# How Bizarre: Does the color bizarreness effect extend to long-term memory?

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**Abstract**

A well-known phenomenon of memory is the bizarreness effect which refers to enhanced memory for objects that are highly incongruent with people's prior expectations. This phenomenon was recently extended into the visual domain of color, showing enhanced memory for objects paired with expectation-incongruent (or bizarre) colors. Here, we explore whether the enhanced memory for bizarre/expectation-incongruent objects extends to memory for the object-color binding and whether this binding is well-preserved long-term. Using a 4-Alternative forced choice task, we assessed memory for object colors as a function of expectation-congruency on one day and 3 days later. Our results revealed no significant difference in recognition memory for bizarre colors compared to expectation-congruent colors, and no enhanced memory for bizarre colors in long-term memory. These findings highlight conditions where the enhanced memory for expectation-incongruent information is limited, providing an interesting challenge to current mechanistic accounts of memory for expectation-related information.

**Keywords:** Bizarreness effect, long-term memory, prior expectations, congruency, color

## Introduction

A long-standing question of memory that has garnered recent attention is the role of expectation-congruency in the encoding and retrieval of information from memory. Recent evidence suggests that expectations play an important role in shaping memory, particularly in cases where those expectations are incongruent with to-be-remembered information (Chang & Sanfay, 2009; Foster & Keane, 2019; Greve et al., 2017; Morita & Kambara, 2022). It was previously argued that when an item is incongruent with an established expectation, it triggers a prediction error signaling that learning can take place (expectations need to be updated or revised). As such, an individual might prioritize the encoding and storage of that information in memory, such that they can recall it quite well later on (Cognitive Conflict - Verguts & Notebaert, 2008). This misalignment of expectations and to-be-remembered information is doubly important in development, where previous research has shown that children better remember novel information when it is associated with an expectation-incongruent event (i.e., an object travels *through* a wall) relative to when it is associated with an expectation-congruent event (i.e., an object *collides* with a wall; Stahl & Feigenson, 2015; 2017). The finding of better memory for objects that are incongruent with prior expectations is the basis for the well-known bizarreness effect which refers to the behavioral pattern of enhanced memory for items that are perceptually and/or semantically atypical compared to typical items (McDaniel et al., 1995).

Much of the classic literature on the bizarreness effect in memory has explored this phenomenon with verbal stimuli (Cornoldi et al., 1988; McDaniel et al., 1995; Wollen & Cox 1981), visually distorted object shapes (Marchal & Nicolas, 2000; Nicolas & Marchal, 1988), and bizarre scenarios (Wollen et al., 1972). More recent research has sought to extend the bizarreness effect into the visual domain of color (e.g., Morita & Kambara, 2022). In this study, adult participants were shown objects paired with different colors and were tested on their free recall of the objects. Importantly, they found that participants displayed better memory for objects presented in bizarre/expectation-incongruent colors (e.g., Blue banana) compared to objects presented in expectation-congruent colors (e.g. Yellow banana). This finding suggests that the bizarreness effect extends to the domain of color, such that the bizarreness or the unexpectedness of an object-color pair impacts how well the object itself is remembered. This finding is consistent with earlier theories of memory for expectation-incongruent events. For example, the distinctiveness account of memory suggests that expectation-incongruent information tends to stand out due to its uniqueness, resulting in prioritized and more elaboration at encoding. This elaboration, in turn, facilitates easier retrieval of these items compared to expectation-congruent items (McDaniel & Geraci, 2006).

The extension of the bizarreness effect into the domain of color highlights the important role that expectations play in episodic memory and provides a watershed moment to further probe the impact of expectation-incongruency and explore the underlying representational structure of bizarre events. More specifically, this work facilitates the opportunity to test two follow-up questions of memory for expectation-incongruent objects: First, while Morita & Kambara (2022) found that adults have better memory for objects presented in bizarre/expectation-incongruent colors, it remains unclear whether that enhanced memory also extends to the colors themselves. While intuitively it might seem that enhanced memory for the object extends to the feature, recent evidence lobbies for independent storage of objects and features, suggesting that in some cases, objects and features are not always represented as bound entities in memory (Utochkin & Brady, 2020). As such, the representational structure of bizarre objects and their features in memory remains unclear.

Second, while Morita & Kambara (2022) found better memory for objects paired with bizarre/expectation-incongruent colors shortly after study, it remains to be seen if those objects (and potentially object-color pairings) will be remembered well into long-term memory (e.g., three days after initial encoding). While it's likely that expectation-incongruent objects are sufficiently encoded and initially easily retrieved, it's possible that this information will be lost



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over time due to memory consolidation processes that prioritize expectation-congruent items and regularizes expectation-incongruent items to better fit with existing expectation schemes in memory (Van Kesteren et al, 2012).

The current study aims to build on previous work by examining whether the enhanced memory for expectation-incongruent objects extends to memory for object features (e.g., color) and whether that enhancement is preserved in long-term memory. This would extend the findings of Morita & Kambara (2022) by 1) exploring how fine-grain memory representations are for expectation-incongruent and expectation-congruent items and 2) how well expectation-related information is preserved and retrieved long-term. This line of work has important implications for furthering our understanding of the role congruency of expectations plays in memory, particularly for incongruent events, when it comes to real world scenarios such as instances of learning.

We hypothesize that if we find enhanced memory for objects paired with bizarre colors, that enhanced memory will extend to object-color binding, such that the bizarre color-object pairs will be better recognized compared to expectation-congruent object-color pairs. We further hypothesize, however, that any enhancement in memory for bizarre/expectation-incongruent object-color pairs will not extend to long-term memory due to consolidation processes that favor expectation-congruent information (Van Kesteren et al, 2012).

## Overview of Study

The purpose of the current study was to further probe the color bizarreness effect by examining whether expectation congruency enhances memory for bizarre features (i.e., color) and whether bizarre objects and features are well remembered over time. To explore this question, we first examined adults' memory for object-color binding by using a recognition task where adults had to recognize the object-color pair they previously studied. We then examined adults' memory for objects by using a self-paced free-recall task, where adults typed as many studied objects as they could remember[1]. Finally, we further validated people's expectations for the studied object-color pairings using a prior knowledge task that confirms whether participants know the objects and their prototypical color associations.

## Method

### Participants

Forty-five undergraduate students at Rutgers University-Newark participated in this study for course credit. All participants provided self-reports of normal or corrected to normal vision and color vision. All participants were run online via the Zoom video conference software (Zoom Video Communications Inc., 2016) and gave written informed consent prior to the start of the study. Previous research has found a medium sized effect of incongruency on memory (d=.57; Greve, et al, 2017) when testing 20 subjects. Based on this medium effect size and our current design, we planned to recruit a total of 30 non-excluded adult participants to test for the main effect of incongruency on memory. In a pilot study, we observed a dropout rate of 31% —the number of participants that did not return for testing on day 3. To account for the expected dropout rate, we added an additional 9 participants to our total desired number of participants. Four participants were dropped due to technological and experimental error. Two participants were dropped due to failure to complete the study (i.e., missed testing session). The final sample consisted of 39 participants which provided 95% power to detect a medium incongruency effect. This study was approved by the Rutgers University-Newark Institutional Review Board.

### Materials

The stimuli consisted of 27 objects (10 natural objects, 8 man-made objects, and 9 popular cartoon characters). These objects were a subset of stimuli used in a previous pilot study exploring college aged adults' familiarity with and color knowledge of different objects. They were chosen based on the degree to which they had a priori color associations. Object-color pairs were equally divided into three within - subject conditions such that 9 objects were presented with expectation-congruent colors (e.g., yellow banana), expectation-incongruent colors (e.g., blue stop sign), or no expectation (filler) color (T-shirts, which could be any color).

The colors of each object spanned 7 basic color categories (Red, Orange, Yellow, Green, Blue, Purple, and Pink) and were learned from the same pilot study mentioned above. In the pilot study, adults were presented with different objects, one at a time, and answered two questions: "Do you recognize this object?" and "What color do you expect this object to be?". They identified the color of each object using a color wheel. From this pilot study, we determined the mean expectation-congruent color of each object (see Persaud et al, 2014; 2021 for a similar approach). We used the a priori color expectations learned in the pilot study to form the expectation-congruent and expectation-incongruent object-color pairings[2].

The three distractors used in the 4-alternative forced-choice (AFC) recognition task were created using the same a priori color expectations learned from the pilot study. One of the

[1] While previous research suggests that expectation congruence might differentially impact recall and recognition processes (e.g., Sherman & Frost, 2000; van Kesteren et al., 2012), our main dependent measure in this work was object-color recognition.

[2] The expectation-congruent object-color pairings fell within the expected color category but deviated away from the mean expected color of the object. This ensured that the accuracy or performance in the expectation-congruent condition would not be solely based on adults' strategic guessing using a priori expected color. In fact, the expected color was always an option in the 4-AFC design, such that guessing with the expected color would result in an incorrect response.

distractors always fell within the same color category as the target, while the remaining two distractors came from a non-neighboring color category. For instance, if the target color was yellow (e.g., for banana) and blue was the distractor, the within color category distractor would be average expected yellow, and the two blue distractors would be either average expected blue (e.g., expected color for the blue object genie) or 2 standard deviations away from the average. For the incongruent condition (e.g., blue banana), the out of category lures always came from the expected color category for the object (yellow colors).

In the current study, object-color pairs varied only in hue value—saturation and luminance were held constant across all objects at 100 and 50 units, respectively. HSL values were converted into RGB values to be presented within the objects in Matlab via a Matlab color conversion algorithm (Bychkovsky, 2020 – hsl2rgb and rgb2hsl conversion (https:// www.mathworks.com/ matlabcentral).

All stimuli were presented virtually via the Zoom videoconferencing software (Zoom Video Communications Inc., 2016). Using Zoom's screen share feature, participants studied object-color pairs created and administered in Matlab. Using Zoom's remote-control feature, participants indicated their recognition and recall choices by controlling the shared screen and typing the number that corresponded with each of the remembered object-color pairs (see Figure 1).

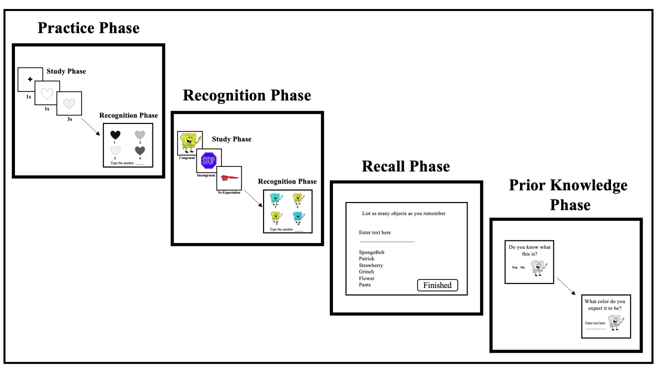


*Figure 1.* A schematic representation of the procedure used in this current study.

## Procedure

The experimental task was carried out in four phases: a practice phase, a recognition phase, a recall phase, and a prior knowledge assessment phase. Participants completed two online testing sessions, three days apart. In this within-subjects design, each participant saw 27 object-color pairs (9 expectation-congruent, 9 expectation-incongruent, and 9 objects not associated with strong color expectations). The object-color pairings were counterbalanced such that half the participants studied the expectation-related objects paired with a congruent color and the other half studied those objects paired with incongruent colors. Objects with no strong color expectation (e.g., t-shirt) were paired with a filler color. Participants made color recognition judgements for all studied pairings and recall judgements for all studied objects.

**Practice Phase** On day 1, participants were told that they would first study a series of object-color pairs and then be tested on their memory for the object colors. Before beginning the task, participants completed two practice trials where they studied and recalled the color of two-grey scale shapes— a heart (dark grey) and then a star (light grey). Each shape was preceded by a 1s fixation cross, followed by a line drawing of the shape for 1s and then a filled-in greyscale shape for 2s, for a total study time of 3s. Participants were then presented with a 4-alternative forced-choice question for each studied object. Participants identified which color went with each shape (e.g., dark-grey heart) by typing the number that corresponded with their answer choice in a text box located at the bottom of their screen (see Figure 1). All participants accurately identified the studied colors from the practice trials, indicating an understanding of the experimental task.

**Recognition Phase** Immediately following the practice trials, participants moved on to the main experimental task. In the main experimental task, participants studied and recognized 27 unique object-color pairs that fell into the three color-expectation conditions (e.g., congruent, bizarre/incongruent, and no expectation). Identical to the practice trials, each object-color pair was preceded by a 1s fixation cross and then shown as a line drawing for 1s and finally, as a filled-in object for 2s, for a total study time of 3s. Participants studied each object-color pair one at a time in a randomized order. At test, participants made color recognition judgments for all studied object-color pairings and recall judgments for all studied objects, in that respective order. In a 4-AFC design, participants identified studied object-color pairs by typing in the number that corresponded with their answer choice in a text box located at the bottom right of the screen (see Figure 1).

**Recall Phase** Next, in a free recall task, participants were asked to type as many object labels as they could remember. Responses were typed into a text box presented at the top-center of the screen. Once entered, typed responses were shown below the text box and remained visible until participants were satisfied that they recalled all the objects they could remember. Responses were self-paced.

**Prior Knowledge Assessment** After the free recall task, participants completed a prior knowledge assessment in which they were shown the line-drawings of each of the 27-studied objects again, one at a time, and were asked two questions: "Do you know what this is?" (yes or no) and "What color do you expect this object to be?". Participants indicated their expected colors by typing the color label into a text box located to the center left of the screen (see Figure 1). All responses were self-paced.

Three days later, participants returned to complete the same memory tasks again. To control for potential influences of recognition on recall performance, on day 3 we reversed the presentation order of the memory tasks, such that participants completed the free-recall task first and the object recognition task second.

## Results

Prior to the analysis, we implemented pre-registered exclusion criteria (http://aspredicted.org/). Given that the goal of the study was to assess the impact of color expectation-congruency on long-term memory, responses to objects that were unfamiliar to participants were excluded from all analyses. Following our pre-registered exclusion criteria, we removed responses where participants indicated that they did not know what the object was (~.02%).

To analyze memory performance, we first calculated recognition accuracy for each participant as the number of correctly identified color-object pairs divided by the total number of objects studied. Similarly, recall accuracy was calculated as the number of correctly named objects divided by the total number of objects. To assess whether recognition and recall accuracy differed as a function of congruency condition (i.e., expectation-congruent, expectation-incongruent, and no expectation) and testing day, we conducted two 2 by 3 repeated measures ANOVAs, followed by Bayesian post hoc comparisons. All analyses were conducted using JASP 0.17 (JASP Team, 2018) and R Statistical Software (v4.1.2; R Core Team 2021).

### Recognition Results

A two-way repeated measures ANOVA revealed a statistically significant main effect of testing day $F(1, 38)= 15.45$, $p<.001$, such that there was a significant decrease in recognition accuracy between day 1 and day 3 but no main effect of color condition $F(2, 76)=2.34$, $p=.103$ (see Figure 2). There was also a statistically significant interaction between color condition and testing day $F(2, 76)=3.24$, $p=.045$. Post hoc analyses revealed a significant decrease in recognition accuracy for no expectation color-object pairs between day 1 ($M= .51$, $SD=.17$) and day 3 ($M=.37$, $SD=.20$), $t(38)=4.47$, $p<.001$; Bonferroni corrected $\alpha = .017$, BF 10=341.85; very strong evidence for the alternative hypothesis. Additionally, post hoc analyses revealed a significant decrease in recognition for expectation-incongruent object-color pairs between day 1 ($M=.53$, $SD= .20$) and day 3 ($M=.42$, $SD=.23$), $t(38)=3.03$, $p=.004$; Bonferroni corrected $\alpha = .017$, BF 10=8.36; moderate evidence for the alternative hypothesis. There was no statistically significant difference between the recognition of expectation-congruent object-color pairs on day 1 ($M=.52$, $SD=.18$) and day 3 ($M=.49$, $SD=.17$), $t(38)=.96$, $p=.343$, BF 10=.265; weak evidence for the null.

### Recall Results

A two-way repeated measures ANOVA revealed no statistically significant main effect of testing day $F(1, 38)= 2.93$, $p=.10$ or color condition $F(2, 76)= 1.38$, $p=.26$ on recall accuracy of objects (see Figure 3). Additionally, there was no statistically significant interaction between the effects of color condition and testing day $F(2, 76)= 2.35$ $p=.102$. Taken together, these findings suggest that recall performance on day 1 and day 3 did not differ significantly by color condition.

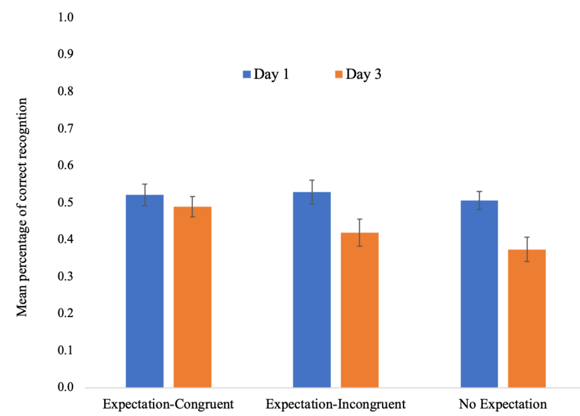


*Figure 2.* Mean percentage of correct recognition of expectation-congruent, expectation-incongruent and no expectation object color pairs on day 1 and day 3. The error bars on this figure represent standard error.

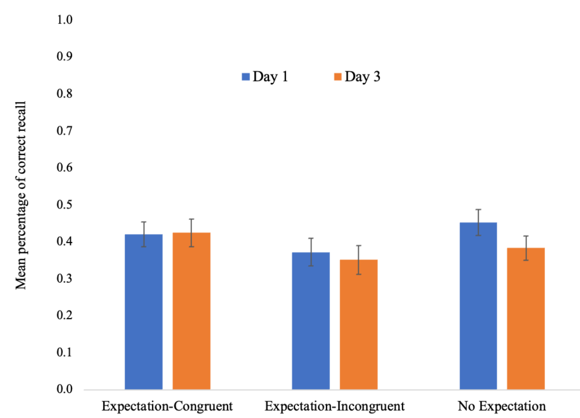


*Figure 3.* Mean percentage of correct recall of expectation-congruent, expectation-incongruent and no expectation object color pairs on day 1 and day 3. The error bars on this figure represent standard error.

### Exploratory Analysis

We conducted an additional exploratory analysis to evaluate how expectation congruence shapes the kinds of errors participants make. We compared the proportion of incorrect within-category lure responses in the congruent and incongruent conditions on day 1 and day 3. A paired samples t-test revealed that there was a significant difference in the proportion of within-category lure responses in the congruent ($M=.73$, $SD=.29$) condition compared to the incongruent

(*M*=.53, *SD*=.28) condition, $t(38)=3.8503$, $p=.0004$ on day 1. Similarly, there was a significant difference in the proportion of within-category lures responses between the congruent (*M*=.68, *SD*=.29) and incongruent (*M*=.37, *SD*=.20) conditions, $t(38)=4.6168$, $p<.001$ on day 3. There are two potential explanations for this finding. First, it's possible that in the congruent condition adults have better memory for the overall color category they studied, such that when they miss the target color, they still choose a color within the correct color category. Alternatively, it could be the case that in the congruent condition, adults pick the within-category lure more often because they are guessing with prior knowledge of the expected color. Interestingly, it does not appear that overall, participants were using a strategy of guessing with the prior expected color of the objects. If this were the case, we might expect no significant difference between that amount of within-category lure responses in the congruent condition and the out of category expected color lure in the incongruent condition. These two options are instances of guessing with the expected object color. Instead, we found a significant difference in the amount of within-category lure responses (*M*=.73, *SD*=.29) and out of category expected color lure responses (*M*=.28, *SD*=.22) between the congruent and incongruent conditions, $t(38)=6.91$, $p<.001$. The lack of overall guessing with the prior might potentially suggest that the within-category choices in the congruent condition are a function of some memory of the presented color and not simply guessing with prior expectations. Future research is needed to explore this point.

## Discussion

In this study, we sought to investigate the color bizarreness effect in long-term memory. Previous research has found better memory for objects that were paired with bizarre colors (e.g., blue bananas) compared to objects that were paired with expectation-congruent colors (e.g., yellow bananas - Morita & Kambara, 2022). This work argued that the bizarreness effect is attributed to a process of elaboration, such that expectation-incongruent information is unique and thus prioritized for processing during encoding, and this additional processing leads to a mnemonic advantage at retrieval (McDaniel & Geraci, 2006).

Here we asked whether this potential enhancement extends to memory for the bizarre feature of the object (i.e., blue + banana) and whether that enhanced memory is preserved over time. Using a 4-AFC recognition task and a free recall task, we tested memory for expectation-congruent, bizarre, and no-expectation object-color pairs immediately following study and then again three days later. For recognition of the color, we found no significant difference in accuracy across color conditions on day 1 of testing, suggesting that all objects, regardless of condition, were equally well encoded and initially retrieved. Interestingly, however, we did find a significant difference in memory across days, such that recognition accuracy in the no-expectation condition and in the expectation-incongruent condition decreased between the first and second testing sessions. Importantly, this decrease in accuracy was not observed in the expectation-congruent condition. For recall of the object, across both study sessions, we found no significant differences in memory for the objects as a function of congruency. These findings suggest that while all items were initially well remembered, only expectation-congruent object-color binding was well preserved in long-term memory. Taken together, we found little support for the extension of the bizarreness effect to object-color binding and in long-term memory.

Instead, these results appear to support an alternative theory of expectation-congruency and memory known as schema-linked interactions between medial prefrontal and medial temporal (SLIMM- Van Kesteren et al., 2012). According to the SLIMM account, expectation-incongruent and expectation-congruent object-color pairs can be equally remembered due to different underlying mechanisms[3] that support the memory of both kinds of expectation-related information, but better than no expectation object-color pairs (Greve et al., 2018; Van Kesteren 2012). In other words, the relationship between expectation congruency and memory can be conceptualized as a U-shaped relationship were highly expectation-congruent and expectation-incongruent information are equally remembered and items that fall in between or have weak expectation-relationships are remembered less well (they fall in the middle of the U-shaped curve- Van Kesteren et al., 2012). While the SLIMM account might explain the lack of difference between expectation-congruent and bizarre objects, it does not explain the comparable performance in the no-expectation condition relative to the expectation-congruent and expectation-incongruent conditions. This suggests that further research and theory is necessary to illuminate the relationship between expectation congruency and memory.

There are several possibilities for why our results deviate from those of the original color bizarreness paper. First, in the original task, only strongly expectation-congruent and expectation-incongruent or bizarre object-color pairs were shown without including the no-expectation condition. It is possible that the inclusion of the no-expectation condition in our task hampered the strength of the bizarreness of the expectation-incongruent object colors, such that the bizarre objects were not prioritized or further elaborated on compared to all other objects in memory.

Second, and relatedly, the original task also varied the distribution of expectation-incongruent and expectation-congruent objects (i.e., 50/50% vs. 75/25% expectation-

[3] According to the SLIMM model, expectation-incongruent information is remembered well because the comparison of the expectation-incongruent information and the schema produces a prediction error which triggers the hippocampus to encode the incongruent information, and irrelevant contextual details (van Kesteren et. al, 2012). In contrast, expectation-congruent information is remembered well because it is rapidly processed and encoded directly into the medial prefrontal cortex (independent of the hippocampus).

incongruent) and observed a stronger bizarreness effect when there were more expectation-congruent relative to expectation-incongruent object-color pairs. This finding might suggest that the color bizarreness effect is not solely a function of the relationship between to-be-remembered information and prior expectations but is also contingent upon other contextual information in the study event, such as the number of items that are either expectation-congruent or expectation-incongruent with expectations. As such, it is unclear how the reduced bizarreness effect due to the change in the distribution of study items is explained by current theories of expectation-incongruency in memory.

It is also unclear what the tradeoffs are between expectations and other information (like the number of congruent and incongruent studied items) in terms of the degree to which they impact memory performance. Current theoretical accounts might need updating to accommodate this tradeoff. For instance, according to the SLIMM model expectation-incongruent information is better remembered because it triggers a prediction error and all information, including contextually irrelevant information, should be remembered well. Specifically, this theory proposes that memory for expectation-incongruent information is a consequence of the direct comparison between the expectation-incongruent information and an existing expectation. However, it is not clear how the SLIMM framework would account for the difference in encoding, storage, and retrieval of incongruent information as a function of the distribution of incongruent items within the study set.

Taken together, our results call into question the mechanisms that underlie memory for expectation-incongruent or bizarre information and suggest that further research is needed to tease apart relevant contextual features that impact the influence of expectation-congruency on memory.

### Limitations

It's worth noting a potential limitation of this current study. Overall, we observed a drop-off in the accuracy for recognition of both the no expectation and bizarre object color pairings which may be a consequence of poor consolidation of that information in long-term memory (Van Kesteren et al., 2012). However, we do acknowledge that any strong interpretation of the drop-off in accuracy across testing sessions for the expectation-incongruent or bizarre object color pairings should be tempered. Further, we reversed the presentation order of the recognition and recall tasks on day 3 to prevent participants from restudying the objects during the recognition test, which could then be used to inform recall of the objects during the recall test. This change in task presentation order limits our ability to make strong claims about any differences between day 1 and day 3 performance solely due to the passage of time and/or any relevant consolidation mechanisms. Critically, we do not find any statistically significant differences in recall performance on day 1 and day 3 which suggests that the order of task presentation did not strongly impact performance. Nevertheless, our overall results fail to find support for the color bizarreness effect, and no extension of this effect to object-feature binding and long-term memory.

## Conclusion

In general, this work highlights the importance of understanding how expectations influence memory and further emphasizes the point that memory doesn't happen in a vacuum but is instead shaped by an array of factors. This work opens up additional and interesting lines of research regarding episodic memory for color. Understanding the role of expectations in memory, particularly for incongruent events has important implications for memory in real world scenarios such as learning and eyewitness contexts.

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