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# A single perceptual comparison is sufficient, but not necessary, to induce lasting memory distortion

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ABSTRACT

Humans constantly compare their visual memories with similar visual inputs to modify their behavior adaptively. However, basic and applied studies suggest that these comparisons can produce systematic distortions in observers' memory reports that persist across time and contaminate subsequent reports. This has led to the hypothesis that perceptual comparisons, while adaptive, are both *necessary* and *sufficient* to produce persistent memory distortions. In three experiments, we tested this hypothesis by independently manipulating demands for perceptual comparisons and memory reports across a pair of memory tests separated by a 24-h delay. At each test, observers were cued to recall colored object silhouettes that they had learned previously. At the first test, following cued recall, the silhouette was presented again in a similar color to serve as a perceptual probe to be compared with memory or to be used in a control task where comparisons were omitted and attention to the probe varied. Afterwards, observers either reported their memory of the recalled silhouette or not. Memory reports at the first test exhibited attractive biases towards the probe after comparisons and each of the control tasks. While biases persisted into the second test following comparisons, as previously demonstrated, they also persisted when the control task required processing of the probe that was commensurate with comparisons. In both cases, persistence was not contingent upon making an initial memory report. Therefore, a single perceptual comparison is indeed sufficient for memory distortions to persist, but persistence may be primarily determined by attentional engagement with similar visual inputs.

In daily life, humans compare their visual memories to incoming percepts constantly. In some cases, these comparisons are made intentionally, such as when searching for one's keys on a cluttered desk, while in other cases, they occur incidentally, such as when spontaneously recognizing an old roommate at the shopping mall. In each of these scenarios, comparing memories to percepts is considered functionally adaptive, as it allows the observer to discriminate between familiar and novel stimuli in the environment and modify behavior accordingly.

Despite these clear functional advantages, some empirical findings suggest that performing perceptual comparisons can trigger memory updating, including in situations where updating is undesirable. In the long-term memory (LTM) literature, for example, applied studies describe a pervasive unreliability of memories that were previously used in comparisons. For example, mounting evidence suggests that a single identification test of an eyewitness' memory is sufficient to contaminate subsequent tests. Following an initial test, eyewitnesses become more likely to falsely endorse an innocent suspect as the perpetrator (Charman & Cahill, 2012; Goodsell, Gronlund, & Neuschatz, 2015; Steblay & Dysart, 2016; Steblay, Tix, & Benson, 2013) and their confidence becomes a less reliable index of memory accuracy (Wixted, Mickes, Clark, Gronlund, & Roediger III, 2015; Wixted & Wells, 2017). Leading theories propose that elaborative processing of the innocent suspect during the initial identification test produces a sense of familiarity with the suspect during later testing that is misattributed to the source of the crime (Johnson, Hashtroudi, & Lindsay, 1993; Wixted, Wells, Loftus, & Garrett, 2021; Zaragoza & Lane, 1994). These types of empirical patterns have led to claims by some experts in the field that the only trustworthy test of eyewitness memory occurs during the first comparison that is made (Mickes, Wilson, & Wixted, 2025; Wixted, 2022; Wixted et al., 2021; Wixted & Mickes, 2022).

In corroboration with these findings, studies in the field of visual working memory (VWM) have levied evidence that performing

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perceptual comparisons modulates integration between visual memories and similar visual inputs. After comparing one's memory of a target stimulus to a similar perceptual probe, memory reports of the target that are made several moments later show reliable attraction towards the probe, meaning that observers report their memory as being more alike the probe than it actually was (Fukuda et al., 2022; Saito, Kolisnyk, & Fukuda, 2023). When compared to other sources of report bias, such as task-irrelevant distraction (e.g., Rademaker, Bloem, De Weerd, & Sack, 2015; Sun et al., 2017; Teng & Kravitz, 2019) or simultaneous memory maintenance (e.g., Bae & Luck, 2017; Chunharas, Rademaker, Brady, & Serences, 2022; Scotti, Hong, Leber, & Golomb, 2021), biases following comparisons tend to be larger and more reliable. Moreover, much like the misattributions observed in eyewitness testimony, biases following comparisons have shown the propensity to persist into subsequent retrieval episodes (Saito, Duncan, & Fukuda, 2023) and generalize across different retrieval cues that observers use to access the same LTM representation (Teoh, Saito, Yeo, Winter, & Fukuda, 2024). These findings have led to the hypothesis that the act of comparing memories to similar visual inputs plays a mechanistic role in determining the persistence of memory distortions over time.

However, this hypothesis entails at least two tacit assumptions that have yet to be empirically tested. First, the hypothesis assumes that performing a perceptual comparison is *necessary* for memory distortions to persist across time. As aforementioned, memory distortions have also been observed in a variety of tasks where comparisons are not explicitly required (Huang & Sekuler, 2010; Mallett, Mummaneni, & Lewis-Peacock, 2020; Nemes, Parry, Whitaker, & McKeefry, 2012; Nemes, Whitaker, Heron, & McKeefry, 2011; Rademaker et al., 2015; Teng & Kravitz, 2019), but no study has directly measured their persistence. In these other tasks, distortions are viewed as the consequence of perceptual distraction, where similar percepts draw observers' attention away from memory and create systematic interference in the memory signal (Zhang & Lewis-Peacock, 2025; see Lorenc, Mallett, & Lewis-Peacock, 2021 for a recent review). When distraction is relatively weak, as when passively viewing a similar percept with no corresponding action (Huang & Sekuler, 2010; Mallett et al., 2020; Nemes et al., 2011; Nemes et al., 2012), observers may continue focusing their attention on their memory representation, thereby minimizing signal intrusion (Oberauer & Lin, 2017; Saito, Printzlau, Yeo, & Fukuda, 2025; Souza & Oberauer, 2016). However, when similar inputs coincide with an interrupting task that draws attention away from memory, signal intrusions get stronger (Gresch, Boettcher, van Ede, & Nobre, 2021; Rademaker et al., 2015; Sun et al., 2017; Teng & Kravitz, 2019). These intrusions may be especially potent when interruptions require explicitly attending to perceptual features that overlap with memory, as in the case of a comparison, compared to performing a secondary task where the features of the percept are task-irrelevant. From this perspective, comparisons may be analogous to a strong form of perceptual distraction where observers are forced to shift their attention away from memory towards the features of a similar percept in order to satisfy task demands. Therefore, before embracing the claim that perceptual comparisons are necessary for distortion persistence, one must demonstrate that persistence cannot be easily replicated in other tasks where attention to similar percepts is commensurate with performing a comparison.

The second tacit assumption of the mechanistic hypothesis is that performing a single comparison between memory and perception is *sufficient* to produce persistent distortions. However, in many of the previous studies that have demonstrated distortion persistence, distortions are initially captured by memory reports that are made approximately one second after the comparison is performed (Saito, Duncan, & Fukuda, 2023; Teoh et al., 2024). Therefore, it is unclear whether distortion persistence is explained by the initial comparison, the initial report, or their combination. Indeed, memory report procedures can permit additional learning and interference that is not currently accounted for. Consider the case of continuous memory reports where observers manually adjust the features of a perceptual probe to match their memory. This procedure, by definition, requires a series of additional perceptual comparisons where the observer can incur further distortion (Makovski, Sussman, & Jiang, 2008; Wang, Theeuwes, & Olivers, 2018) or engage in strategic re-encoding of the target at the time of test (Born & Spitzer, 2026; Miner, Schurgin, & Brady, 2020; Ovalle Fresa & Rothen, 2019; Sutterer & Awh, 2016; Tozios & Fukuda, 2024). Moreover, by selecting and committing to a response, the observer engages in goal-directed motor actions that can facilitate long-term retention (Bulatova & Fukuda, 2025; Yebra et al., 2019; Kinder & Buss, 2021). In order to claim then that a single perceptual comparison provides the sufficient conditions for distortion persistence, one must confirm that persistence occurs even when processes tied to memory reports are controlled or eliminated.

To address these theoretical gaps, we conducted three multi-session experiments where we manipulated attention to similar visual inputs and the demands for immediate memory reports. In each experiment, we asked observers to encode colored object silhouettes into their LTM in anticipation of immediate (i.e., same session as encoding) and delayed (i.e., 24-h after encoding) memory testing. During the Immediate Test, after recalling a cued silhouette to mind from LTM, participants were presented a probe copy of the silhouette in a similar color and were told to either compare the color of the probe with their memory to satisfy a similarity judgment or perform a control task where attention to the probe varied across experiments. The control tasks included ignoring the probe and focusing on the memory representation (weak distraction, Experiment 1), performing a rapid serial visual presentation (RSVP) task that was superimposed on the probe (strong distraction without attention to the probe, Experiment 2; Teng & Kravitz, 2019), or categorizing the color of the probe as warm or cold (strong distraction with attention to the probe, Experiment 3). Afterwards, observers either submitted a continuous memory report of the learned silhouette's color or completed a visual search in which no color information was presented or reported.

We found attractive biases in observers' memory reports at the Immediate Test following weak distraction, both forms of strong distraction, and perceptual comparisons, consistent with previous literature. We also found that report biases following perceptual comparisons persisted into the Delayed Test in all three experiments, further solidifying their propensity to induce lasting memory change. However, when we measured persistence in the control tasks, we found that distortions also persisted when observers needed to categorize the probe's color. Importantly, persistence following comparisons and color categorization was observed even when observers did not report their memory at the Immediate Test. Thus, these findings suggest that a single perceptual comparison is indeed sufficient to produce a lasting distortion in memory, but that persistence is primarily determined by attentional engagement with similar visual inputs during active memory maintenance.

## 1. Experiment 1

### 1.1. Method

#### 1.1.1. Participants

All participants in the experiment were undergraduate students at xxxx that reported normal or corrected-to-normal visual acuity and color vision. Each participant provided informed consent in accordance with the procedures approved by the Institutional Review Board at xxxx.

A previous study was able to successfully capture the persistence of comparison-induced report biases across a 24-delay with 30 participants (i.e., Saito, Duncan, & Fukuda, 2023). However, because we could not anticipate the effect of removing the comparison or the memory report on persistence, we increased our target sample size to 40 participants to be conservative. Participants were recruited on a weekly basis until the sample size exceeded this target. This resulted in the recruitment of 48 participants. Each participant reported their gender identity and age on

a computerized prompt at the beginning of the experiment. For gender identity, participants selected between male, female, and prefer not to answer. Race and ethnicity were not collected. Data from eight participants was excluded due to attrition between the two experimental sessions (5) or for failing to report any memories confidently in the entire experiment (3). This resulted in a final sample of 40 participants whose data were subjected to analysis (32 female, 8 male, age range = 18–45 years, mean age = 21.40 years old).

### 1.1.2. Apparatus and stimuli

The object silhouettes were sampled from an existing database (Sutterer & Awh, 2016) and the color set consisted of 360 equally-spaced color values from CIE *L*a*b** space centered at L = 54, a = 21.5, and b = 11.5, with a radius of 49 (Schurgin, Wixted, & Brady, 2020). During the experiment, participants were seated approximately 60 cm from an LCD monitor (refresh rate = 60 Hz) where colored silhouettes were presented on a white background (80 cd/m$^2$) using the Psychophysics Toolbox in MATLAB (Brainard, 1997).

### 1.1.3. Procedure

Fig. 1A shows a timeline of the multi-session procedure that was used.

*1.1.3.1. Encoding task.* Participants performed 16 blocks of an explicit encoding task (Fig. 1B). In each block, participants were presented a sequence of 72 colored silhouettes and were instructed to remember each silhouette and its color for subsequent memory testing. The colors of the silhouettes were sampled uniformly from the circular color space (see *Apparatus and Stimuli*) at an iteration that was matched to the total number of studied silhouettes (i.e., 288 silhouettes amongst 360 possible colors = 1.25° steps between targets rounded to the nearest degree). The same 288 colored silhouettes were presented every four blocks in a

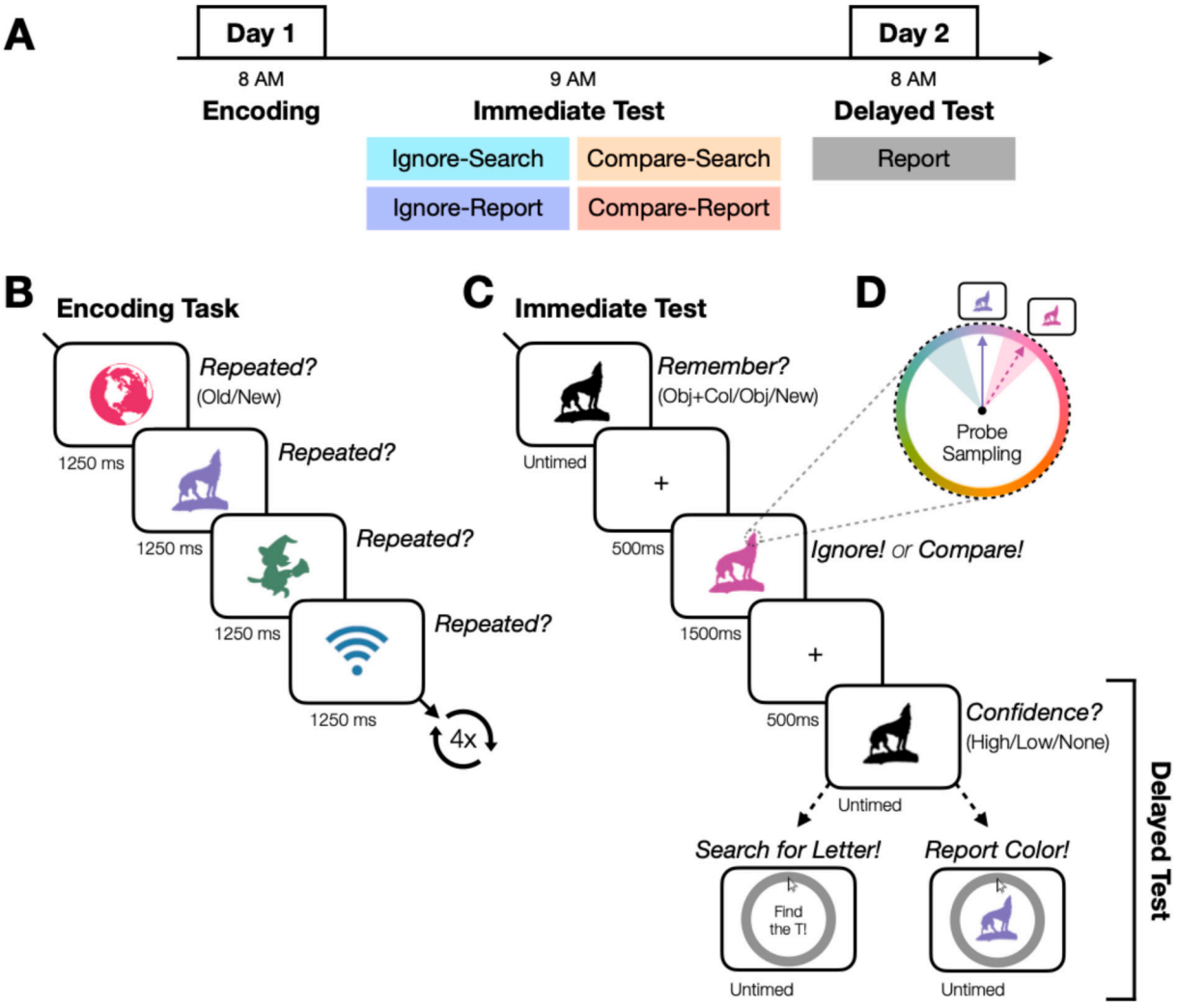


**Fig. 1.** Experiment 1 Procedure and Task Schematics (A) The two-day experimental procedure. Participants completed an encoding task followed by an immediate memory test that took place on the same day and a delayed memory test that took place 24 h later. The times of day presented above each experimental phase are included only as an illustrative example and differed for each participant in the actual experiment. **(B)** The encoding task procedure. Each colored silhouette was presented one at a time until all silhouettes were presented. The entire stimulus set was presented four times in a shuffled order, resulting in four repetitions per object. To encourage attentiveness, participants submitted a repetition judgment each time an object was presented. **(C)** The memory test procedure. Each trial of the Immediate Test began with the presentation of a black object silhouette and an untimed recognition report. After a short delay, a uniquely-colored probe copy of the silhouette was presented that participants either ignored or compared with their memory to satisfy a similarity judgment. Following another short delay, the black silhouette re-appeared and participants indicated their memory confidence for the color of the original target. The trial ended with participants either reporting the original target color by selecting from a continuous wheel or searching for a letter that was occluded by the wheel. Participants only completed the confidence report and color report at the Delayed Test. **(D)** The probe color sampling procedure. The color of the probe was randomly sampled 16–45° away from the target color on the color wheel. The direction of offset was randomly determined to be clockwise or counter-clockwise on every trial.

randomized order, such that each silhouette was presented four times by the end of the encoding task. On each trial, a colored silhouette (200 × 200 pixels) was presented at the center of the screen for 1250 ms followed by a number indicating the number of silhouettes remaining in that block for 250 ms. To encourage attentiveness, participants were instructed to indicate whether the current silhouette had already been presented previously by pressing one of two buttons on the keyboard while the silhouette was still onscreen (1 = new object, 0 = old object).

*1.1.3.2. Immediate memory test.* Following the Encoding Task, participants were tested on their memory of the learned silhouettes. This Immediate Test consisted of 8 blocks of 36 trials. The trial procedure is shown in Fig. 1C. Each trial began with a black silhouette presented at the center of the screen (200 × 200 pixels) and participants were instructed to complete an untimed recognition judgment by indicating whether they remembered the silhouette and its color by pressing of three buttons on the keyboard (1 = remember object and color, 2 = remember object only, 3 = new object). These response options were presented onscreen during the recognition report. This recognition report was intended to cue retrieval of the corresponding silhouette from LTM back into VWM at the start of the trial.

Five hundred ms after participants submitted their recognition report, the same silhouette was presented again in color at the center of the screen for 1500 ms (200 × 200 pixels). The color of this probe silhouette was randomly sampled from a range of values 16–45° away from the color of the learned target silhouette in the circular color space (Fig. 1D). This proximal sampling range was implemented to maximize the number of trials where participants perceived the color of the probe as similar to the color of the target while ensuring that its precise physical similarity was not predictable (Fukuda et al., 2022; Saito, Duncan, & Fukuda, 2023). The directional offset of the probe color was determined randomly on each trial. In the *Compare condition*, participants were instructed to judge whether the color of the probe was similar or dissimilar to the color of the learned target. Participants were told that this judgment was subjective, meaning that there was not an objectively correct answer and that they were free to use whatever criteria they wanted to make this judgment. Once decided, participants submitted their judgment by pressing one of two buttons on the keyboard (Left = similar, Right = dissimilar). These response options were not presented onscreen during the comparison, and the probe silhouette remained onscreen for 1500 ms regardless of when the judgment was submitted. In the *Ignore condition*, participants were instructed to ignore the probe silhouette while maintaining fixation. The Compare and Ignore conditions were blocked and counterbalanced, such that observers completed four blocks of the Compare condition before completing four blocks of the Ignore condition, or vice versa.

Five hundred ms after the offset of the probe silhouette, the black silhouette was presented again at the center of the screen and participants completed an untimed report where they indicated how confident they were that they remembered the color of the learned target silhouette by pressing one of three buttons on the keyboard (1 = high confidence, 2 = low confidence, 3 = no confidence). These response options were presented onscreen during the confidence report.

Immediately after the confidence report, the trial concluded in one of two manners. In the *Report condition*, a grayscale wheel (diameter = 800 pixels) appeared around the black silhouette that cued participants to report the color of the learned target silhouette as precisely as possible. To do this, participants used the mouse to move the cursor along the wheel. While the cursor was on the wheel, the color of the silhouette at the center of the screen (i.e., report probe) updated continuously with the color value at the cursor location. Once the participant was satisfied that the report probe matched their memory of the learned target, they clicked with the mouse to submit their response. The color wheel occluded by the grayscale wheel was rotated randomly on each trial and the cursor always started at the center of the screen. In the *Search condition*, the grayscale wheel appeared, but the report probe was replaced by the message "Find the letter T!" at the center of the screen. On these trials, participants were told that the wheel was occluding a collection of "L" letters and one "T" letter and that they needed to find where the T was hidden amongst the Ls. To do this, participants used the mouse to move the cursor along the wheel. While the cursor was on the wheel, the letter assigned to that location of the wheel was presented at the center of the screen. Participants moved the cursor along the wheel until the cursor landed on the location where the T was assigned and the letter T appeared at the center of the screen. When the T appeared, participants clicked with the mouse to end the trial. The location of the T was randomly assigned to one of 12 equidistant locations on the wheel (i.e., separated by 30°). This search procedure was intended to match all of the motor actions corresponding to the memory report in the Report condition without including any of the memory-related processes. The Report and Search conditions were pseudorandomized within each block, such that observers could not predict how any given trial would end.

Half of the learned silhouettes were randomly assigned to be recalled in the Compare condition, while the remaining half were recalled in the Ignore condition. Within each of these conditions, the silhouettes were further split randomly between the Search and Report conditions. This crossing of conditions resulted in four total experimental conditions (Ignore-Search, Ignore-Report, Compare-Search, Compare-Report) that each contained 72 learned silhouettes. Participants completed four practice trials prior to the start of the Compare and Ignore conditions.

*1.1.3.3. Delayed memory test.* Twenty-four hours after the start of the first experimental session, participants returned to the research lab to complete a delayed memory test. This Delayed Test consisted of 6 blocks of 48 trials where each of the objects recalled at the Immediate Test were recalled for a second time. The trial procedure was an abbreviated version of the Immediate Test, where observers only completed the memory confidence report and the color report from the wheel (see Fig. 1C). Participants completed four practice trials prior to the start of the main test.

### *1.1.4. Analysis*

For each trial, we computed the error in the color report as the angular deviation between the location of the reported color on the color wheel and that of the target color was learned originally. To provide directional information about this report error relative to the probe color that was presented, we aligned the report errors across trials such that positive error values indicated report errors in the direction of the probe (signed report errors). The mean signed report error was used to quantify the overall bias in the reports, with positive bias values indicating attraction towards the probe color.

We filtered the data to minimize the influence of silhouettes that were forgotten. When observers are forced to report a forgotten representation, they often resort to guessing behaviors that can contaminate systematic measures like report bias and make the results harder to interpret. On the one hand, when observers guess randomly, this appends highly-variable reports to the dataset that can mask systematicity present in reports that were based on remembered objects. On the other hand, strategic forms of guessing can artificially inflate systematicity and lead to spurious patterns in the data. For example, when observers fail to retrieve the color of the target from memory, they may attempt to guess its color by selecting near the color of a non-target (see, e.g., Pratte, 2019; Huang, 2020). This strategy is especially problematic for the present study, as it can lead to "biases" in the memory reports that are divorced from memory content itself. The trial breakdown in Table 1 shows that an overwhelming majority of color reports made with low confidence (71%) or no confidence (95%) at the Immediate Test were associated with recognition judgments where the observer reported that they did not remember the color of the cued object. Therefore, we

**Table 1**
Color confidence binned by recognition at immediate test in experiment 1.

| Confidence | Recognition | Count | Proportion |
|---|---|---|---|
| High | Object & Color | 96.53 (55.35) | 0.83 (0.21) |
| | Object, No Color | 18.10 (25.66) | 0.15 (0.19) |
| | No Object, No Color | 1.08 (3.55) | 0.01 (0.05) |
| | Object & Color | 35.48 (32.85) | 0.30 (0.23) |
| Low | Object, No Color | 90.9 (52.38) | 0.68 (0.22) |
| | No Object, No Color | 3.55 (8.56) | 0.03 (0.07) |
| | Object & Color | 1.15 (2.01) | 0.05 (0.16) |
| None | Object, No Color | 22.85 (31.45) | 0.45 (0.35) |
| | No Object, No Color | 18.38 (24.72) | 0.50 (0.36) |

Values reported in the table represent the mean counts and proportions of color confidence reports at the Immediate Test binned by recognition judgments with the standard deviation reported in parentheses.

decided to focus our analysis on objects whose color was recalled confidently by the observer, consistent with prior literature (Saito, Duncan, & Fukuda, 2023). When measuring bias persistence, we focused on objects whose color was recalled confidently at both memory tests.

As can be seen in Table 2, constraining the data by confidence required excluding a substantial number of objects across conditions at both tests, which could have reduced statistical power. However, we reasoned that minimizing the influence of guessing behaviors was more important for evaluating the present hypothesis than acquiring an exact estimate of the bias effect size. Therefore, we maintained this confidence filtering procedure for the main analyses reported here but include an analysis with all confidence levels in the *Supplemental Materials*.

To account for the limited number of trials contributed by each participant, we used a statistical bootstrapping procedure to re-sample our data. For each bootstrap, we re-sampled the signed report errors from 80% of our participants with replacement and computed the report bias within the sample. We repeated this process 10,000 times to construct a distribution of bootstrapped report biases. To determine the significance of the bias captured by this procedure, we computed the percentage of bootstraps that were offset from zero in the same direction. Following the assumptions of a two-tailed *t*-test with an alpha level of 0.05, if more than 97.5% of the bootstraps were above zero, this was interpreted as evidence of a significant attraction bias, while more than 97.5% of bootstraps below zero was interpreted as evidence of a significant repulsion bias. To determine whether the bias was significantly different between two conditions, we computed the difference in bias magnitude between conditions on each bootstrap iteration and compared the resulting distribution of differences against zero. Here again, if more than 97.5% of the bootstrapped differences were offset from zero in the same direction, this was interpreted as evidence of a significant difference in bias magnitude. *P*-values were therefore derived by computing the complement of these bootstrap probabilities (i.e., 1—bootstrap probability) with the significance threshold set to 0.025.

**Table 2**
Trials with high-confidence color memory in experiment 1.

| Test | Perceptual Demand | Report Demand | Count | Proportion |
|---|---|---|---|---|
| Immediate | Ignore | Search | 28.88 (14.34) | 0.40 (0.20) |
| | | Report | 28.73 (14.62) | 0.40 (0.20) |
| | Compare | Search | 29.68 (16.31) | 0.41 (0.23) |
| | | Report | 28.43 (16.15) | 0.39 (0.22) |
| Delayed | Ignore | Search | 14.53 (11.44) | 0.20 (0.16) |
| | | Report | 15.15 (11.57) | 0.21 (0.16) |
| | Compare | Search | 14.40 (11.11) | 0.20 (0.15) |
| | | Report | 15.03 (12.25) | 0.21 (0.17) |

Values reported in the table represent the mean counts and proportions of high-confidence trials with the standard deviation reported in parentheses. The counts and proportions at the Delayed Test represent target colors that were recalled with high-confidence at both tests.

### 1.2. Results

We began by assessing whether targets reported at the Immediate Test showed evidence of systematic report biases following perceptual comparisons and the weak distraction induced by ignoring the probe. Signed report errors are presented as distributions in Fig. 2. Consistent with prior studies, we found that observers' reports of the target were reliably attracted towards the probe following perceptual comparisons (Fig. 2, $M = 7.94°$, 95% CI [3.49, 12.16°], $p < 0.001$) and weak distraction (Fig. 2, $M = 5.58°$, 95% CI [2.68, 8.51°], $p < 0.001$). While the magnitude of comparison-induced biases was numerically larger than those induced by ignoring, this difference was not significant ($M = 2.37°$, 95% CI [−2.27, 6.76°], $p = 0.152$), likely owing to higher noise in the current bias estimates that were measured from LTM compared to those measured from VWM in prior studies (e.g., Saito, Kolisnyk, & Fukuda, 2023). Nonetheless, these findings confirmed that perceptual comparisons and weak distraction both resulted in attractive report biases.

We then moved to assess whether any of these biases persisted into the Delayed Test. To do this, we separated the memory reports at the Delayed Test based on whether the probe was initially ignored or used in a perceptual comparison, as well as whether the target was initially reported or not. Fig. 3 shows signed response distributions and bootstrapped bias estimates for each of these four conditions. For targets that were reported at the Immediate Test, memory reports at the Delayed Test continued to show attraction biases following perceptual comparisons (**Fig. 3A**, $M = 7.10°$, 95% CI [2.48, 12.05°], $p < 0.001$), consistent with Saito, Duncan, and Fukuda (2023), but not following weak distraction (**Fig. 3B**, $M = 3.84°$, 95% CI [−0.06, 7.92°], $p = 0.028$). Both of these biases reported at the Delayed Test were statistically comparable to their respective biases reported initially at the Immediate Test (compare: $M = 1.31°$, 95% CI [−3.89, 6.84°], $p = 0.326$; ignore: $M = -0.35°$, 95% CI [−4.94, 5.24°], $p = 0.417$) and did not differ in magnitude from one another ($M = 3.26°$, 95% CI [−2.83, 9.52°], $p = 0.148$). These results provide preliminary evidence that simply seeing a similar visual input during memory maintenance is insufficient for resulting distortions to persist reliably into subsequent recollections.

We then performed the same analysis again for targets that were not reported at the Immediate Test. Here again, we found that targets reported for the first time at the Delayed Test showed attraction biases towards the probe from a day earlier if the observer had performed a perceptual comparison (**Fig. 3A**, $M = 5.38°$, 95% CI [0.63, 11.16°], $p = 0.012$), but not if the probe had been ignored (**Fig. 3B**, $M = 2.77°$, 95% CI [−0.61, 6.60°], $p = 0.061$). For both comparisons and weak distraction, respectively, biases that persisted in the absence of an initial memory report were comparable to the biases that were initially reported at the Immediate Test (compare: $M = -0.41°$, 95% CI [−5.98, 5.96°], $p = 0.424$; ignore: $M = -1.43°$, 95% CI [−6.90, 4.33°], $p = 0.305$) and those that persisted following an initial report (compare: $M = 1.72°$, 95% CI [−4.33, 8.08°], $p = 0.290$; ignore: $M = 1.07°$, 95% CI [−3.76, 6.03°], $p = 0.338$). There was also no significant difference in the magnitude of the bias between these conditions ($M = 2.61°$, 95% CI [−3.53, 9.43°], $p = 0.212$). These results show that a single perceptual comparison was able to produce a persistent bias, even when processes tied to memory reporting were eliminated. Thus, in Experiment 1, performing a perceptual comparison appeared both necessary and sufficient to produce a report bias that persisted across the 24-h delay. In Experiment 2, we increased the strength of perceptual distraction to

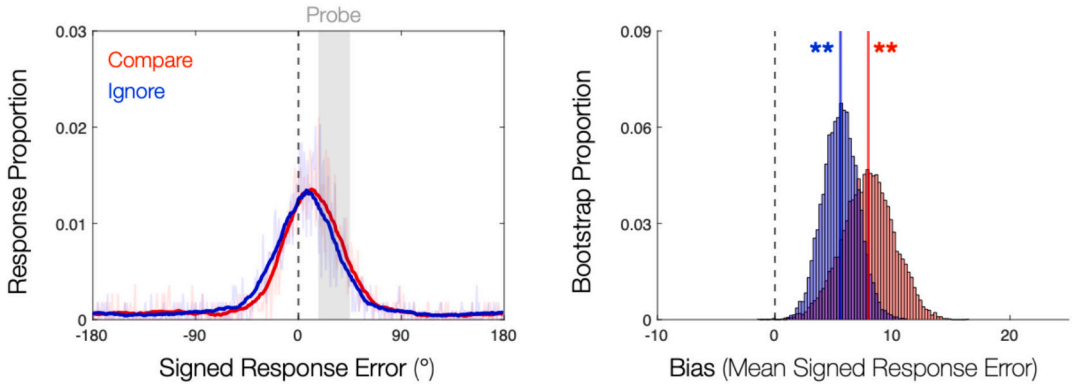


**Fig. 2.** Immediate attractive biases across comparisons and passive viewing Signed response distributions (left) and bootstrapped bias estimates (right) for objects reported at the Immediate Test. Signed response distributions: Bolded lines depict the mean response proportion for a given signed response error averaged across a 30° smoothing window centered at the error value. Transparent lines plotted in the background depict the same proportions without smoothing applied. The vertical black dashed line indicates the location of the zero-centered target across trials. The vertical gray bar depicts the sampling window that the probe was sampled from on each trial. Bootstrapped bias estimates: Solid vertical lines depict the mean bias in each condition across bootstrap iterations. ** $p < 0.001$.

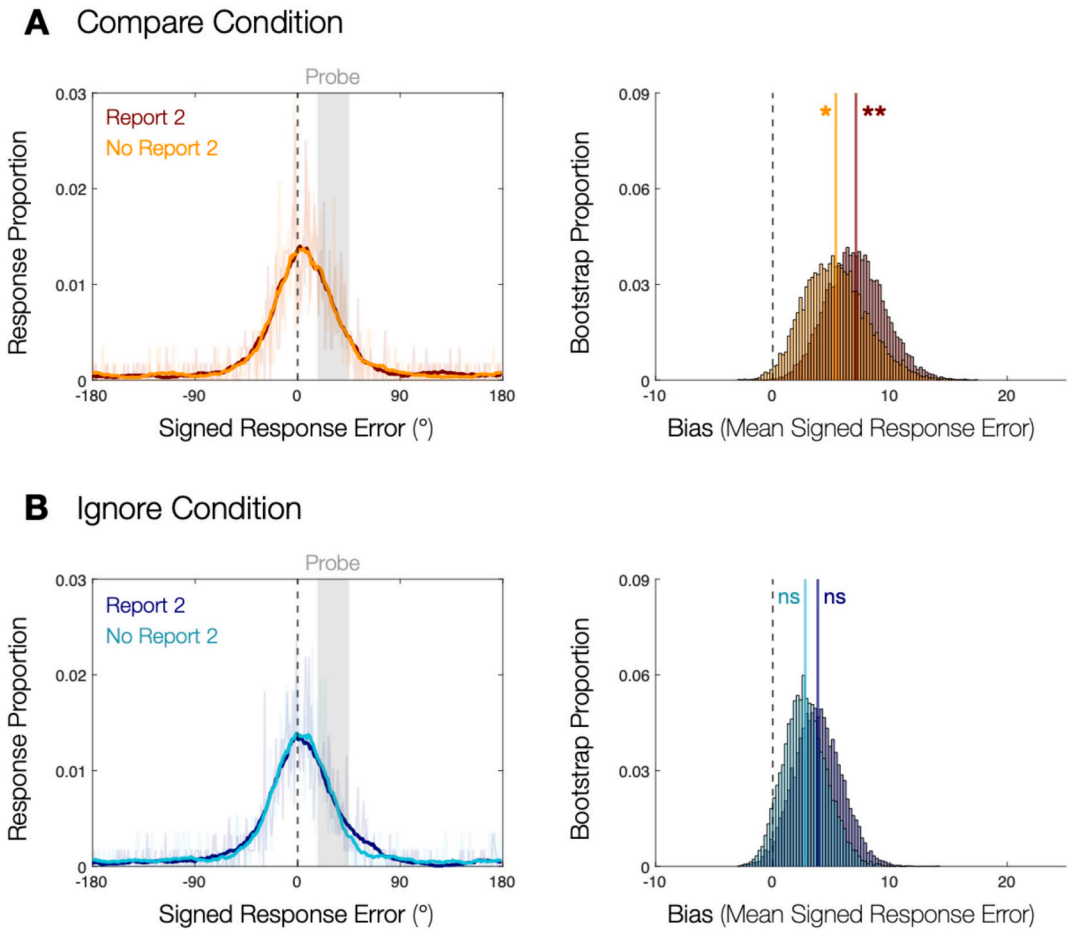


**Fig. 3.** Persistent biases following comparisons, but not passive viewing Signed response distributions (left) and bootstrapped bias estimates (right) for objects recalled again at the Delayed Test after being reported or not reported in the **(A)** Compare condition or **(B)** Ignore condition at the Immediate Test. Signed response distributions: Bolded lines depict the mean response proportion for a given signed response error averaged across a 30° smoothing window centered at the error value. Transparent lines plotted in the background depict the same proportions without smoothing applied. Vertical black dashed lines indicate the location of the zero-centered target across trials. Vertical gray bars depict the sampling window that the probe was sampled from on each trial. Bootstrapped bias estimates: Solid vertical lines depict the mean bias in each condition across bootstrap iterations. * $p < 0.025$, ** $p < 0.001$, *ns* = not significant.

determine whether bias persistence could be explained by the need to shift attention away from memory during comparisons, rather than the act of comparison per se.

## 2. Experiment 2

### 2.1. Method

#### 2.1.1. Participants

All participants in the experiment were undergraduate students at xxxx that reported normal or corrected-to-normal visual acuity and color vision. Each participant provided informed consent in accordance with the procedures approved by the Institutional Review Board at xxxx.

We used the same target sample size as Experiment 1 ($n$ = 40). Participants were again recruited on a weekly basis until the sample size exceeded this target, resulting in the recruitment of 46 total participants. Data from six participants was excluded due to attrition between the two experimental sessions (5) or for failing to report any memories confidently at the Delayed Test (1). This resulted in a final sample of 40 participants whose data were subjected to analysis (27 female, 13 male, age range = 18–25 years, mean age = 20.48 years old).

#### 2.1.2. Apparatus and Stimuli

Same as Experiment 1.

#### 2.1.3. Procedure

*2.1.3.1. Encoding Task.* Same as Experiment 1.

*2.1.3.2. Immediate memory test.* Same as Experiment 1, with the following exceptions (see Fig. 4A). First, we replaced the *Ignore Condition* of Experiment 1 with an *RSVP condition*. In the *RSVP condition*, participants performed a letter RSVP task that was superimposed on the probe silhouette (Teng & Kravitz, 2019, Fig. 4B). This manipulation was intended to increase the strength of perceptual distraction by forcing observers to shift their internal attention away from their memory representation for the entire probe presentation.

A stream of 12 letters was presented continuously on top of a gray disk (10 pixels in radius) at the center of the screen. The gray disk

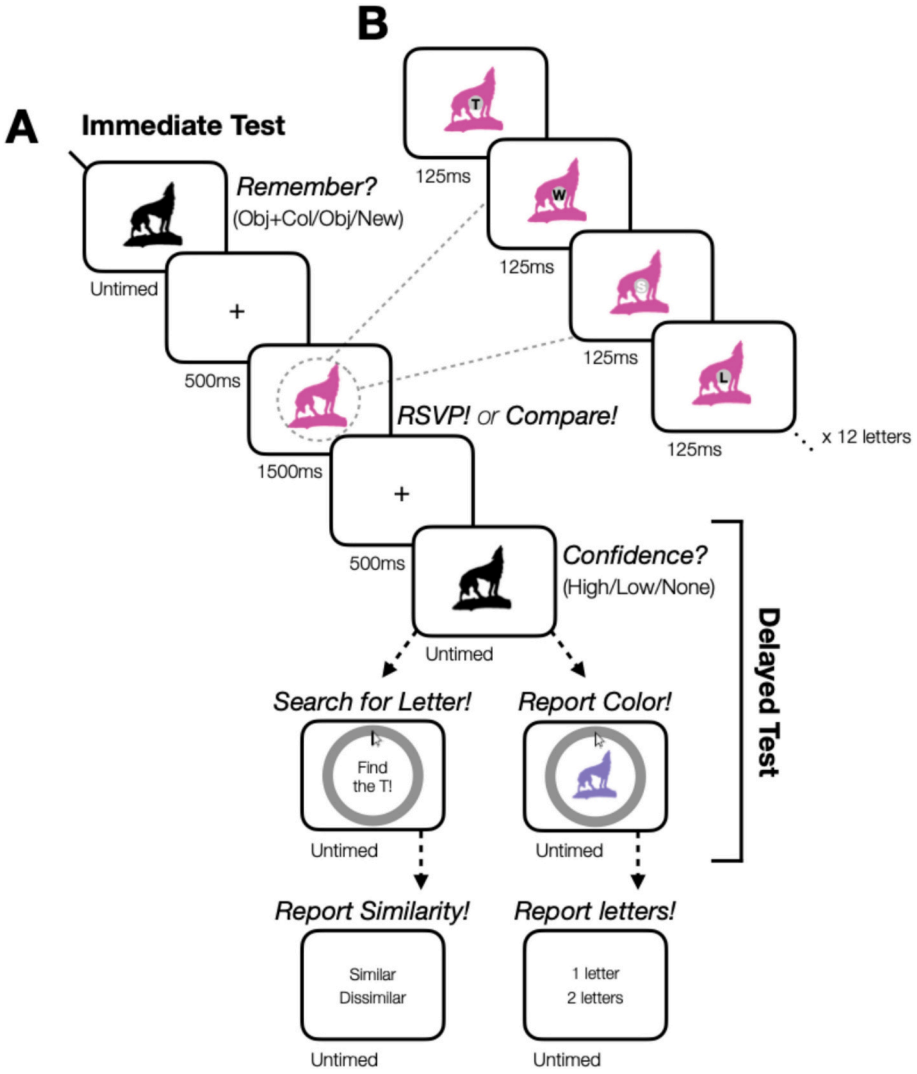


**Fig. 4.** Experiment 2 Procedure and Task Schematics (A) The memory test procedure. Each trial of the Immediate Test began with the presentation of a black object silhouette and an untimed recognition report. After a short delay, a uniquely-colored probe copy of the silhouette was presented that participants either compared with their memory to satisfy a similarity judgment or ignored while performing a letter RSVP. Following another short delay, the black silhouette re-appeared and participants indicated their memory confidence for the color of the original target. Immediately after reporting their confidence, participants either reported the original target color by selecting from a continuous wheel or searched for a letter that was occluded by the wheel. The trial ended with participants either reporting the answer to their similarity judgment or the number of white letters in the RSVP task. Participants only completed the confidence report and color report at the Delayed Test. **(B)** The letter RSVP task procedure. A rapid stream of 12 black or white letters was flashed continuously on a gray disk superimposed on the probe silhouette. Participants counted the number of white letters in the stream, which varied between one or two. The stream persisted for the entire duration of the probe silhouette.

ensured that the contrast between each letter and its background was matched across trials regardless of the silhouette shape or color. Each letter was presented for 125 ms before being immediately replaced by the next letter in the stream, totalling 1500 ms in total. The letters were randomly sampled without replacement from all 26 letters in the alphabet. Participants were instructed to monitor the letter stream to detect the presence of white letters amongst black letters. The number of white letters in the stream varied between one or two letters, with the number determined randomly each trial. The white letters were never presented first or last in the stream and were never presented consecutively.

Second, in both the RSVP and Compare conditions, observers reported their probe responses at the end of the trial (Fig. 4A). This was intended to match the presence and timing of motor demands between perceptual comparisons and perceptual distraction. In the Compare condition of Experiment 1, observers submitted their similarity judgment with a button press at the time of the probe, meaning that comparisons and distraction differed in terms of their internal cognitive demands and overt motor demands. By moving the motor response associated with the probe to the end of the trial, we preserve the critical differences in internal cognitive demands between conditions while eliminating differences in their respective motor demands. The probe report at the end of each trial was untimed.

#### 2.1.3.3. *Delayed memory test.*

Same as Experiment 1.

### 2.1.4. *Analysis*

Same as Experiment 1. Table 3 shows that an overwhelming majority of color reports made with low confidence (71%) or no confidence (98%) at the Immediate Test were once again associated with recognition judgments where the observer reported that they did not remember the color of the cued object. Table 4 shows the counts and proportions of confident color reports at each test. See *Supplemental Materials* for results with all confidence levels included.

## 2.2. *Results*

We began once again by assessing whether targets reported at the Immediate Test showed evidence of systematic report biases following perceptual comparisons and the strong distraction induced by the RSVP task. As shown in Fig. 5, we found that observers' reports of the target were biased towards the probe following comparisons ($M = 6.40°$, 95% CI [2.16, 10.46°], $p = 0.002$) and strong distraction ($M = 4.38°$, 95% CI [1.06, 8.10°], $p = 0.004$). The magnitude of comparison-induced biases was numerically larger than those induced by strong distraction, but the difference was not significant ($M = 2.02°$, 95% CI [−3.16, 6.87°], $p = 0.210$). These findings replicate those from Experiment 1 and show that comparisons and strong distraction both yielded attractive report biases.

We then assessed whether any of the biases reported at the Immediate Test persisted into the Delayed Test. Memory reports at the Delayed Test continued to show attraction biases when the memory was previously used in a comparison (**Fig. 6A**, $M = 4.66°$, 95% CI [0.44, 8.99°], $p = 0.015$) but not when it was subjected to strong distraction (**Fig. 6B**, $M = 0.92°$, 95% CI [−2.19, 4.19°], $p = 0.286$), though their magnitudes did not significantly differ ($M = 3.74°$, 95% CI [−1.49, 9.01°], $p = 0.083$). Moreover, while the persistent biases following comparisons were comparable to those reported respectively a day earlier ($M = -1.00°$, 95% CI [−5.38, 2.52°], $p = 0.328$), those that persisted following strong distraction were significantly smaller than their respective biases from the Immediate Test ($M = -3.86°$, 95% CI [−8.42, −0.18°], $p = 0.019$). These results converge with those of Experiment 1 and show that shifting attention away from memory is also insufficient to replicate the persistent biases observed following perceptual comparisons.

For objects that were not reported at the Immediate Test, we found that reports at the Delayed Test showed attraction towards the probe from a day earlier if the observer had performed a perceptual comparison (**Fig. 6A**, $M = 6.81°$, 95% CI [2.48, 10.87°], $p < 0.001$), but not if they had performed an RSVP task instead (**Fig. 6B**, $M = 3.04°$, 95% CI [−1.40, 7.90°], $p = 0.095$), though their magnitudes did not significantly differ ($M = 3.77°$, 95% CI [−2.70, 9.78°], $p = 0.117$). For both comparisons and strong distraction, biases that persisted in the absence of an initial memory report were comparable to the biases reported at the Immediate Test (compare: $M = 1.16°$, 95% CI [−4.21, 6.58°], $p = 0.343$; RSVP: $M = -1.74°$, 95% CI [−7.72, 4.09°], $p = 0.286$), and those that persisted following an initial report (compare: $M = -2.15°$, 95% CI [−7.44, 3.49°], $p = 0.220$; RSVP: $M = -2.12°$, 95% CI [−8.11, 3.77°], $p = 0.243$). These findings provide further support for the claim that a single perceptual comparison is sufficient to induce a persistent memory distortion and show that this persistence cannot be explained by the need to shift attention away from memory during comparisons. In Experiment 3, we attempted to maximally equate the attentional demands between our control task and comparisons by asking observers to attend to the color of the probe and categorize its color as warm or cold.

**Table 3**
Color confidence binned by recognition at immediate test in experiment 2.

| Confidence | Recognition | Count | Proportion |
|---|---|---|---|
| High | Object & Color | 104.88 (55.74) | 0.87 (0.12) |
| | Object, No Color | 13.25 (13.32) | 0.13 (0.12) |
| | No Object, No Color | 0.15 (0.42) | < 0.01 (< 0.01) |
| Low | Object & Color | 29.63 (21.80) | 0.28 (0.21) |
| | Object, No Color | 93.10 (58.83) | 0.70 (0.22) |
| | No Object, No Color | 1.85 (3.65) | 0.01 (0.02) |
| None | Object & Color | 1.23 (2.63) | 0.02 (0.06) |
| | Object, No Color | 24.55 (29.39) | 0.44 (0.28) |
| | No Object, No Color | 19.38 (16.71) | 0.54 (0.29) |

Values reported in the table represent the mean counts and proportions of color confidence reports at the Immediate Test binned by recognition judgments with the standard deviation reported in parentheses.

**Table 4**
Trials with high-confidence color memory in experiment 2.

| Test | Perceptual Demand | Report Demand | Count | Proportion |
|---|---|---|---|---|
| Immediate | RSVP | Search | 25.78 (14.31) | 0.36 (0.20) |
| | | Report | 27.35 (14.53) | 0.38 (0.20) |
| | Compare | Search | 32.73 (16.04) | 0.45 (0.22) |
| | | Report | 32.43 (16.77) | 0.45 (0.23) |
| Delayed | RSVP | Search | 14.38 (10.36) | 0.20 (0.14) |
| | | Report | 16.28 (11.03) | 0.23 (0.15) |
| | Compare | Search | 18.08 (11.97) | 0.25 (0.17) |
| | | Report | 17.88 (11.37) | 0.25 (0.16) |

Values reported in the table represent the mean counts and proportions of high-confidence trials with the standard deviation reported in parentheses. The counts and proportions at the Delayed Test represent target colors that were recalled with high-confidence at both tests.

# 3. Experiment 3

## 3.1. *Method*

### 3.1.1. *Participants*

All participants in the experiment were undergraduate students at xxxx that reported normal or corrected-to-normal visual acuity and color vision. Each participant provided informed consent in accordance with

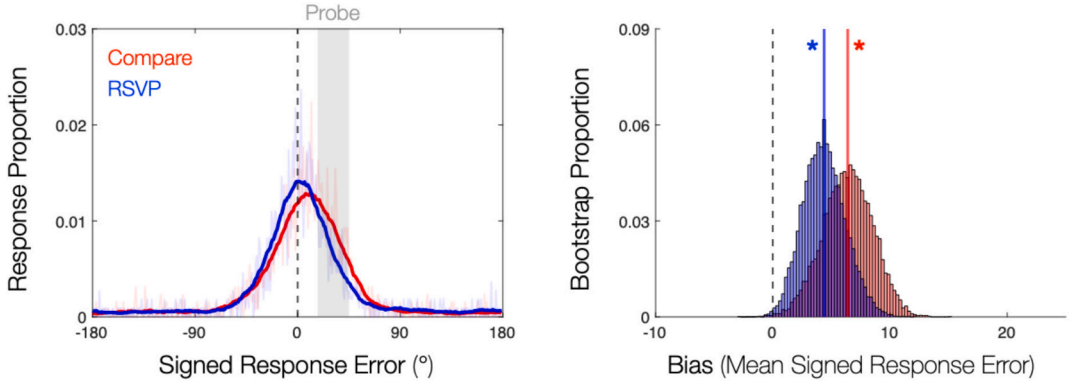


**Fig. 5.** Immediate attractive biases across comparisons and RSVP Signed response distributions (left) and bootstrapped bias estimates (right) for objects reported at the Immediate Test. Signed response distributions: Bolded lines depict the mean response proportion for a given signed response error averaged across a 30° smoothing window centered at the error value. Transparent lines plotted in the background depict the same proportions without smoothing applied. The vertical black dashed line indicates the location of the zero-centered target across trials. The vertical gray bar depicts the sampling window that the probe was sampled from on each trial. Bootstrapped bias estimates: Solid vertical lines depict the mean bias in each condition across bootstrap iterations. * $p < 0.025$.

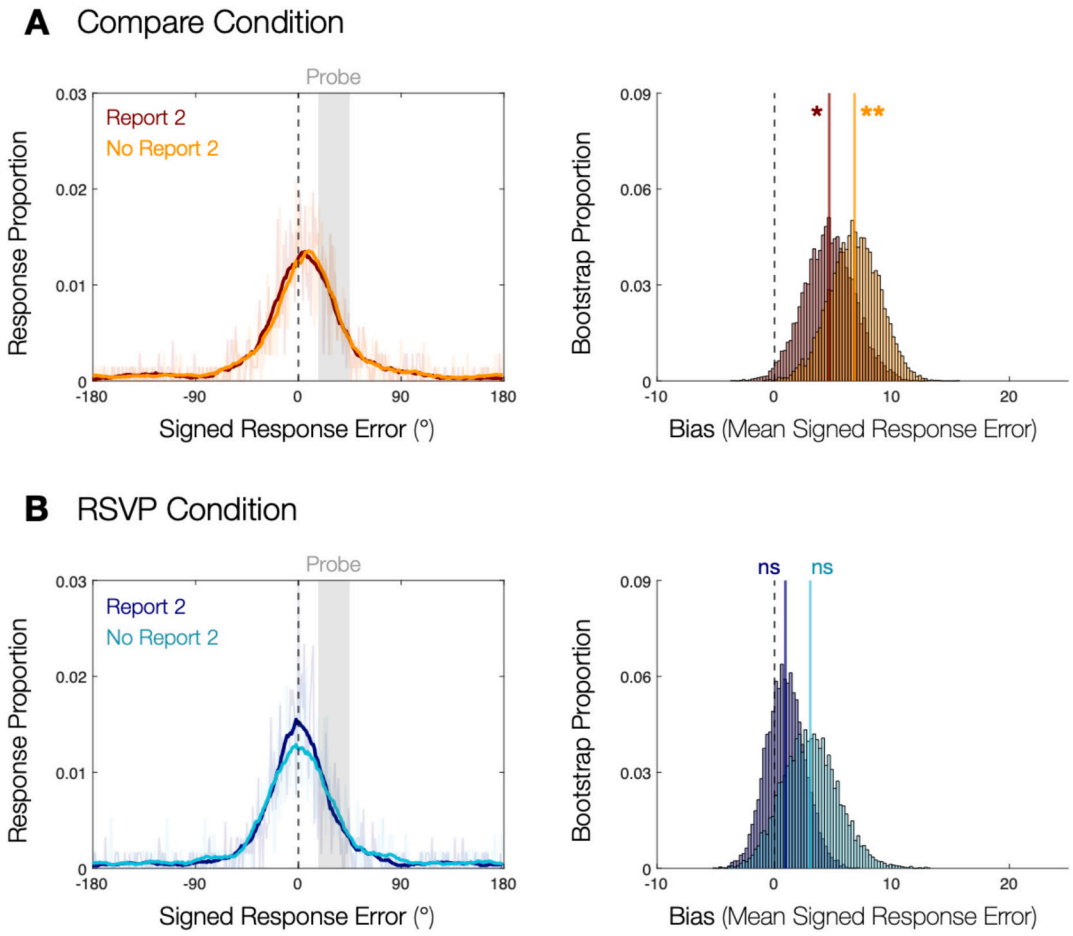


**Fig. 6.** Persistent biases following comparisons, but not RSVP Signed response distributions (left) and bootstrapped bias estimates (*right*) for objects recalled again at the Delayed Test after being reported or not reported in the (A) Compare condition or (B) RSVP condition at the Immediate Test. Signed response distributions: Bolded lines depict the mean response proportion for a given signed response error averaged across a 30° smoothing window centered at the error value. Transparent lines plotted in the background depict the same proportions without smoothing applied. Vertical black dashed lines indicate the location of the zero-centered target across trials. Vertical gray bars depict the sampling window that the probe was sampled from on each trial. Bootstrapped bias estimates: Solid vertical lines depict the mean bias in each condition across bootstrap iterations. * $p < 0.025$, ** $p < 0.001$, *ns* = not significant.

the procedures approved by the Institutional Review Board at xxxx.

We used the same target sample size as Experiment 1 ($n = 40$). Participants were again recruited on a weekly basis until the sample size exceeded this target, resulting in the recruitment of 41 total participants. Data from one participant was excluded for failing to report any memories confidently at the Delayed Test. This resulted in a final sample of 40 participants whose data were subjected to analysis (33 female, 7 male, age range = 18—38 years, mean age = 20.70 years old).

#### 3.1.2. Apparatus and stimuli

Same as Experiments 1 and 2.

#### 3.1.3. Procedure

*3.1.3.1. Encoding task.* Same as Experiments 1 and 2.

*3.1.3.2. Immediate memory test.* Same as Experiment 2, except we replaced the *RSVP Condition* of Experiment 1 with a *Judge condition*. In the *Judge condition*, participants were instructed to decide whether the color of the probe silhouette was "warm" or "cold", which were both defined for the participant prior to starting the task. Warm colors include hues of red, orange, and yellow, which are commonly associated with warmer temperatures, including objects like fire and the Sun, and cold colors include hues of blue, purple, and green, which are commonly associated with colder temperatures, including objects like water and ice. This manipulation required observers to shift their attention towards the color of the probe and perform a cognitive operation, much like a perceptual comparison.

*3.1.3.3. Delayed test.* Same as Experiments 1 and 2.

#### 3.1.4. Analysis

Same as Experiments 1 and 2. Table 5 shows that an overwhelming majority of color reports made with low confidence (67%) or no confidence (99%) at the Immediate Test were once again associated with recognition judgments where the observer reported that they did not remember the color of the cued object. Table 6 shows the counts and proportions of confident color reports at each test. See *Supplemental Materials* for results with all confidence levels included.

### 3.2. Results

As in the first two experiments, we found that observers' reports of the target showed systematic biases towards the features of the probe following comparisons (Fig. 7, $M = 12.82°$, 95% CI [9.19, 16.69°], $p < 0.001$) and categorization judgments (Fig. 7, $M = 10.22°$, 95% CI [6.86, 13.76°], $p < 0.001$). Once more, the magnitude of biases following comparisons was numerically larger than those induced by categorizing the probe color, but the difference was not significant ($M = 2.60°$, 95% CI [−0.95, 6.25°], $p = 0.077$).

However, unlike the first two experiments, the results of Experiment 3 differed when we measured the persistence of the report biases at the Delayed Test. While we replicated the persistent biases reported after comparisons for the third time (**Fig. 8A**, $M = 6.21°$, 95% CI [2.71, 10.50°], $p < 0.001$), we also found that biases reported after categorization judgments persisted (**Fig. 8B**, $M = 6.12°$, 95% CI [1.92, 10.42°], $p = 0.003$) and were nearly identical in magnitude to those following comparisons ($M = 0.98°$, 95% CI [−5.47,5.98°], $p = 0.496$). Both of these persistent biases were comparable to those that were reported in each condition, respectively, a day earlier (compare: $M = -2.37°$, 95% CI [−6.25, 1.02°], $p = 0.094$; judge: $M = -2.12°$, 95% CI -7.45, 3.24°], $p = 0.213$). These results suggest that bias persistence is attributable to high levels of attentional engagement with similar visual inputs, rather than the act of comparison per se.

These persistence effects were preserved in objects that were not reported at the Immediate Test. Even when observers abstained from completing an immediate memory report, biases induced by comparisons (**Fig. 8A**, $M = 7.05°$, 95% CI [3.47, 10.50°], $p < 0.001$) and categorization judgments (**Fig. 8B**, $M = 6.15°$, 95% CI [1.86, 10.19°], $p = 0.002$) still persisted and with comparable magnitude ($M = 0.90°$, 95% CI [−4.43, 6.40°], $p = 0.376$). In both conditions, biases that persisted in the absence of an initial memory report were comparable to those reported at the Immediate Test (compare: $M = -1.54°$, 95% CI [−6.73, 3.33°], $p = 0.279$; judge: $M = -2.09°$, 95% CI [−6.32, 1.62°], $p = 0.153$), and those that persisted following an initial report (compare: $M = 0.83°$, 95% CI [−4.65, 6.04°], $p = 0.374$; judge: $M = 0.03°$, 95% CI [−5.45, 4.78°], $p = 0.475$). When taken together, these findings suggest that the act of performing a single comparison between memories and similar visual inputs is sufficient to produce a lasting distortion, as previously claimed, but that comparisons themselves do not play a mandatory role in such distortion.

**Table 5**
Color confidence binned by recognition at immediate test in experiment 3.

| Confidence | Recognition | Count | Proportion |
|---|---|---|---|
| High | Object & Color | 103.53 (56.70) | 0.82 (0.25) |
| | Object, No Color | 16.50 (24.18) | 0.18 (0.25) |
| | No Object, No Color | 0.38 (0.70) | < 0.01 (0.01) |
| Low | Object & Color | 33.30 (32.92) | 0.33 (0.25) |
| | Object, No Color | 79.08 (55.28) | 0.65 (0.26) |
| | No Object, No Color | 1.28 (2.45) | 0.02 (0.07) |
| None | Object & Color | 1.03 (1.98) | 0.02 (0.03) |
| | Object, No Color | 25.48 (45.84) | 0.33 (0.32) |
| | No Object, No Color | 27.45 (22.96) | 0.66 (0.33) |

Values reported in the table represent the mean counts and proportions of color confidence reports at the Immediate Test binned by recognition judgments with the standard deviation reported in parentheses.

**Table 6**
Trials with high-confidence color memory in experiment 3.

| Test | Perceptual Demand | Report Demand | Count | Proportion |
|---|---|---|---|---|
| Immediate | Judge | Search | 30.25 (13.90) | 0.42 (0.19) |
| | | Report | 29.45 (14.00) | 0.41 (0.19) |
| | Compare | Search | 29.78 (15.54) | 0.41 (0.22) |
| | | Report | 30.93 (15.33) | 0.43 (0.21) |
| Delayed | Judge | Search | 16.23 (12.44) | 0.23 (0.17) |
| | | Report | 16.98 (12.48) | 0.24 (0.17) |
| | Compare | Search | 16.23 (13.30) | 0.23 (0.18) |
| | | Report | 17.00 (13.55) | 0.24 (0.19) |

Values reported in the table represent the mean counts and proportions of high-confidence trials with the standard deviation reported in parentheses. The counts and proportions at the Delayed Test represent target colors that were recalled with high-confidence at both tests.

## 4. General discussion

Comparisons between visual memories and percepts are ubiquitous. While these comparisons play an important functional role in discriminating between familiar and novel stimuli, a sizable body of evidence from applied (Mickes et al., 2025; Wixted, 2022; Wixted et al., 2021; Wixted & Mickes, 2022) and basic scientific studies (Fukuda et al., 2022; Saito, Bae, & Fukuda, 2024; Saito, Duncan, & Fukuda, 2023; Saito, Kolisnyk, & Fukuda, 2023; Teoh et al., 2024) suggests that they can induce lasting changes in memory content. Here, we tested a pair of tacit assumptions made by a mechanistic hypothesis which states that perceptual comparisons are necessary and sufficient for producing persistent change in observers' memory reports.

Across three experiments, we measured the formation and persistence of memory report biases that were induced by perceptual comparisons and similar control tasks. First, we replicated previous work showing that report biases induced by perceptual comparisons persist into subsequent reports made up to 24-h later (Saito, Duncan, & Fukuda, 2023; Teoh et al., 2024) and revealed that this persistence occurs even when observers abstain from making a report immediately after the

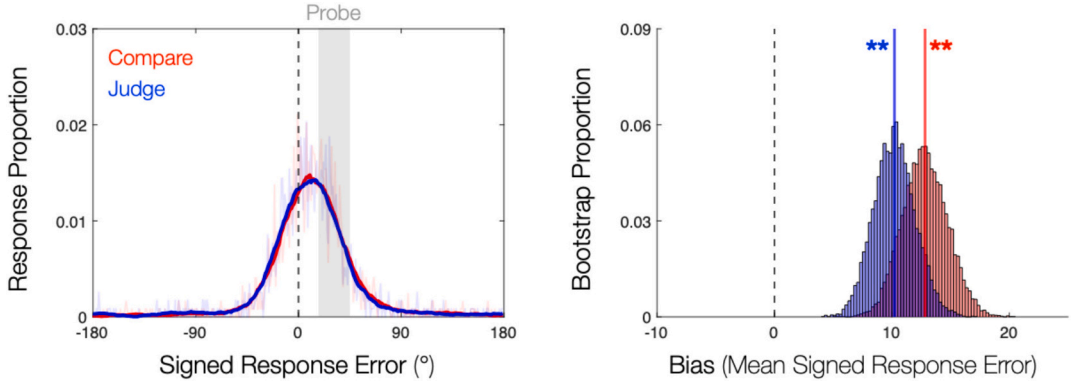


**Fig. 7.** Immediate attractive biases across comparisons and category judgments signed response distributions (left) and bootstrapped bias estimates (right) for objects reported at the Immediate Test. Signed response distributions: Bolded lines depict the mean response proportion for a given signed response error averaged across a 30° smoothing window centered at the error value. Transparent lines plotted in the background depict the same proportions without smoothing applied. The vertical black dashed line indicates the location of the zero-centered target across trials. The vertical gray bar depicts the sampling window that the probe was sampled from on each trial. Bootstrapped bias estimates: Solid vertical lines depict the mean bias in each condition across bootstrap iterations. ** $p < 0.001$.

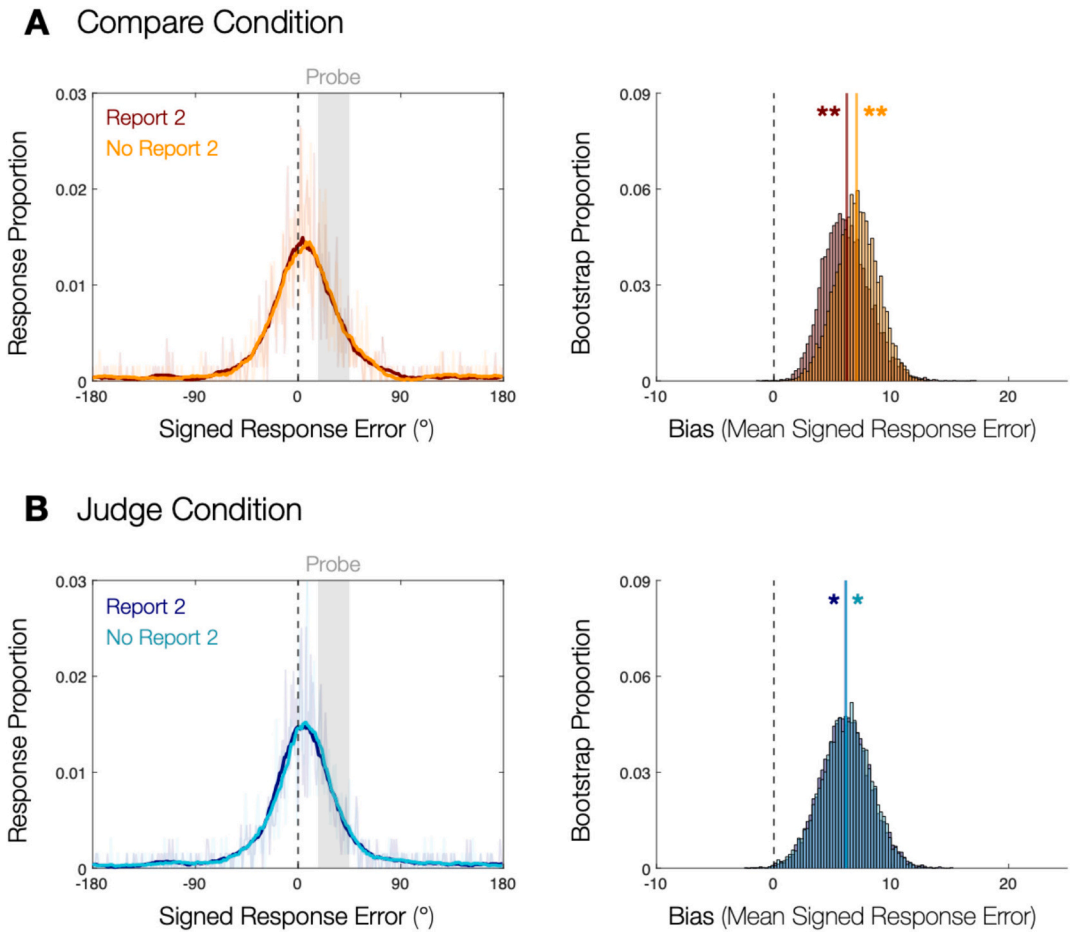


**Fig. 8.** Persistent biases following comparisons and category judgments Signed response distributions (left) and bootstrapped bias estimates (*right*) for objects recalled again at the Delayed Test after being reported or not reported in the (A) Compare condition or (B) Judge condition at the Immediate Test. Signed response distributions: Bolded lines depict the mean response proportion for a given signed response error averaged across a 30° smoothing window centered at the error value. Transparent lines plotted in the background depict the same proportions without smoothing applied. Vertical black dashed lines indicate the location of the zero-centered target across trials. Vertical gray bars depict the sampling window that the probe was sampled from on each trial. Bootstrapped bias estimates: Solid vertical lines depict the mean bias in each condition across bootstrap iterations. * $p < 0.025$, ** $p < 0.001$.

comparison. Second, we showed that the persistence of report biases is not exclusive to performing a comparison but can occur whenever task demands require the observer to attend to new visual features and use them to perform a cognitive operation. When taken together, these findings affirm that performing a single perceptual comparison is indeed sufficient to produce a lasting memory distortion and reveal that this lasting influence is primarily explained by attentional engagement with similar visual inputs rather than the act of comparison per se.

### 4.1. On the role of memory reports

The present study clearly demonstrates that explicit memory reports do not play a necessary role in the persistence of report biases across time. This should not be taken to mean, however, that report processes, such as target re-encoding (Miner et al., 2020; Ovalle Fresa & Rothen, 2019; Sutterer & Awh, 2016; Tozios & Fukuda, 2024) or the engagement of the motor system (Bulatova & Fukuda, 2025; Yebra et al., 2019; Schreiner, Feustel, & Kunde, 2024; Kinder & Buss, 2021), did not play *any* role in the durability of memories. For example, when we re-introduced memory reports that were made with little-to-no confidence to the dataset, we found that systematic report errors induced by weak distraction in Experiment 1 showed some evidence of persistence into the Delayed Test (see *Supplemental Material*). Given that a vast majority of these low-confidence reports were tied to objects that were forgotten (see Table 1), these systematic errors likely reflect re-encoding strategies that were employed to offset the cost of forgetting. For example, when observers failed to successfully recall the original target color, they may have strategically encoded the similar probe into memory and, if prompted, guessed near its color on the wheel and re-encoded this guess. This strategy would not only generate a "distortion" in the initial report but should also increase the likelihood of reporting a similar "distortion" again at the subsequent report. For example, a recent study by Born and Spitzer (2026) showed that strategically re-encoding one's subjective memory report can lead to larger retrieval practice benefits for weak, deprioritized memories than strong, prioritized memories. In this sense, the presence of a guessing strategy with forgotten targets nicely illustrates how typical report processes might influence the persistence of encoded information. However, because the "distortions" that follow from guessing are qualitatively different from true perceptual interference with a remembered item, these errors were treated as a nuisance variable that we sought to minimize by focusing on confident reports.

### 4.2. Report biases reflect both misattribution and memory integration

The present findings also motivate important questions regarding the nature of the biases that were reported. While applied studies might interpret these systematic errors as source misattributions, where observers misreport the features of the non-target probe (Johnson et al., 1993; Wixted et al., 2021; Zaragoza & Lane, 1994), psychophysical studies commonly interpret these errors as bona fide biases in the target that follow from integration with the probe (Dubé, Zhou, Kahana, & Sekuler, 2014; Fukuda et al., 2022; Zhang & Lewis-Peacock, 2025). While these sources of report bias are not mutually-exclusive, they are typically confounded in summary measures like mean signed error because they both produce reports that are offset in the direction of the non-target.

Fortunately, these unique sources of report bias are partially discriminable in observers' distribution of responses: misattributions generate errors that cluster around the non-target and produce a second mode in the distribution, while memory biases generate errors that fall between the target and non-target, which shifts the target mode towards the non-target (see Fig. 4C in Bays et al., 2024 for illustration). As can be seen across all three experiments, the distributions with a significant report bias exhibit a visible shift in the target mode and contain a sizable number of responses at the location of the probe, which suggests that both types of distortions are present. However, because the target and probe were always sampled close together in the feature space, the target and probe modes are highly-overlapping, making it difficult—either by visual inspection or computational mixture modelling (e.g., Huang, 2020; Lively, Robinson, & Benjamin, 2021)—to confidently determine whether any given error was drawn from the target or probe mode without an exceptionally large amount of data. As such, we conclude that misattributions and memory biases were both present in our experiments but we encourage future work to pursue datasets that are adequately powered to precisely estimate the prevalence of each.

### 4.3. How attentional engagement facilitates distortion persistence

What is it about comparisons (and category judgments) that make it more likely for their resulting distortions to persist from one retrieval episode to the next? Here, we used a parametric manipulation of attention to show that biases are more likely to persist when observers must attend to the similar features of a new percept to satisfy a task goal. In this sense, our findings suggest that attentional selection plays a meaningful role in persistence beyond mere perception, but we cannot dissociate the role of selection, per se, from the cognitive operations that follow. That is, we cannot determine whether persistence was explained by the act of selecting the probe color with attention and drawing it into VWM or the subsequent act of elaborating on the probe color by comparing it with an existing sensory representation, as with perceptual comparisons, or comparing it against existing semantic knowledge, as with category judgments. In fact, these processes may never be fully dissociable given that attentional selection exists precisely to facilitate the use of stimulus information to guide ongoing behavior (Fuster, 2004; van Ede & Nobre, 2023). Therefore, we use the term attentional "engagement" to encompass both the selection and usage of the probe representation.

It is also unclear at a process level whether the probe representation persists into LTM independently of the target memory, or if it persists by virtue of its integration with the target memory during initial encoding. According to theories of memory reconsolidation, retrieving a memory from a latent state in LTM back into an active state in VWM destabilizes the representation and makes it available for updating (Hardt, Einarsson, & Nader, 2010; Lee, 2009; Lee, Nader, & Schiller, 2017; Nader & Hardt, 2009; Scully, Napper, & Hupbach, 2017). In the case of visual objects, retrieval is known to reinstate cortical activity that was present at the time of encoding, including in early sensory regions, such as V1, where new visual inputs are processed (Bone & Buchsbaum, 2021; Bosch, Jehee, Fernández, & Doeller, 2014; Naselaris, Olman, Stansbury, Ugurbil, & Gallant, 2015; Vo et al., 2022). Sensory recruitment models propose that using sensory cortices to temporarily buffer mnemonic representations allows them to integrate with new perceptual inputs at a sensory level (Hallenbeck, Sprague, Rahmati, Sreenivasan, & Curtis, 2021; Zhang & Lewis-Peacock, 2025; Kiyonaga & Serences, 2025; Rademaker et al., 2015; Magnussen, Greenlee, Asplund, & Dyrnes, 1991). Indeed, memory representations decoded from visual cortices often exhibit attractive biases towards recent visual inputs that mediate the biases that are reported in behavior (Hallenbeck et al., 2021; Lorenc, Sreenivasan, Nee, Vandenbroucke, & D'Esposito, 2018; Rademaker, Chunharas, & Serences, 2019). Critically, computational models designed to approximate this integration process propose that as attention to new visual inputs increases, so does the strength of their sensory signal, which produces a two-fold effect following integration where memories are biased towards new inputs but also receive a boost in representational strength (Dubé et al., 2014; Fukuda et al., 2022; Zhang & Lewis-Peacock, 2025). These models also tacitly assume that misattributions can emerge from this same underlying integration process when the strength disparity between memory and perception is especially large. Thus, persistence may be a natural consequence of sensory integration, where greater attentional gain in perceptual signals confers a larger boost in memory strength following integration that increases the memory's resistance to forgetting over time.

Another possibility is that new perceptual signals, when encoded into memory, are stored separately from the existing target signal, but the two are linked in some way. Unlike traditional models of reconsolidation, which propose that memory distortions occur by modifying the existing target representation, temporal context models propose that such distortions arise as a result of binding new representations to the same context as the target (Sederberg, Gershman, Polyn, & Norman,

2011; Howard & Kahana, 2002; Klingmüller, Caplan, & Sommer, 2017; see also Sinclair & Barense, 2018). According to these accounts, elaborative processing of the probe during comparisons or category judgments should increase the likelihood that its representation will be bound to the same context as the target and be reactivated again during later retrieval attempts. While these context models have traditionally focused on misattributions as the source of systematic error during subsequent retrieval (e.g., Gershman, Schapiro, Hupbach, & Norman, 2013; Hupbach et al., 2008; Carpenter & Schacter, 2017), their tenets appear broadly compatible with memory biases as well. For example, it may be the case that biases emerge when the target and probe representations are reactivated with similar strength during retrieval, whereas misattributions occur when the probe is reactivated much more strongly than the target. Note that this hypothesized relationship between the relative strength of each representation and the type of error induced is already predicted by computational models of sensory integration. It may be the case that both classes of models are actually describing the same underlying integration process, but one class predicts that integration occurs at the time of perception, while the other predicts that integration occurs at the time of retrieval or report. Thus, distinguishing these accounts along different levels of analysis (i.e., mathematical models, neural activity, behavior) will be key to generating a unified theory of memory distortion across different timescales (see Woodman & Polyn, 2026 for a recent review).

### 4.4. Maladaptive interference or rational integration?

In addition to identifying the locus of memory distortions in the mind, it is also necessary for future work to better characterize their functional significance in human behavior. Some have proposed that memory distortions that arise from perceptual interference represent a shortcoming in observers' ability to shield their memory representations against unwanted contamination (Fukuda et al., 2022; Lorenc et al., 2021; Lorenc & Sreenivasan, 2021; Rademaker et al., 2015; Saito, Duncan, & Fukuda, 2023). This view follows from the fact that distortions reduce the fidelity between memories and their corresponding stimuli, which can be counterproductive in tasks that require exact memories of prior experiences. While this maladaptive perspective is intuitive, its framing conflicts with adaptive perspectives that have been applied to other instances of distortion in visual cognition (Kiyonaga & Serences, 2025; Lieder & Griffiths, 2019). For example, the proactive integration between recent and current perceptual representations, commonly referred to as attractive serial dependence, is widely-regarded as a rational process where observers use their knowledge about the strong temporal dependencies in the visual world to make better inferences about its current state (Cicchini, Anobile, & Burr, 2014; Dong & Atick, 1995; Fischer & Whitney, 2014; Stocker & Simoncelli, 2006; Wei & Stocker, 2015). While integrating perception in this way produces a less veridical representation of the physical world, this action is considered adaptive insofar as it helps to overcome perceptual noise by taking advantage of the mutual information shared between consecutive percepts (Ceylan, Herzog, & Pascucci, 2021; Cicchini, Mikellidou, & Burr, 2018; Kalm & Norris, 2018; van Bergen & Jehee, 2019). Much like the retroactive memory biases we focused on here, these attractive serial dependencies are also shown to be stronger when previous percepts are attended as opposed to ignored (Fischer & Whitney, 2014; Fritsche & de Lange, 2019; Kim, Burr, Cicchini, & Alais, 2020; Rafiei, Hansmann-Roth, Whitney, Kristjánsson, & Chetverikov, 2021) and can occur even when previous percepts are not reported (Fornaciai & Park, 2018; Manassi, Liberman, Kosovicheva, Zhang, & Whitney, 2018). Given these clear parallels, we speculate that memory distortions induced by new visual inputs may also reflect the rational integration between memories and perceptual inputs to optimize reports in the face of memory noise. If so, these distortions would fall within a larger body of memory "errors" that are considered adaptive, despite detracting from performance in certain task contexts (Schacter, 2012; Schacter, Guerin, & St. Jacques, 2011).

## CRediT authorship contribution statement

**Joseph M. Saito:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Keisuke Fukuda:** Writing – review & editing, Supervision, Software, Resources, Funding acquisition, Conceptualization.

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## Declaration of competing interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2026.106604.

## Data availability

The data are posted publicly online at https://osf.io/28e4w/

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