). Data from 10 additional participants were excluded due to non-responses, program failure, or extremely low performance. The final sample included 28 Asian, 17 White, 1 Black, 2 “Other,” and 3 multiracial participants; race was unknown for 2 participants. Nine participants identified as Hispanic, 42 as non-Hispanic, and ethnicity was unknown for 2. In Experiment 2, the planned sample size and procedures were identical. Usable data were obtained from 54 participants (32 female, 22 male; M_{age} = 20.10, SD_{age} = 2.03). Data from 19 additional participants were excluded for the same reasons as Experiment 1. The final sample included 28 Asian, 17 White, 1 Black, 2 “Other,” and 6 multiracial participants; 6 identified as Hispanic and 48 as non-Hispanic.

Design and Materials

The experiments used object-based MST procedures with stimuli drawn from the Stark lab database (https://faculty.sites.uci.edu/starklab/mnemonic-similarity-task-mst/). Both used a within-subjects design with three item types: repeated targets, similar lures, and novel foils (Figure 1). The stimulus set included two versions of each object for assignment to the similar lure condition. Each study-test cycle included: a study phase (Phase 1), a modified recognition test with all three item types (Phase 2), and a relative recency test (Phase 3) that displayed both object versions on each trial. Experiment 1 comprised four study-test cycles using 480 total images. In each cycle, Phase 1 included 40 items; Phase 2 included 60 items (20 repeated targets, 20 similar lures, 20 novel foils), and Phase 3 included both versions of the 60 objects presented in Phase 2. Item types were counterbalanced across blocks and rotated through 12 task formats. Experiment 2 retained this structure but reduced the number of cycles from four to three to accommodate an additional Phase 2 memory probe (details below). The total image set was reduced to 360 unique items. To increase sensitivity in conditional analyses of lure items, the number of similar lures was increased, and the number of repeated targets and novel foils was reduced. In each cycle, Phase 1 included 45 items (30 similar lures, 15 repeated targets), Phase 2 included 60 items (30 similar lures, 15 repeated targets, 15 novel foils), and Phase 3 included 60 item pairs from Phase 2.

Procedure

The procedures were identical across experiments except where noted (see Figure 1). Participants completed the experiment online and unsupervised using E-Prime GO 3.0 (Psychology Software Tools, Pittsburgh, PA). Each study-test cycle included three phases. In Phase 1, participants viewed pictures of everyday objects and classified each as “indoor” or “outdoor.” In Experiment 1, each image appeared centrally for 2 s followed by a 500 ms ISI above the response labels. Participants responded using the v (indoor) and n (outdoor) keys. In Experiment 2, the procedure was the same except that each image appeared above a verbal label describing the object.

In Phase 2, participants classified each object relative to Phase 1 as “old” (repeated target), “similar” (similar lure), or “new” (novel foil). In Experiment 1, each image appeared for 2 s followed by a

500 ms ISI, and participants responded using the v (old), b (similar), and n (new) keys. In Experiment 2, each trial began with presentation of a verbal label corresponding to the upcoming object. Participants had 3 s to indicate whether their memory for that item was “clear,” “fuzzy,” or “no memory” (d, s, a keys), followed by a 500 ms ISI and then classified the object using the j (old), k (similar), or l (new) keys.

In Phase 3, participants completed a relative recency test. On each trial, both object versions appeared side-by-side for 4 s followed by a 500 ms ISI. Participants first made a relative recency judgment by selecting the object that appeared in Phase 2 using the z (left) and m (right) keys. The unselected image then remained onscreen for 2 s, and participants indicated whether that object appeared in Phase 1 using the x (yes) and n (no) keys. The correct Phase 1 probe response depended on item type and the preceding recency judgment. For repeated targets, the same object appeared in both Phase 1 and Phase 2. If participants correctly selected that object as the Phase 2 item, the remaining object was novel and the correct Phase 1 response was “no”; if they incorrectly selected the novel object, the remaining object appeared in Phase 1 and the correct response was “yes.” For novel foils, only one object appeared (in Phase 2 only), and therefore the correct Phase 1 response was always “no,” regardless of the recency judgment. For similar lures, one object version appeared in Phase 1 and a similar version appeared in Phase 2. If participants correctly selected the Phase 2 version, the remaining object was the Phase 1 version and the correct response was “yes”; if they incorrectly selected the Phase 1 version as the Phase 2 item, the remaining object had not appeared in Phase 1 and the correct response was “no.”

Statistical Methods

All analyses were conducted in R (R Core Team, 2025). Binary outcomes were analyzed using logistic mixed-effects models fit with the glmer function from the lme4 package (Bates et al., 2015) with a logit link. Models included fixed effects for categorical predictors of interest and crossed random intercepts for subjects and items. Models were fit using the bobyqa optimizer with increased iteration limits to ensure convergence. Type III Wald χ^2 tests of fixed effects were performed using the Anova function from the car package (Fox & Weisberg, 2019). Pairwise comparisons of model-estimated marginal means were conducted using the emmeans package (Lenth & Piaskowski, 2025). Contrasts were computed on the log-odds scale and exponentiated to odds ratios (*ORs*), which served as effect size estimates of the relative likelihood of outcomes across conditions. The significance threshold was $\alpha = .05$.

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Competing Interests Statement

The authors declare no competing interests.

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Table 1

Recognition Memory Response Probabilities in Phase 2: Experiments 1 and 2

	Item Type					
	Repeated Targets		Similar Lures		Novel Foils	
Response	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
Old	**.81 [.78, .83]**	**.59 [.56, .62]**	.28 [.26, .31]	.22 [.18, .25]	.04 [.02, .07]	.04 [.01, .07]
Similar	.12 [.09, .14]	.23 [.20, .26]	**.57 [.55, .60]**	**.49 [.46, .52]**	.10 [.07, .12]	.06 [.03, .09]
New	.06 [.03, .08]	.12 [.09, .15]	.11 [.09, .14]	.23 [.20, .26]	**.84 [.81, .86]**	**.84 [.81, .87]**
Missing	.02 [.00, .04]	.05 [.02, .08]	.03 [.00, .05]	.07 [.04, .10]	.02 [.00, .05]	.06 [.03, .09]

Note. The bolded values indicate the correct classification rates for each item type. 95% confidence intervals appear in brackets. “Missing” responses indicate the probabilities of participants failing to classify objects before the response deadline.

Table 2

Phase 1 Object Retrieval Quality Responses in Phase 2: Experiment 2

	Item Type		
Retrieval Quality	Repeated Targets	Similar Lures	Novel Foils
Clear	.70 [.66, .74]	.70 [.66, .74]	.09 [.05, .13]
Fuzzy	.19 [.15, .23]	.20 [.16, .24]	.19 [.15, .23]
No Memory	.10 [.06, .14]	.08 [.04, .13]	.70 [.66, .74]
Missing	.01 [.00, .05]	.01 [.00, .05]	.02 [.00, .06]

Note. 95% confidence intervals appear in brackets. The “Missing” row indicates the probability of participants failing to provide their memory quality judgment before the response deadline.

Table 3

Phase 1 Object Occurrence "Yes" Response Probabilities in Phase 3: Experiments 1 and 2

	Item Type		
Experiment	Similar Lures	Repeated Targets	Novel Foils
Experiment 1	.67 [.63, .70]	.16 [.14, .19]	.11 [.09, .13]
Experiment 2	.61 [.57, .64]	.22 [.19, .25]	.12 [.11, .14]

Note. The probabilities of "yes" responses to Phase 1 recognition probes were correct for similar lures and incorrect for repeated targets and novel foils. 95% confidence intervals appear in brackets.

Figure 1

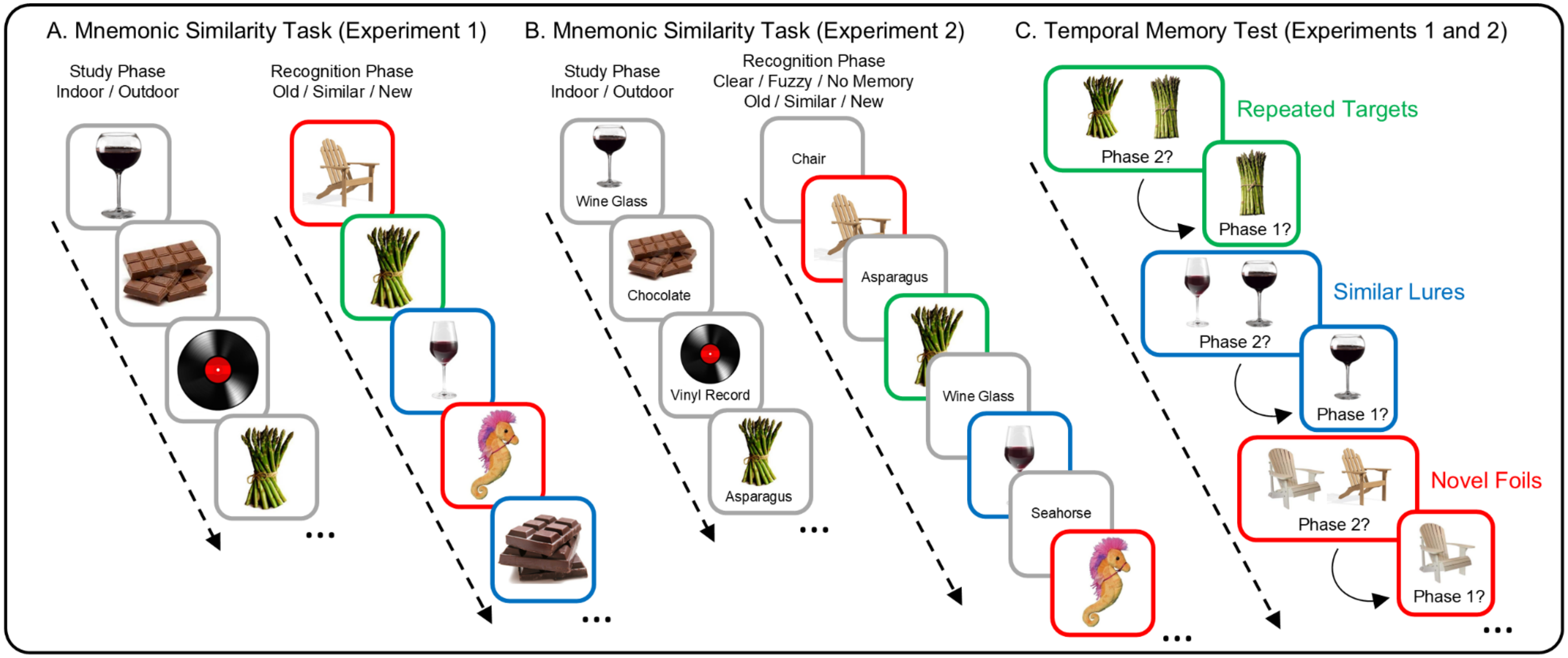
A. Mnemonic Similarity Task (Experiment 1)
Study Phase
Indoor / Outdoor
Recognition Phase
Old / Similar / New
B. Mnemonic Similarity Task (Experiment 2)
Study Phase
Indoor / Outdoor
Recognition Phase
Clear / Fuzzy / No Memory
Old / Similar / New
Wine Glass
Chocolate
Vinyl Record
Asparagus
Chair
Asparagus
Wine Glass
Seahorse
C. Temporal Memory Test (Experiments 1 and 2)
Repeated Targets
Phase 2?
Phase 1?
Similar Lures
Phase 2?
Phase 1?
Novel Foils
Phase 2?
Phase 1?

Figure 2

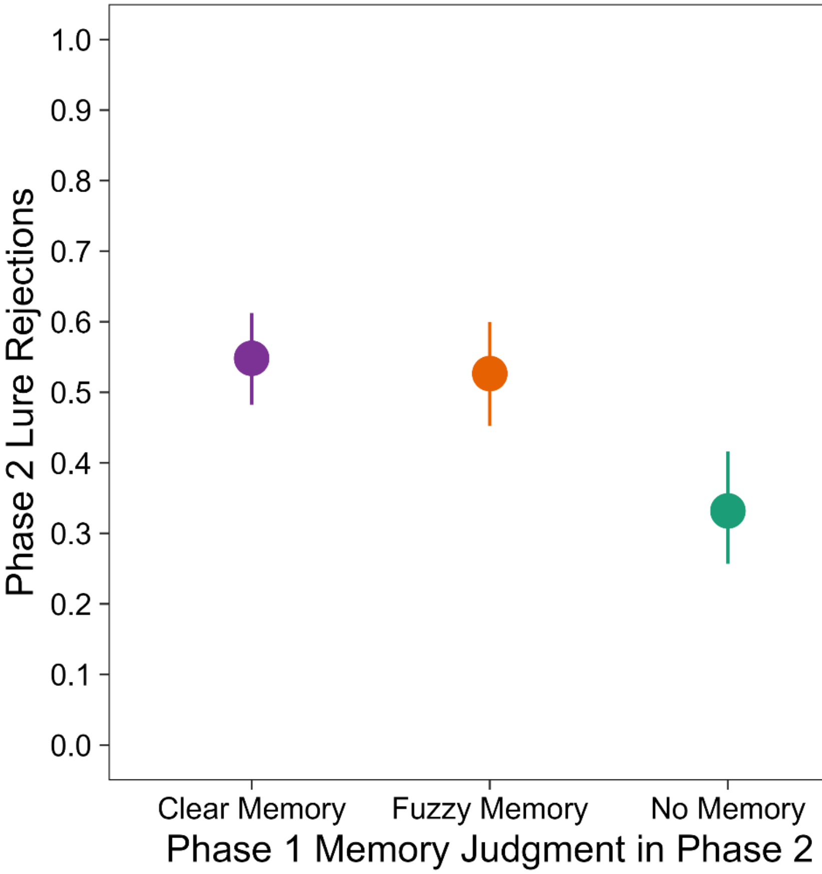
Phase 2 Lure Rejections
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Clear Memory
Fuzzy Memory
No Memory
Phase 1 Memory Judgment in Phase 2

Figure 3

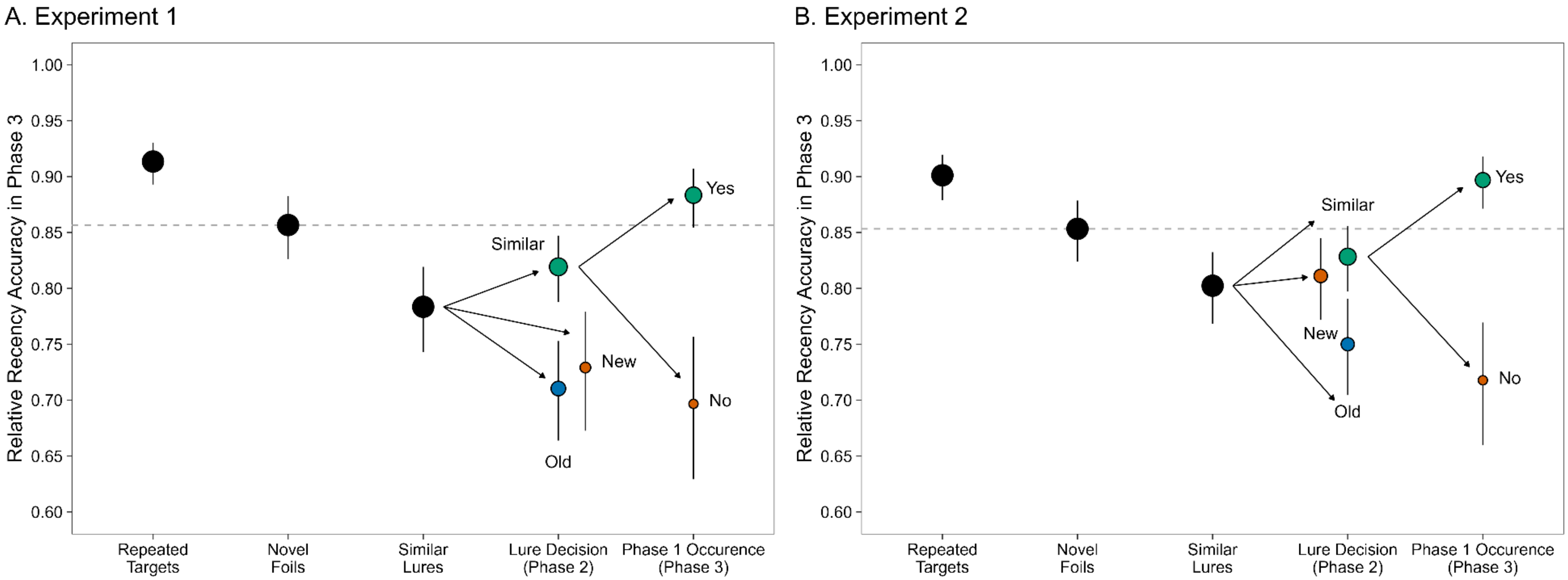
A. Experiment 1
B. Experiment 2
Relative Recency Accuracy in Phase 3
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
Repeated Targets
Novel Foils
Similar Lures
Lure Decision (Phase 2)
Phase 1 Occurence (Phase 3)
Similar
New
Old
Yes
No

Figure 4

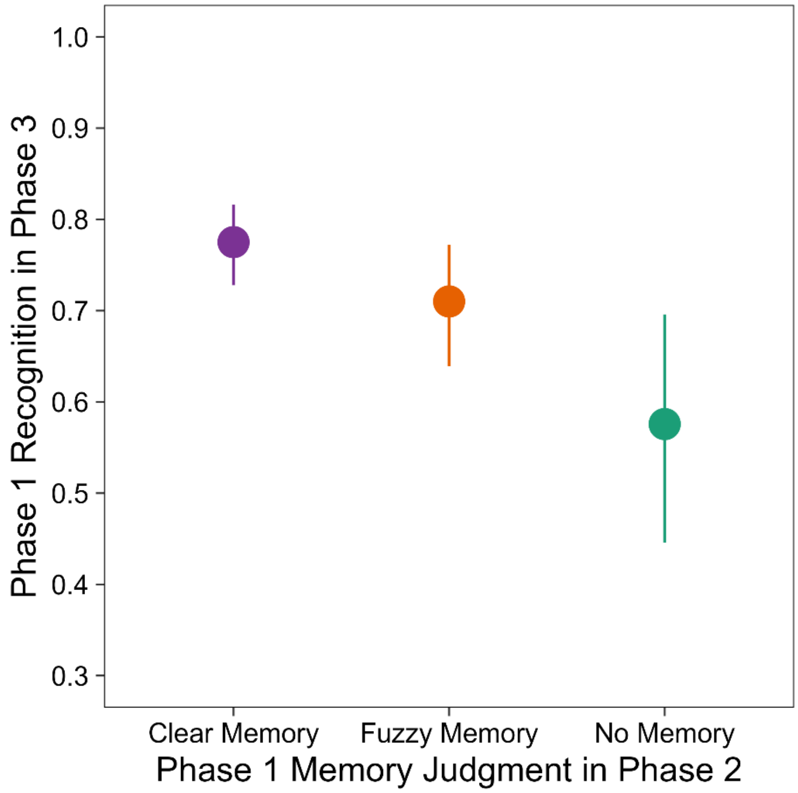
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
Phase 1 Recognition in Phase 3
Clear Memory
Fuzzy Memory
No Memory
Phase 1 Memory Judgment in Phase 2

Figure Captions

Figure 1. Schematic of the experimental procedures. Panel A illustrates the MST used in Experiment 1. In the study phase, participants encoded everyday objects by indicating whether each object belongs indoors or outdoors. In the recognition phase, they classified repeated targets, similar lures, and novel foils as "old," "similar," and "new," respectively. Panel B illustrates the MST used in Experiment 2. The study phase was identical except that each object appeared above a verbal label. In the recognition phase, each trial began with presentation of a verbal label, and participants indicated whether they had clear, fuzzy, or no memory for the corresponding Phase 1 object before classifying the object as "old," "similar," or "new." Panel C illustrates the temporal memory task used in both experiments. Two versions of an object appeared side-by-side. Participants first made a relative recency judgment by selecting the object that appeared in Phase 2 and then indicated whether the other object had appeared in Phase 1 by responding "yes" or "no." Colored outlines denote repeated targets (green), similar lures (blue), and novel foils (red).

Figure 2. Phase 2 Similar Lure Rejections Conditionalized on Phase 1 Retrieval-Quality Judgments (Experiment 2). The points show the probabilities of correct "similar" responses to Phase 2 similar lures as a function of the retrieval-quality judgments regarding memory for Phase 1 objects made prior to the lure decision. Error bars are 95% confidence intervals.

Figure 3. Relative Recency Accuracy in Phase 3: Experiments 1 (A) and 2 (B). Point areas show relative differences in the observations comprising each cell. The black points show relative recency accuracy across all items within each item type. The colored points show relative recency accuracy for similar lures conditionalized on the lure decisions made in Phase 2 (fourth column) and the Phase 1 occurrence responses made in Phase 3 for lures classified as "similar" in Phase 2 (fifth column). In the fourth column, the green point represents lures called "similar," the blue point represents lures called "old," and the red point represents lures called "new." In the fifth column, the green point represents "yes" responses indicating that participants believed the initially unchosen object appeared in Phase 1, whereas the red

point represents “no” responses. Memory for change was assumed to occur primarily on trials when participants responded “yes” rather than “no” to the Phase 1 occurrence probe. The gray dashed horizontal line extends the relative recency accuracy for novel foils to facilitate comparison with the conditional lure cells and highlight proactive memory effects. Error bars are 95% confidence intervals.

Figure 4. Phase 1 Object Recognition in Phase 3 Conditionalized on Phase 2 Retrieval-Quality Judgments (Experiment 2). The points show the probabilities of correct “yes” responses to the Phase 1 occurrence probe in Phase 3 for similar lures as a function of the retrieval-quality judgments regarding memory for Phase 1 objects made prior to lure decisions in Phase 2. Error bars are 95% confidence intervals.