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The Interplay of Long-Term Memory and Working Memory: When Does Object-Color Prior Knowledge Affect Color Visual Working Memory?

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Elaboration enriches newly encoded information by connecting it to prior knowledge. Here, we tested if prior knowledge about object-color associations improves visual working memory (VWM) for colors. A sequence of four colored objects was presented in four screen locations for a continuous color reproduction test. Object-color associations were either congruent with prior knowledge (e.g., red tomato) or incongruent (e.g., blue tomato). In Experiments 1 and 2, congruency had no effect on memory irrespective of memoranda format (images or words), encoding time (1,500 vs. 4,500 ms), and an instruction to elaborate. In Experiment 3, the object was also tested with a three-alternative forced-choice before or after probing color memory. We also included neutral objects (no color association) and abstract shapes and tested VWM and episodic memory. Congruent items were remembered better than in all other conditions, which did not systematically differ. In Experiment 4, we assessed the congruency effect when only color or both color and object were tested. Congruent objects were remembered better only when both features were tested. Hence, prior knowledge boosts VWM only when this knowledge is relevant at test. Our results suggest that retrieval manipulations can be critical for promoting the use of long-term memory knowledge.

Public Significance Statement

A long-standing question is how we can leverage long-term memory knowledge to bypass the capacity limitations of working memory. Working memory keeps a small amount of information accessible to guide our thoughts and actions. Elaboration is a memory strategy that capitalizes on prior knowledge to boost the retention of new memories. Here, we tested if prior knowledge about object-color associations can enhance retention of colors in visual working memory. When only color was test relevant, providing object-color associations at encoding did not substantially boost memory irrespective of how prior knowledge was activated (images or words), the amount of study time, and a direct instruction to elaborate. When object and color were test relevant, an elaborative benefit was observed. Our findings start to map the conditions that promote the exchange of information between working memory and long-term memory: For elaboration to alleviate memory limitations, associations need to be activated at retrieval.

Keywords: elaboration, visual working memory, visual long-term memory, mixture modeling, delayed estimation tasks

Supplemental materials: https://doi.org/10.1037/xhp0001071.supp

How do we remember our visual surroundings? If we close our eyes, we may get surprised about the scarcity of details we remember regarding the scene that was just before us. Our limited ability to keep visual details in mind is due to the constraints on

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the capacity of visual working memory. Working memory can hold, on average, approximately 3–4 visual items with sufficiently good precision to guide our thoughts and actions (Fukuda et al., 2010; Luck & Vogel, 1997). This capacity, however, is more limited for information that lacks semantics, for instance simple visual features, than for information that has rich semantics, as is the case for complex objects (Brady & Störmer, 2021; Brady et al., 2016). This indicates that prior knowledge may help retention in visual working memory. Here, we examined whether individuals could leverage prior knowledge to boost maintenance of simple features in visual working memory.

The Effects of Prior Knowledge and Elaboration

Studies on the retention of episodic events in long-term memory have indicated that individuals benefit from the use of so-called elaboration strategies: the strategic use of prior knowledge to enrich the representation of new, to-be-retained information (Bartsch & Oberauer, 2021; Bartsch et al., 2019, 2018; Craik & Tulving, 1975; Kerr & Winograd, 1982; Lyman & McDaniel, 1990; Xiaofeng et al., 2016). For example, participants could be instructed to create mental interactive images or links between different pieces of information through imagery (Willoughby et al., 1997) or by elaborative interrogation, in which people are encouraged to connect novel information to previous knowledge (Willoughby et al., 1997; Xiaofeng et al., 2016).

Although the benefits of elaboration have been consistently observed in long-term memory, fewer studies have focused on the effect of elaboration in working memory with more variable results. Studies showed that in working memory tasks, individuals report using elaboration in about one third of the trials, and self-reported elaboration was associated with better recall (Bailey et al., 2011; Dunlosky & Kane, 2007). When elaboration is manipulated experimentally, though, the picture is less clear. For example, Loaiza et al. (2011) studied the effect of different levels of processing (shallow vs. deep) during verbal tasks requiring immediate and delayed recall. Participants recalled more words in the immediate than in the delayed test and more words from the deep than the shallow condition. Hence, this study pointed to a benefit of elaboration in both verbal working memory and long-term memory, but it was unclear whether this benefit was larger for the latter. Subsequent studies, however, failed to observe an effect of the levels of processing in working memory (Jonker & MacLeod, 2015; Loaiza & Camos, 2016).

Other studies have manipulated elaboration by instructing participants to apply this process to the memoranda. Bartsch et al. (2019, 2018) showed that instructed elaboration helped long-term memory for words, but not the immediate recognition of these words from working memory. Similar findings were obtained by Bartsch and Oberauer (2021) with the instruction to use sentences and imagery as elaboration strategies.

The studies reviewed above focused mostly on the learning of verbal information, especially words, over the short and long term, in which the depth of processing can be increased through the use of orthographic, phonological, and semantic decisions (Craik & Tulving, 1975). Overall, in verbal working memory tasks, benefits of experimentally induced elaborative strategies were usually not found. It is unknown whether the same is true for other domains. For example, visual information may also benefit from processes that support elaboration, but this question has not been the focus of research.

Elaboration of Visual Information: Object-Color Associations

How could we use elaboration to help visual working memory? There is some evidence that some objects have strong ties to colors. For example, color-word associates are words that have "strong perceptual and experiential ties to colors (e.g., ocean and blue, yolk and yellow, frog and green, blood and red, etc.)" (Cortese et al., 2019, p. 924). Lorentz et al. (2016) used a Stroop task to assess whether color word associates are processed to the level of meaning and activate color concepts. The results of four experiments showed that congruent associations between color (e.g., red) and color associates (e.g., blood) produced faster naming responses. Naor-Raz et al. (2003) also used a Stroop task to assess whether presenting color associates either in pictorial or verbal format facilitates color naming when these are presented in their congruent versus incongruent color. Naming responses were faster for congruent pictures compared to incongruent ones, but the effect was reversed for words, with naming times being longer for congruent than incongruent trials, which is the opposite of what was observed by Lorentz et al. (2016). Results of Cortese et al. (2019) also showed that words associated with colors were better recalled when presented with a congruent color than with an incongruent one. Hence, there is some evidence that object concepts may be linked to colors creating interference with ongoing perceptual and memory tasks. Therefore, object-color associates seem like a good candidate to manipulate elaboration of colors.

The Present Study

The main purpose of the present study was to investigate whether visual working memory performance in a delayed estimation task can be improved by conditions that facilitate elaboration. We designed four experiments that examined whether prior knowledge of object-color associations could improve visual working memory. The main task was to memorize the colors of four words (Experiment 1) or images (Experiments 1, 2, 3, and 4) presented across four screen locations. Across different trials, the words or images were presented either in colors that we normally associate with them—"yellow sun"—or with an incongruent color—"purple sun"—creating congruent and incongruent conditions, respectively. We also examined color memory in two baseline conditions: neutral objects (concrete objects with no specific color association, e.g., a book) and abstract images (novel shapes; Experiments 3 and 4). In all studies, participants recalled the colors of all items using a color wheel, and the probed item was cued by the position in which the object appeared.

Our main hypothesis was that presenting a color with a congruent object at encoding would allow participants to use prior knowledge about the object to facilitate the storage of the relevant feature (i.e., the color) in visual working memory. If elaboration helps visual working memory, then color reproduction will be more accurate when participants studied this feature in a congruent than incongruent, neutral, or abstract condition.

In addition to manipulating the object-color congruency, across our four experiments, we assessed whether other manipulations implemented at encoding (Experiments 1 and 2) and at retrieval (Experiments 3 and 4) could facilitate the use of elaboration. In Experiment 1, we assessed the role of the memoranda format (words vs. images) with the aim to address the question of how to best activate prior knowledge. In Experiment 2, we assessed the role of encoding time, blocking the congruency conditions, and providing a direct elaboration instruction. This allowed us to test if elaboration could boost memory when more time to implement elaboration is provided, when the demand of use of the strategy is reduced (by keeping it consistent across a block of trials), and by directly instructing its use. None of these manipulations produced a congruency effect. In Experiment 3, we manipulated retrieval requirements by probing memory for both the color and object. We also assessed for a congruency effect both in working memory and episodic long-term memory and additionally included further baseline conditions, that is, neutral and abstract trials. Memory was better for congruent items compared to all other conditions and in both memory tests (i.e., working memory and episodic memory). Given that one of the main changes between Experiments 1 and 2 (no congruency effect) versus 3 (congruency benefit) was the inclusion of the object test, in Experiment 4 we compared the task of reproducing only the color with the one of reproducing both the color and the object—keeping all other details equal—to evaluate how the retrieval demand affected the congruency effect. Again, a congruency benefit was only robustly observed when both the color and the object had to be reproduced.

Experiment 1

The goal of Experiment 1 was to assess whether prior knowledge about object-color associations could boost the retention of colors in visual working memory. Participants encoded a sequence of four colored objects for an immediate color delayed estimation task.

Additionally, we wanted to explore how to best activate object-color prior knowledge. Images and words are assumed to activate prior knowledge in long-term memory differently, which may have consequences for their use as elaboration support. On the one hand, according to the picture superiority effect, images tend to be better remembered than words. This has been explained by the *dual-coding theory* (Paivio, 1991), which states that while words are processed only in the verbal code, images are processed in two codes: visual and verbal. Compared to words, pictures may contain richer information, which causes a more elaborated encoding (Cherry et al., 2008). The picture superiority effect has been observed in memory tasks requiring free recall (Cherry et al., 2012; Paivio et al., 1968; Paivio & Csapo, 1969, 1973), cued recall (Nelson & Reed, 1976), serial recall (Nelson et al., 1977; Paivio & Csapo, 1969), and recognition (Defeyter et al., 2009; Paivio & Csapo, 1969). On the other hand, words (e.g., "dog") can serve as effective cues to conceptual categories in long-term memory (e.g., the concept of dogs). They activate these concepts in a broader and more effective way than exemplars of the category (e.g., the sound of a barking dog), thereby facilitating perception and memory (Boutonnet & Lupyan, 2015; Edmiston & Lupyan, 2015; Lupyan & Thompson-Schill, 2012). Words are therefore an effective way to activate semantic knowledge, and some argue that they are even essential in constructing this knowledge (Lupyan & Lewis, 2019).

Hence, there are arguments in favor of using both images and words as a means to activate prior knowledge about color categories. Accordingly, we decided to explore both words and images as a mean to activate prior knowledge. If the picture superiority effect helps elaboration, the congruency effect would be larger when studying colored images compared to studying colored words. If a broad activation of the semantic network by verbal information is more beneficial to elaboration, then studying colored words would yield a larger congruency effect than studying colored images.

Method

Transparency and Openness

All materials, data, and analysis code of all experiments can be accessed at https://osf.io/a8p3g. The experiments reported here were not preregistered.

Participants

Thirty young adults, aged between 18 and 26 years old (M = 22.4, SD = 1.43; 18 men, 11 women, and one other), with Portuguese as their native language and normal (or corrected-to-normal) visual acuity and color vision participated in a 20–30-min online session on a voluntary basis. Two participants were excluded from the final analysis because they were outliers in the average recall error (2 standard deviations above the mean), leaving a final sample size of 28 participants. Sample size was defined based on our experience with this type of task. We relied on Bayesian inference to assess evidence in favor or against our hypothesis. Our goal was to increase sample size in case evidence was ambiguous to accept or reject the effect of congruency on memory. The initial sample size was sufficient to provide strong evidence against our main hypothesis.

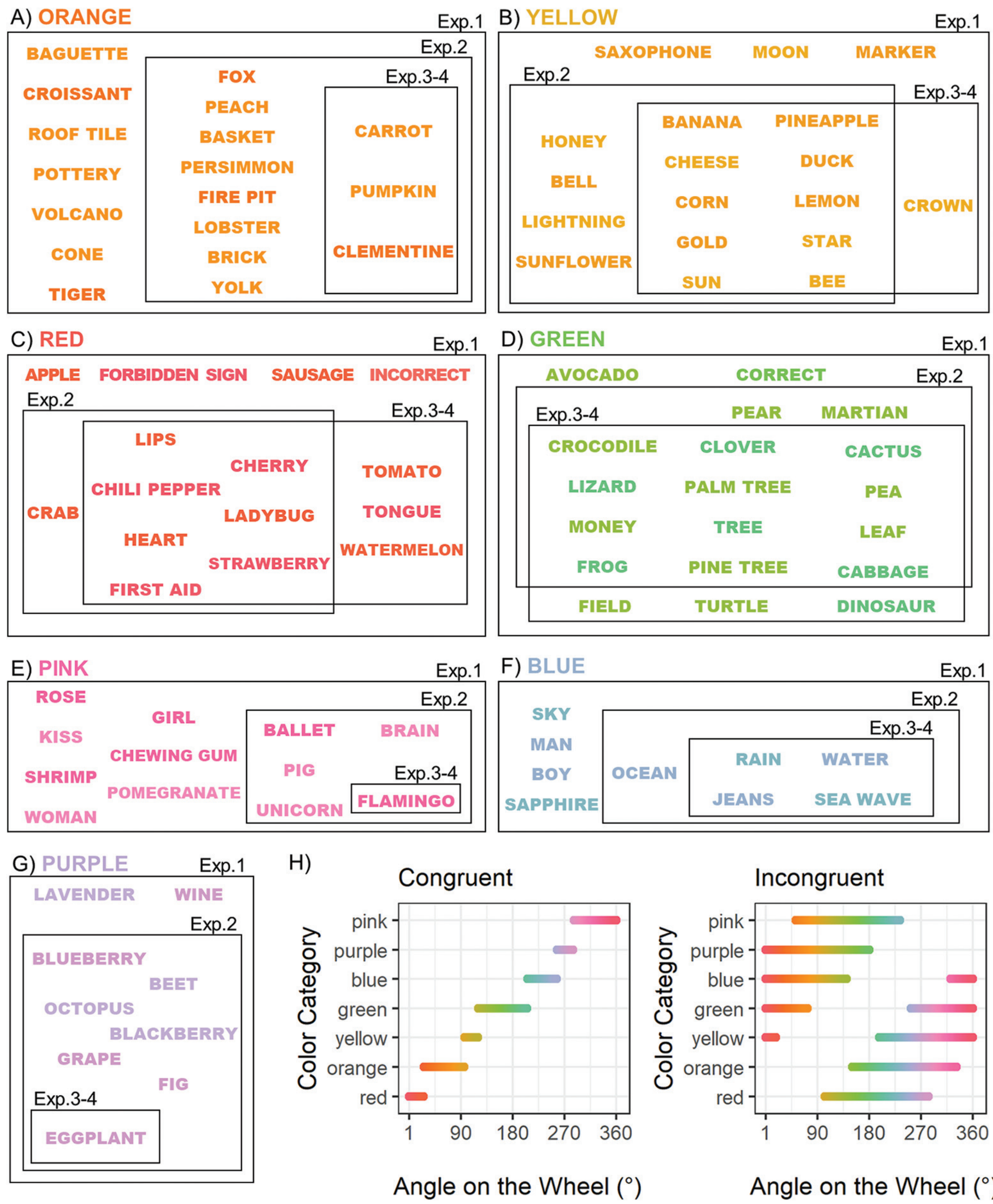
In all experiments reported here, participants provided their consent to participate by clicking on an online form and were debriefed regarding the goals of the study at the end. The experimental protocol was approved by the Ethics Committee of Faculty of Psychology and Education Sciences of the University of Porto (approval number: 2020/11-06b).

Materials

Participants memorized colors from a color wheel defined in the CIELAB color space with the following settings: L = 70, centered at a = 20, b = 38, and a radius = 60 (Zhang & Luck, 2008). We did a search on the internet with the goal of finding a set of 100 objects that are usually associated with a specific color, for example, ocean with blue, tree with green, sun with yellow, pumpkin with orange, strawberry with red, grapes with purple, and flamingo with pink. The authors of each icon are mentioned in online supplemental materials. Figure 1 presents the set of 100 objects used in their respective color category. A complete list of the object names selected and their assumed associated colors is presented on the OSF project page: https://osf.io/a8p3g/. The objects were selected both as an image (visual cue) from freely available icon databases (see sources in online supplemental materials) and as a (Portuguese) word (verbal cue). The online supplemental materials present the words in Portuguese and their translation in English. The icons are available on our Open Science Framework page. In a pilot study,

Figure 1

Names of the Objects Used in Their Congruent Colors (Panels A–G) and the Color Ranges for Congruent and Incongruent Conditions for Each Color Category (H)



Note. The different sets of stimuli used in each experiment (exp.) are indicated by the frames surrounding the stimuli. The images used in the experiments are available on the OSF project page: https://osf.io/a8p3g/. See the online article for the color version of this figure.

we asked 10 participants to report the color they associated with each word/image from a set of seven basic colors (i.e., red, orange, yellow, green, blue, purple, and pink). Participants could also indicate the responses "other" or "I do not know." The online supplemental materials also present the results of this first assessment of the congruency between our assumptions regarding color association and the ones of the participants. All 100 images and words were used in Experiment 1.

To create the congruent and incongruent conditions, it was necessary to choose congruent and incongruent color ranges in the color wheel for each color category. For the congruent conditions, the color ranges in the unrotated color wheel for each color category were defined as follows: [1° to 25°] for red, [26° to 96°] for orange, [97° to 120°] for yellow, [121° to 205°] for green, [206° to 256°] for blue, [257° to 285°] for purple, and [286° to 360°] for pink. These color ranges were selected based on the study of Souza and Skóra (2017) in which data regarding labeling of the wheel colors with these categories were obtained (the ranges are visualized in Figure 1H). For the incongruent conditions (see Figure 1H), colors were sampled from the section of the wheel containing the 180 colors at the opposite side of the center of the congruent range, resulting in the following ranges: [103° to 283°] for nonred, [151° to 331°] for nonorange, [198° to 18°] for nonyellow, [253° to 73°] for nongreen, [321° to 141°] for nonblue, [1° to 180°] for nonpurple, and [53° to 233°] for nonpink.

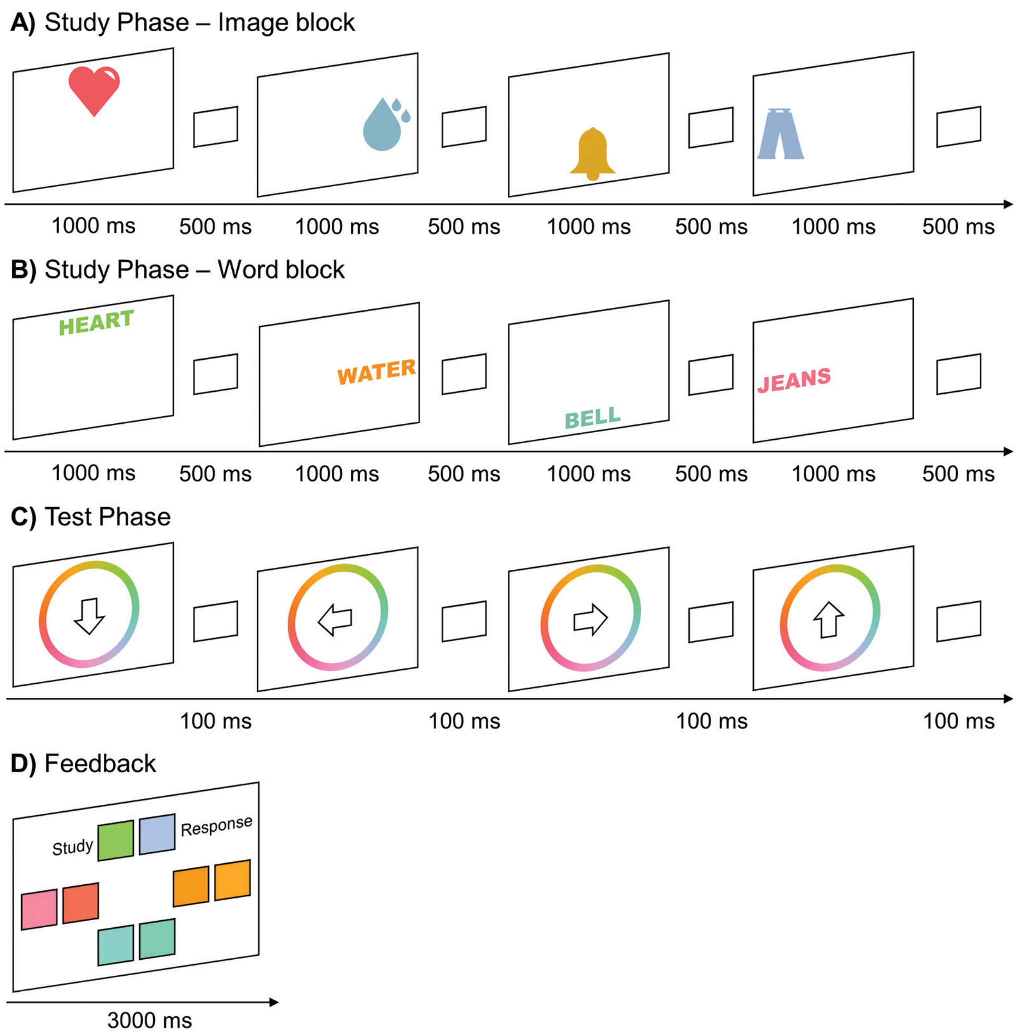
Procedure

All experiments reported herein were programmed in lab.js (Henninger et al., 2020), which is an HTML and JavaScript interface to program online experiments. The code for the task of all experiments is available at https://osf.io/a8p3g/.

Participants completed two blocks of 24 trials each. In one block, participants memorized the colors of images. In the other block, they memorized the colors of words. Block order was randomly determined for each participant. Each block was preceded by one practice trial that was excluded from further analysis. Each of the 100 stimuli (images and words) appeared only once in each block. Hence, participants saw each stimulus either in a congruent or incongruent color, but not in both. Figure 2 shows an illustration of the trials in each experimental block. During the study phase, four colored stimuli were presented sequentially in four different screen positions that were evenly spaced around an imaginary circle (radius = 150 pixels) centered on the middle of the screen. In the image block, the size of each image was 150 × 150 pixels; in the word block, each word was presented in bold, lowercase, 40-point sans-serif font. Each stimulus was presented for 1,000 ms against a white background, with a blank interval of 500 ms between stimuli. Participants were instructed to memorize the precise color that appeared in each location. Memory for the words or images was not required, and these stimuli appeared only at study. This was done to avoid a guessing strategy at test such that participants could guess the common color of the object whenever they had no information about the presented color in visual working memory.

Figure 2

Flow of Events in the Study and Test Phases of Experiment 1



Note. Panel A shows the study phase of the image block (example of a congruent trial). Panel B shows the study phase of the word block (example of an incongruent trial). Panel C shows the test phase (equal for both blocks). Panel D illustrates the feedback screen. Images are drawn by the author and not drawn to scale. See the online article for the color version of this figure.

After presentation of all stimuli, the test phase started: A color wheel appeared (radius = 250 pixels) together with an arrow in the screen center and the mouse cursor. The arrow randomly pointed to each of the four memory locations (one by one), and participants reproduced the color that appeared in the probed position by clicking on a color on the color wheel. All presented stimuli were tested. Recall order and the rotation of the color wheel changed from trial to trial. In the end of the trial, there was a feedback screen for 3,000 ms (Figure 2D): Two squares appeared next to each memory position. The square on the left showed the studied color, and the one on the right showed the color selected by the participant.

Each stimulus was only shown once in the corresponding block (i.e., "sun" only occurred once as an image and once as a word). Half of the trials in each block consisted of congruent and half of incongruent trials. All four stimuli in a trial were of the same congruency level (i.e., all congruent or all incongruent). Congruent and incongruent trials were randomly intermixed in each block. The assignment of the congruency level of each stimulus was randomly determined for each participant.

Participants received a link to the experiment by email and completed the task on their own computer (monitor size and viewing distance unconstrained) at their preferred location and time of day. The task lasted for about 20–30 min. Across the two blocks (images and words), there were four conditions for statistical analysis: (a) congruent images, (b) incongruent images, (c) congruent words, and (d) incongruent words, consisting of the within-subject factors of congruency and format.

Data Analysis

The main dependent variable in this study was recall error, which represents the absolute distance in degrees on the color wheel between the true color of the tested stimulus and the response given by the participant. Performance in each condition were compared by averaging the recall error over all trials in that condition per participant. We submitted this data to a Bayesian repeated-measures analysis of variance (ANOVA) with two factors (congruency and format). We used the default settings of the BayesFactor package implemented in R (Morey & Rouder, 2018). The Bayesian ANOVA calculates the Bayes factor (BF), which is the ratio of the likelihood of the models assuming that the data were generated by the alternative hypothesis (e.g., that there is an effect of the predictor) over the likelihood that the data were generated under the null hypothesis. This ratio indicates how many times more likely it is that one hypothesis explains the data compared to the other. It is possible to obtain two values of BF. BF_{10} refers to the evidence in favor of the alternative hypothesis compared to the null. BF_{01} presents the reverse, namely the evidence in favor of the null hypothesis compared to the alternative (i.e., $BF_{01} = 1/BF_{10}$). For instance, if we obtain a $BF_{10} = 10$, the data are 10 times more likely under the alternative hypothesis than the null hypothesis. Here, we will only report BF_{10}. Values of BF_{10} between .33 and 3 were regarded as ambiguous evidence (i.e., not favoring either the null or the alternative hypotheses). Values between 3 and 10 were regarded as showing moderate evidence, and values larger than 10 were regarded as showing strong evidence for the alternative hypothesis. Values between .33 and .10 were considered as showing moderate evidence for the null, and values smaller than .10 were considered as showing strong evidence for the null (Jeffreys, 1961; Kass & Raftery, 1995; Wetzels & Wagenmakers, 2012).

In addition, for condition comparisons in the raw recall error score, we calculated Cohen's *d* using the package BEST (Kruschke & Meredith, 2021). This package computes *d* according to one of the following formulas, depending on the design (between subjects, Equation 1; within subjects, Equation 2):

$$(\mu_1 - \mu_2)/\sqrt{\left(\delta_1^2 + \delta_2^2\right)/2} \tag{1}$$

$$(\mu_u - compVal)/\delta_u \tag{2}$$

μ refers to the means of the two groups (1 and 2, see Equation 1) or the mean difference between the two within-subject conditions (Equation 2); δ refers to the variance of the respective groups or of the within-subject condition difference; and compVal refers to the comparison value when the data are from a single group (in our case, this was always set to 0). We present the mean effect size and its 95% credible interval (CI).

Finally, several models have been developed to analyze responses from delayed estimation tasks. We submitted our data to the between-item variant of the categorical-continuous mixture model developed by Hardman et al. (2017), implemented in a Bayesian hierarchical framework in the CatContModel package (Hardman, 2017). We used this model to explore which parameters were affected by the factors manipulated in our study. This model assumes that each response given by the participants is either informed by memory (with probability P^M) or reflects a guess (with probability $1\text{-}P^M$). When responses are informed by memory, they could reflect continuous information about the memory stimulus (with probability P^O)—that is, a representation of the precise hue studied—or they could reflect memory of the category the item belonged to—for example, that it was red (with probability $1\text{-}P^O$). More specifically, the between-item variant of the model assumes that a response is either continuous or categorical (and not a mixture of both). Furthermore, continuous responses could be more or less precise, which is reflected in the parameter defined as continuous imprecision (δ^O). This is the standard deviation of the circular normal distribution of responses centered on the tested value. The CatContModel package (Hardman, 2017) computes the BF of the main effects and interactions for each model parameter using the Savage-Dickey density ratio method. The procedure to compute the BFs implemented in the package is detailed in Ricker and Hardman (2017). All BFs reported here regarding the mixture model parameters were obtained from the package. For the data of Experiment 1, we fit the model with 15,000 iterations and discarded the first 4,000 iterations as burn-in.

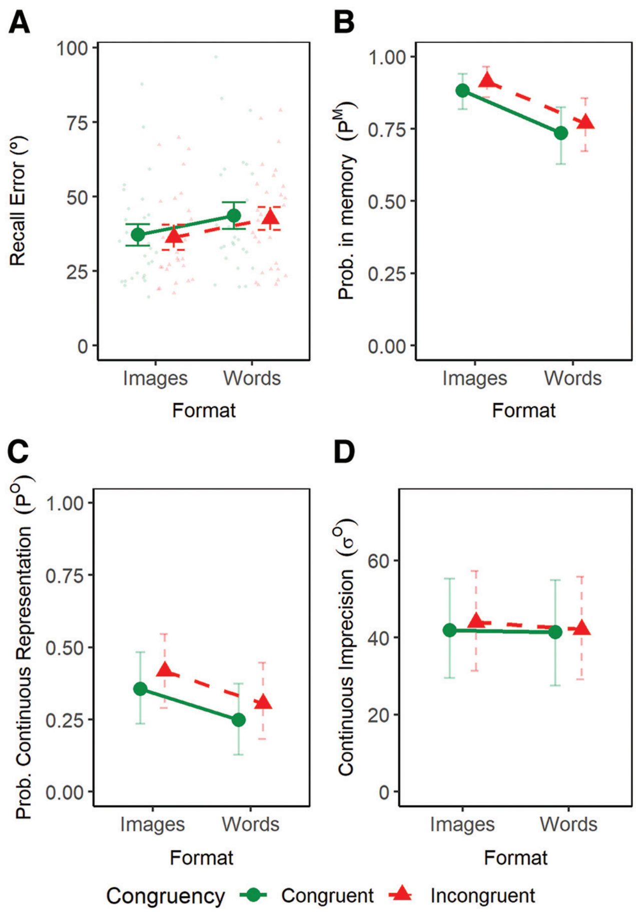
Results

Color Recall

Figure 3A presents the average recall error as a function of stimulus format and congruency. The best model of the data included only the format effect, $BF_{10} = 2.87 \times 10^5$, showing overwhelming evidence for the format effect. This is because colors of images tended to be recalled with lower error than colors of words. The

Figure 3

Recall Error (A), Probability in Memory (B), Probability of Continuous Representation (C), and Continuous Imprecision (D) for the Data of Experiment 1



Note. Overall, the colors of images were better recalled than of words, but congruency had no effect on performance. In Panel A, the small dots represent the data of each participant and the larger dots represent the mean of the conditions. The error bars represent 95% within-subjects confidence interval (Morey, 2008). In Panels B, C, and D, the error bars represent the 95% credible interval of the posterior of the estimated parameters. Prob. = probability. See the online article for the color version of this figure.

effect size of the comparison between images and words was d_{con} = .42, 95% CI [−.02, .87], and d_{inc} = .35 [−.06, .75] for the congruent and incongruent conditions, respectively. There was strong evidence against the inclusion of congruency, BF_{10} = .05, and its interaction with format, BF_{10} = .04. The effect size for the comparison of the congruent and incongruent conditions was d_{image} = .08 [−.32, .44] and d_{word} = .08 [−.32, .46] for the image and word conditions. Hence, these results are against an effect of elaboration on visual working memory.

Mixture Model for Color Recall

Figure 3B presents the group-level posterior estimates for the probability of having information in memory (P^M). Figure 3C presents the probability of retrieving a continuous representation (P^O), and Figure 3D the continuous imprecision of the continuous response (σ^O). Table 1 presents the evidence for the effects of congruency, format, and their interaction in each mixture model parameter.

Overall, there was extreme evidence for a higher P^M and moderate evidence for a higher P^O for images compared to words. For σ^O, there was ambiguous evidence for a format effect. There was ambiguous to moderate evidence against a main effect of congruency in all parameters and strong to moderate evidence against the interaction of congruency and format in all mixture parameters. These results show that congruent images were not better remembered than incongruent images, and hence there was no evidence of an elaboration effect. Yet the color of images had a higher probability of being stored in memory and of their memory representation being continuous.

Discussion

Experiment 1 showed strong evidence against an effect of congruency on recall error; hence, prior knowledge of color-object associations did not improve color recall. These results are against a putative benefit of elaboration for the retention of color in visual working memory. The only credible effect observed was of the format of the memoranda: Images were associated with better color memory than words. This was reflected in the model-free index of performance, namely the recall error, and also in the mixture model parameters of probability in memory and probability of continuous representations. This better memory for images may be explained by a picture superiority effect (Cherry et al., 2008, 2012; Paivio, 1991) or by other uncontrolled factors such as differences in prior experience in remembering colors of images compared to colors of words. Another potential difference is regarding the colored area: We did not control that the area occupied by the words and the images was identical. Critical to our research question, however, was the lack of an interaction of format with congruency. We were interested in assessing whether the memoranda format could affect the activation of prior knowledge and hence modulate the congruency effect. In our study, there was substantial

Table 1

Evidence (BF_{10}) for the Effects of Congruency, Format, and Their Interaction in the Mixture Model Parameters Considering the Data of Experiment 1

	Parameter		
Factors	Probability memory (P^M)	Probability continuous (P^O)	Continuous imprecision (σ^O)
Congruency	0.79	0.32	0.72
Format	8.01×10^4	3.13	0.66
Congruency × Format	1.00×10^{-4}	1.23×10^{-2}	0.13

evidence against an interaction of format with congruency, indicating that both types of stimuli did not facilitate elaboration.

Why was prior knowledge ineffective to improve visual working memory? There are different alternative explanations that could explain the lack of a congruency effect. One possibility is that there was insufficient time to access and use prior knowledge. In Experiment 1, each item was presented for 1,000 ms with a 500-ms interstimulus interval, producing an encoding time of 1,500 ms per stimulus. It is possible that for elaboration to have a positive effect, the encoding time needs to be longer. Another alternative explanation could be due to a strategy deficit, in the sense that perhaps participants failed to notice the availability of elaboration support (i.e., the fact that in some trials, all objects had an association with the to-be-memorized color). In Experiment 1, congruency was manipulated randomly across trials, which required participants to monitor on every trial if the presented colors were or not congruent in order to decide to apply an elaboration strategy. This monitoring could be costly, reducing the attractiveness of using an elaboration strategy. Last, Experiment 1 did not include a measure of individual object-color associations. Participants may vary regarding whether they also associate the presented objects with the colors selected by the experimenters. If their associations differ from the ones of the experimenters, then the congruency manipulation would be ineffective. Experiment 2 was designed to address these concerns.

Experiment 2

In Experiment 2, we only presented participants with colored images to memorize (because this condition facilitated memory in Experiment 1) and included several manipulations to address three concerns that could explain the absence of a prior-knowledge benefit: (a) lack of time to elaborate, (b) lack of knowledge regarding the manipulation of object-color associations and a potential cost associated with the random presentation of congruency across trials, and (c) individual differences in object-color associations.

Participants completed three sessions. In Session 1, we examined the impact of providing more time to elaborate each item by increasing the interstimulus interval (from 500 to 3,500 ms). Therefore, if more time was needed to successfully elaborate, the congruency effect should be larger in the long-time condition (4,500 ms) compared to the short-time condition (1,500 ms as in Experiment 1).

In Session 2, we examined if blocking the congruent and incongruent trials could facilitate the use of elaboration. In addition, for half of the participants (elaboration group), we provided an elaboration instruction prior to the congruent block; the control group received no instruction. The elaboration group was instructed to use the object-color congruent associations to facilitate the encoding of the presented color. If having the congruency level blocked facilitates elaboration, the congruent block in Session 2 would produce better results than the incongruent block. If having an elaboration instruction exacerbates this effect, the elaboration group would show a larger congruency effect than the control group.

Finally, in Session 3, we assessed the color associations that each participant had for each object. This allowed us to assess whether our assumptions for the congruent conditions matched the ones of the participants. If individual variability in object-color associations have an impact in the congruency effect, removing from the analysis the unmatched objects at the individual level would allow us to observe a congruency effect.

Method

Participants

Participants were invited to take part in an online study consisting of three sessions in exchange of extra course credit. Sessions 1 and 2 lasted for about 20–30 min, and the third session lasted for about 5–10 min. They received the links for each session per email, and the links were sent at consecutive days. Participants were instructed to complete the sessions in the order they were sent to them.

Sample size was based on the number of students that volunteered to take part on the study for extra course credits. Data collection was carried out during a preestablished period (February 25 to April 8, 2021). We accepted all participant submissions during this period to give equal opportunities for all students to earn extra credits. The first session was completed by 119 adults who were second-year students of psychology, were aged between 19 and 42 years old ($M = 21.16$, $SD = 4.24$; 104 women, 13 men, one other, one missing value), and had the same inclusion criteria as in Experiment 1. Session 2 was completed by 110 of the initial participants, and Session 3 was completed by 102 of the participants. Seven participants were excluded from the analysis of Session 1 and six from Session 2 because their recall error was 2 standard deviations above the mean, leaving a final sample of $N = 112$ in Session 1 and $N = 96$ in Session 2.

Materials

In Experiment 1, we had no information regarding each participant's prior association between each object and their color. In order to assess if some stimuli produced unusual effects, we analyzed the effect of congruency for each of the stimuli used in Experiment 1 by computing the mean congruency effect for each stimulus. We removed the images that produced a reverse congruency effect (i.e., better memory for incongruent colors) from our set. This left us with 64 images to use as memoranda in Experiment 2. Note that this is a rough estimate because a single participant was never exposed to the same stimulus twice in Experiment 1, and hence this was a noisier between-subjects estimate of a congruency effect. Thus, to further validate the removal of these stimuli from Experiment 2, in Session 3, we asked participants to rate their association to all 100 items used in Experiment 1. Figure 1 shows the subset of the objects that were used in Experiment 2. We used the same parameters to define the congruent and incongruent colors as in Experiment 1.

Procedure

The task setup in Experiment 2 was exactly as described for the image block of Experiment 1, with the specific modifications implemented in each session detailed below.

For Session 1, we created two blocks that varied in the encoding time of each object (block order was varied randomly across participants). In the short block, each stimulus was presented for 1,000 ms followed by a 500 ms blank (as in Experiment 1). In the long block, the stimulus (1,000 ms) was followed by a 3,500-ms blank interval. This created a variation of presentation rate of

1,500 versus 4,500 ms, thereby providing participants with 3 times more elaboration time in the long block. There were 16 trials in each block: eight congruent and eight incongruent. Unlike Experiment 1, all the stimuli were presented two times, once in a congruent and once in an incongruent color, allowing us to assess the congruency effect for each stimulus at the individual level. There were four conditions for statistical analysis: (a) 1,500 ms congruent, (b) 1,500 ms incongruent, (c) 4,500 ms congruent, and (d) 4,500 ms incongruent, consisting of the within-subject factors of encoding time and congruency.

In Session 2, we blocked the congruency and only used the long encoding time (4,500 ms; i.e., 1,000 ms onscreen and 3,500 blank). There were also 16 trials per block, and the order of blocks was randomized across participants. Again, each stimulus appeared one time in each congruency condition. For a random half of the participants, we provided an elaboration instruction prior to the onset of the congruent block (elaboration group, n = 59). We told the elaboration group that the colors of the images would be the ones that are mostly associated with each object (e.g., a tiger in orange) and that they should use this association to better remember the color for the test phase. The remaining participants (control group, n = 45) received no instruction. There were four conditions for statistical analysis: (a) congruent elaboration group, (b) incongruent elaboration group, (c) congruent control group, and (d) incongruent control group, consisting of the within-subject factors of congruency and the between-subjects factor of group.

In Session 3, participants were asked to indicate which of the seven color categories (blue, green, yellow, orange, red, pink, and purple) they mostly associated with each object. In each trial, the clipart of one object was presented in each of the seven color categories along with the options of "other color," "any of the colors," and "I do not know." They clicked on the color or option that represented their association to that image (see Figure 4). Finally, the participants answered the Style of Processing Scale (Childers et al., 1985). The results of the latter will not be reported here.

Session order was fixed for all participants to avoid carryover effects of the elaboration instruction and of the association question presented in Session 3.

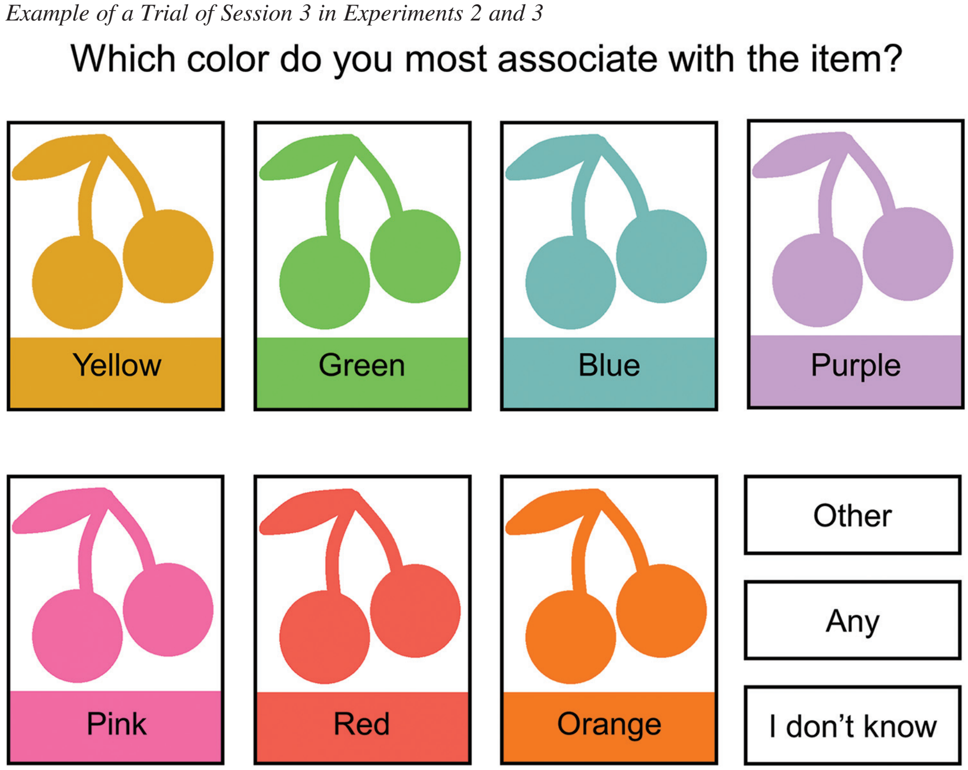
The analysis was similar to the one in Experiment 1. The main dependent variable was the recall error. For Session 1, we computed a Bayesian repeated-measures ANOVA with two factors: congruency and time. For Session 2, the factors were congruency and group.

We submitted the data of Sessions 1 and 2 to the categorical-continuous mixture model (Hardman et al., 2017) separately. We ran 10,000 iterations (with a burn-in of 2,000 iterations) for Session 1 and 15,000 iterations (with a burn-in of 2,000 iterations) for Session 2. The number of iterations was determined by visual inspection to obtain stable converging chains.

For Session 3, we examined the matching of the object-color associations selected by each participant with the one assumed in the experimental task and repeated the analysis for Sessions 1 and 2 using only the trials with these matching objects.

Figure 4

Example of a Trial of Session 3 in Experiments 2 and 3



Note. Images are drawn by the author. See the online article for the color version of this figure.

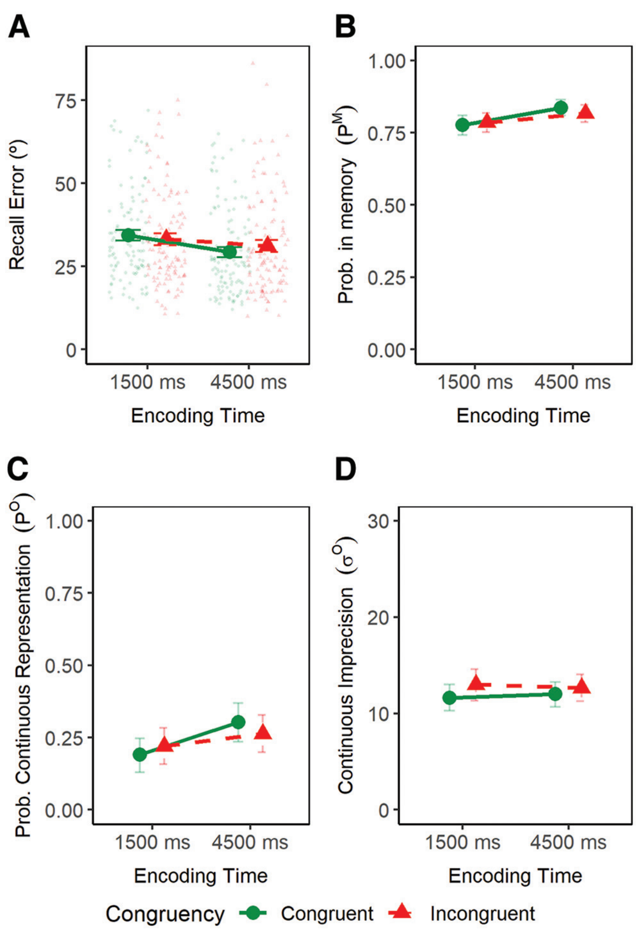
Results

Session 1 – Color Recall

Figure 5A shows the average recall error as a function of encoding time (1,500 ms vs. 4,500 ms) and congruency (congruent vs. incongruent). The best model of the data included only the main effect of encoding time, $BF_{10} = 7.10 \times 10^4$. As shown in Figure 5A, images encoded for a longer time had lower recall error than the images encoded for a shorter time: $d_{con} = .44$, 95% CI [.24, .64], and $d_{inc} = .16$ [−.06, .35] for the congruent and incongruent conditions. There was very strong evidence against the inclusion of congruency in the model, $BF_{10} = .02$, and anecdotal evidence against its interaction with encoding time, $BF_{10} = .43$. Effect sizes for the effect of congruency were $d_{short} = -.14$ [−.34, .04] and $d_{long} = .11$ [−.07, .31] for the short and long conditions.

Figure 5

Recall Error (A), Probability in Memory (B), Probability of Continuous Representation (C), and Continuous Imprecision (D) in Session 1 of Experiment 2



Note. Colors were better recalled in the long encoding time (4,500 ms) condition, but congruency had no effect. Smaller dots in Panel A represent the individual data, and the larger dots represent the mean of each condition. Error bars in Panel A represent 95% within-subjects confidence interval. Error bars in Panels B, C, and D represent 95% credible intervals. Prob. = probability. See the online article for the color version of this figure.

Session 1 – Mixture Model for Color Recall

Figures 5B, 5C, and 5D illustrate the parameter estimates of the categorical-continuous mixture model for Session 1, and Table 2 presents the evidence for the effects of the manipulated variables in each parameter. There was extreme to very strong evidence for an encoding-time effect in P^M and P^O, reflected in a higher memory and higher probability of this memory being continuous for images encoded for a longer time. Encoding time had an ambiguous effect on σ^O. Congruency had no effect in any of the mixture model parameters, and the evidence for the null was between very strong (P^M and P^O) and moderate (σ^O). There was very strong evidence against the interaction of congruency and encoding time.

Session 2 – Color Recall

Figure 6A shows the average recall error as a function of congruency and group. The Bayesian ANOVA showed that neither congruency nor group explained variations in performance. There was very strong evidence against the inclusion of a congruency effect in the model, $BF_{10} = .02$, and strong evidence against a group effect, $BF_{10} = .09$, and their two-way interaction, $BF_{10} = .04$. Effect sizes of the congruency effect were $d_{control} = -.18$, 95% CI [−.57, .22], and $d_{elab} = .06$ [−.22, .33] for each group.

Session 2 – Mixture Model for Color Recall

Figures 6B–6D illustrate the results of the categorical-continuous mixture model for Session 2. Table 3 presents the evidence for the effects of interest. For probability in memory, there was strong evidence against the effect of congruency and group and extreme evidence against their interaction.

For P^O, there was moderate evidence against a congruency and group effect and very strong evidence against their interaction. Regarding σ^O, there was anecdotal evidence for the main effect of group, with the elaboration group having a higher memory imprecision than the control group. There was moderate evidence against an effect of congruency and strong evidence against its interaction with group. Hence, there was no evidence that blocking congruency or providing an elaboration instruction boosted congruency.

Session 3 – Match of Object-Color Associations

Out of the participants that completed Session 3 ($n = 102$), the proportion of matches between the object-color associations the participants selected and the ones assumed by the experimenters was analyzed. Participants were asked to judge the match for the 100 stimuli used in Experiment 1 (from which only a subset of 64 was actually used in Experiment 2). Table 4 shows the average match depending on the color category of the objects when considering the full set of 100 items (as used in Experiment 1) and only the 64 items used in Experiment 2. The results for each specific stimulus are available in the online supplemental materials.

We repeated the analysis of the recall error in Sessions 1 and 2 of Experiment 2, now only including the items for which there was a match between the association reported by the participant and the one used in designing the experiment. The results of this analysis are presented in the online supplemental materials. In sum, the pattern of results remained unchanged.

Table 2

Evidence (BF_{10}) for the Effects of Congruency, Encoding Time, and Their Interaction in the Mixture Model Parameters Considering the Data of Session 1 of Experiment 2

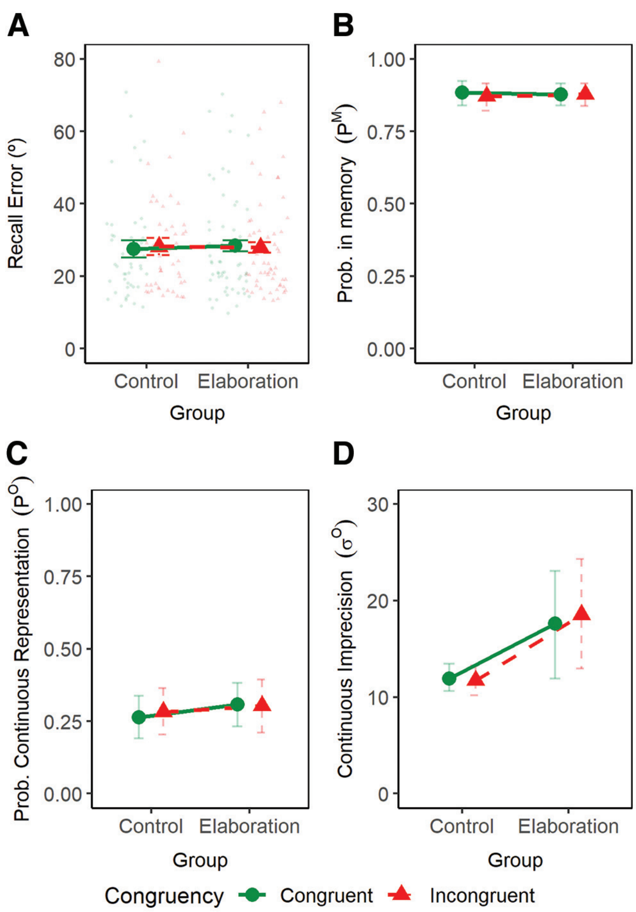
Factors	Parameter		
	Probability memory (P^M)	Probability continuous (P^O)	Continuous imprecision (σ^O)
Congruency	3.99×10^{-2}	8.94×10^{-2}	0.23
Encoding time	3.70×10^{3}	53.46	0.90
Congruency × Encoding Time	1.25×10^{-2}	3.28×10^{-2}	2.04×10^{-2}

Discussion

Experiment 2 was designed to examine if providing more time for elaboration, or blocking the congruency levels, and explicitly asking participants to create a relation between the color and the object would facilitate the process of using prior knowledge of object-color associations to elaborate colors in visual working memory.

Figure 6

Recall Error (A), Probability in Memory (B), Probability of Continuous Representation (C), and Continuous Imprecision (D) in Session 2 of Experiment 2



Note. There was no credible effect of congruency or group on performance. Smaller dots in Panel A represent the individual data, and the larger dots represent the mean of each condition. Error bars represent 95% within-subjects confidence interval. Error bars in Panels B, C, and D represent 95% credible intervals. Prob. = probability. See the online article for the color version of this figure.

Is There an Elaboration Benefit?

In Session 1, memory performance improved with longer encoding time, showing the classical presentation rate effect (Ricker & Hardman, 2017; Souza & Oberauer, 2018, 2020; Tan & Ward, 2008). Despite this, the increase in the encoding time did not facilitate the elaboration process: There was no credible effect of congruency in either block. Thus, the lack of a congruency benefit was not due to insufficient time to elaborate.

Regarding Session 2, the division of congruent and incongruent objects in two homogeneous blocks did not facilitate the elaboration process since congruency continued to not produce an effect in performance (see results of control group). Furthermore, the part of the sample that received an instruction to use the congruent object-color associations to improve their memory (elaboration group) did not differ from the one that had a general instruction in this block (control group). If anything, this group tended to show worse memory precision, which is against the idea that elaboration would help memory. Therefore, the lack of elaboration effect cannot be explained by a strategy deficit or a failure to notice the elaboration opportunity.

In Session 3, we tried to understand if the inexistence of the congruency effect could be due to individual differences in the associations that the participants made between the objects and their colors. However, these associations did not substantially differ from the assumptions used to design the congruency in the experiment: We observed a large proportion of matches across most categories. Furthermore, even after taking in consideration only the stimuli for which there was a match between the individual participants' and the experimenters' associations, the effect of congruency was still not observed.

Further Alternative Explanations

So far, our stimuli consisted of concrete objects that are often associated with a specific color, and we presented these objects either in a congruent or incongruent color. We assumed that congruent colors would lead to a benefit compared to incongruent ones; however, it is also possible for the incongruent color to have an influence on performance via other elaboration processes created by the participants, for example, through a bizarreness effect (Geraci et al., 2013; McDaniel & Einstein, 1986). The bizarreness effect occurs when an atypical association is easier to encode or maintain in memory because it is more distinctive than the typical one. Regarding atypical colors, it was found that objects with bizarre colors were better remembered (in terms of the object's

Table 3

Evidence (BF_{10}) for the Effects of Congruency, Group, and Their Interaction in the Mixture Model Parameter for the Data of Session 2 of Experiment 2

Factors	Parameter		
	Probability memory (P^M)	Probability continuous (P^O)	Continuous imprecision (σ^O)
Congruency	0.08	0.11	0.22
Group	0.09	0.11	1.86
Congruency × Group	7.37×10^{-3}	0.01	0.07

name) compared to objects presented in their typical colors (Morita & Kambara, 2022). Given that our study lacked a neutral or control condition, we could not rule out that other kinds of elaboration or facilitations occurred during the incongruent trials that may have blurred the distinction between congruent and incongruent colors and masked the effect of elaboration. One potential solution to this would be to create control stimuli (e.g., by including abstract images or concrete images that are not typically associated with a specific color), thereby controlling the elaboration process by limiting its occurrence.

Another alternative explanation of our findings is that participants in Experiments 1 and 2 completely ignored the shapes of the objects given that they were completely task irrelevant. As such, they may have tried to simply remember the colors in each position. There is evidence that remembering associations consume more working memory capacity than storing individual features (Allen et al., 2006; Brockmole & Logie, 2013; Fougnie et al., 2010; Vergauwe et al., 2014); thus, this strategy would produce better memory than trying to use this irrelevant information to boost memory through elaboration. One remedy to this situation would be to also require memory for the objects.

Last, we cannot ascertain whether the inexistence of an elaboration effect on visual memory is unique for working memory. For verbal memory, elaboration was found to benefit only episodic long-term memory but not working memory (Bartsch & Oberauer, 2021; Bartsch et al., 2019, 2018). Data on visual memory are still lacking. Experiment 3 was designed to address these issues.

Experiment 3

Experiment 3 examined the role of three alternative explanations of our findings. First, we included additional control conditions that did not involve restricting the range of object colors into either congruent or incongruent. We included two control conditions: (a) neutral objects, that is, objects that are not strongly associated with a specific color (e.g., a shoe), and (b) abstract shapes, that is, relatively novel shapes drawn from the continuous shape wheel (see A. Y. Li et al., 2020), which should likewise not have a prior history with a specific color. These control conditions allowed us to assess the possibility that elaboration improved memory in congruent and incongruent trials alike, thereby preventing us from measuring an elaboration benefit in Experiments 1 and 2.

Second, in the previous experiments, we did not present the objects at the test phase to avoid a simple guessing strategy (i.e., "If I do not know the color of the banana, I will simply guess yellow since I will be correct in 50% of the time"). This created a condition in which the object was completely task irrelevant, and hence participants may have strategically avoided its encoding to save memory capacity. To circumvent this problem, in Experiment 3, we included an object memory test in addition to the color memory test. This forced participants to also store the object presented and prevented the strategic ignoring of the object altogether. Yet we designed our study to prevent them from using the object to guess the color. They needed to remember both.

Finally, we also tested memory for supraspan trials (eight objects instead of four) after a delay (about 20 s) filled with a distractor task. We assumed that this condition forced participants to retrieve information from episodic long-term memory because the large number of objects surpassed the capacity of working memory, and the filled delay also removed the last-presented objects from focal attention (Loaiza & McCabe, 2012). This allowed us to assess if retrieval from episodic long-term memory would show a benefit of prior knowledge that we could contrast to the effect in the working memory test. Previous studies have found that episodic long-term memory is sensitive to the effects of elaboration (Bartsch et al., 2019, 2018). This allowed us to rule out the possibility that our manipulation of prior knowledge was simply ineffective to promote elaboration.

Table 4

Average Match Between Experimenters' and the Participants' Object-Color Associations

Memoranda	100 items (Experiment 1)	64 items (Experiment 2)
All items	66.34%	77.68%
Color category		
Green	88.75%	89.85%
Red	81.11%	87.99%
Yellow	80.17%	86.69%
Blue	63.29%	88.24%
Orange	56.75%	65.60%
Pink	35.03%	55.69%
Purple	40.96%	50.70%

Method

Participants

Participants were invited to take part in an online experiment in exchange for extra course credit. The experiment consisted of three sessions: a working memory session, a long-term memory session, and an object-color association test session. Sessions 1 and 2 lasted between 20 and 30 min, and Session 3 lasted for about 5–10 min. The links to the sessions were sent by email in consecutive days. Sample size was based on the number of students willing to take part in the study to obtain credits. Enrollment took place between October 25 and November 28, 2021.

A total of 154 students started the study, but only $N = 132$ completed all sessions and met the inclusion criteria. Participants were adults, first-year students of psychology, and aged between 17 and 57 years old ($M = 20.23$, $SD = 5.39$; 111 women, 18 men, one other, two missing values) and had the same inclusion criteria as Experiments 1 and 2. We further excluded participants whose recall error was 2 standard deviations above the group mean in each session in the color test and 2 standard deviations below the group mean in the object test in each session. In total, seven participants were excluded from the working memory session (three outliers regarding object and four regarding both object and color) and four from the long-term memory session (related to the object test).

Materials

From the 100 images used in Experiment 1, we selected 45 with the greatest correspondence of object-color associations between the participants and the researchers (higher than 80% match according to the data of Session 3 in Experiment 2). These objects were used for the congruent and incongruent conditions (see Figure 1). We selected 30 new items that were not associated with a specific color to be used in the neutral condition (e.g., books; see Figure 7A). Finally, we selected 30 shapes from the validated circular shape (A. Y. Li et al., 2020) to use in the abstract condition (see Figure 7B). Abstract items were selected from equally spaced sections from the circular space, separated by 12 degrees of angular distance. By mistake, the abstract image "A19" was replaced by "A29," causing the pool of abstract items to consist of 29 elements in total (and shape "A29" to appear twice as frequently as the other abstract shapes).

Procedure

There were three sessions: a working memory session, a long-term memory session, an object-color association test session. The working memory and long-term memory sessions always occurred in the first two sessions, and their order was counterbalanced across participants. The object-color association test always occurred last. For the working memory and long-term memory sessions, there were eight gray outlines of squares (75 × 75 pixels) always visible onscreen (see Figure 8A), which hereafter will be referred to as placeholders. The stimuli appeared within the placeholders.

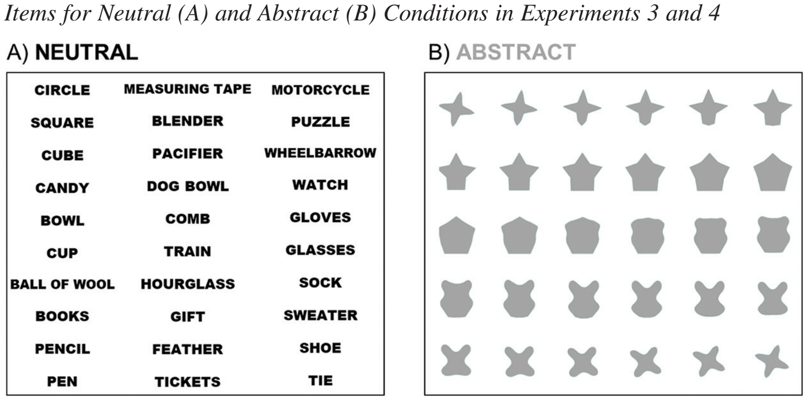
In the working memory session, there were two equal blocks of 20 trials with a short break in between. Trials in each block consisted of a list of four congruent, incongruent, neutral, or abstract objects. There were five trials of each condition, which were randomly intermixed. The stimuli presented in each trial were randomly sampled from the respective stimulus sets (i.e., for an abstract trial, stimuli were randomly sampled from the abstract set).

In the study phase of the working memory session, each trial presented four different colored images in a random subset of four positions. Images appeared for 1,000 ms, with a blank 500-ms interstimulus interval in which only the placeholders were visible onscreen (Figure 8A). In the test phase, the participants had to reproduce the color and the object presented in each position. The order of probing of the positions was random, as well as the order of the color and object tests (i.e., color then object or object then color). During the test, the probed position was highlighted by a thicker black frame (see Figure 8D). For the color test, a color wheel was shown surrounding all the memory positions, and participants indicated the color of the probed item by clicking on the remembered color on the wheel. For the object test, three objects were shown surrounding the probed position (three-alternative forced-choice test). The objects consisted of the target, an object from another position, and a new object that did not appear in the trial. The alternatives were randomly assigned to the three locations surrounding the probed position. Participants clicked on the image they remembered appearing in the probed position. All four encoded objects were probed in random order. This produced a total of 40 responses in each design cell.

Unlike Experiments 1 and 2, there was no trial performance feedback. In the end of each block, average performance for the

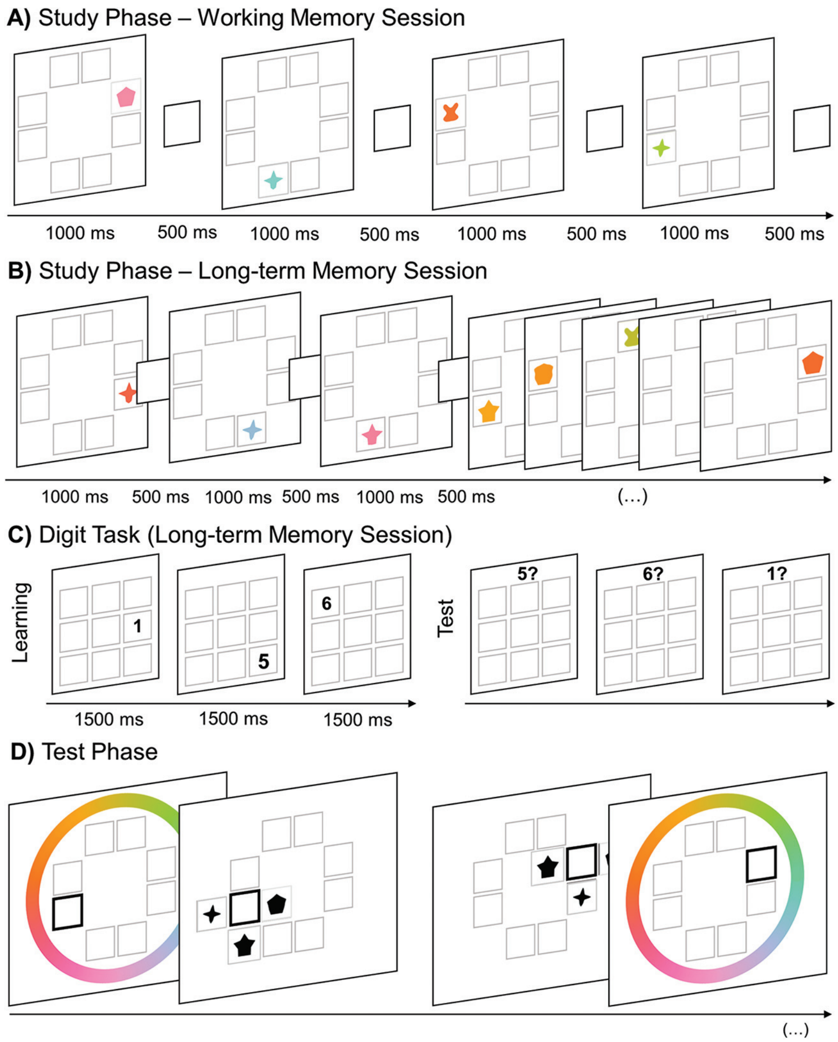
Figure 7

Items for Neutral (A) and Abstract (B) Conditions in Experiments 3 and 4



Note. The images of the neutral objects are available on our OSF project page: https://osf.io/a8p3g/. The abstract image on the fourth row of the first column was not part of the pool of abstract memoranda due to an error. The abstract images are from "The validated circular shape space: Quantifying the visual similarity of shape" by A. Y. Li et al, 2020, *Journal of Experimental Psychology: General*, *149*(5), 949–966 (https://doi.org/10.1037/xge0000693). Copyright 2020 by the American Psychological Association.

Figure 8
Flow of Events in Working Memory and Long-Term Memory Sessions of Experiment 3



Note. Panel A shows the study phase of a working memory trial (example of an abstract trial). Panel B shows the study phase of a long-term memory trial (example of an abstract trial). Panel C shows the digit task implemented in the retention interval of the long-term memory trial. Panel D shows the test phase for the color and object reproduction (randomly ordered). Images are not drawn to scale. The abstract images are from "The validated circular shape space: Quantifying the visual similarity of shape" by A. Y. Li et al, 2020, *Journal of Experimental Psychology: General, 149*(5), 949–966 (https://doi.org/10.1037/xge0000693). Copyright 2020 by the American Psychological Association. See the online article for the color version of this figure.

color and the object reproduction tests was displayed in a feedback screen. The color-recall feedback was a percentage based on the recall error mean (i.e., 90° = 50%; 0° = 100%), and the object feedback was the percentage of correct responses.

In the long-term memory session, there were two equal blocks of 12 trials each, with a small break in between. Trials were randomly sampled from congruent, incongruent, neutral, or abstract conditions (three of each). Again, the images were randomly sampled from the respective stimulus set. In the study phase (Figure 8B), eight images appeared one by one in clockwise order starting at the right bottom. Each image was presented for 1,000 ms with a blank 500-ms period between them. Then, there was a distractor working memory task (see Figure 8C) in which participants had to recall the positions where three numbers were presented on a grid. They completed two distractor-task trials (lasting for around 20 s). Finally, in the test phase (Figure 8D), all eight locations were probed one by one in random order. For each location, participants reproduced the color and the object, with the order of these tests being randomly determined. There were 48 responses in each design cell for analysis. There was a feedback screen after each block, similar to the working memory session.

For both the working memory and long-term memory sessions, there were four conditions (congruent, incongruent, neutral, abstract) and the stimuli were recalled in two orders (color tested first vs. object tested first). All these variables were manipulated within subjects. Finally, Session 3 consisted of the object-color association test, which was identical to the third session of Experiment 2 (see Figure 4) with the exception that participants additionally judged the colors associated with the neutral and abstract objects. The goal was to assess individual variability in object-color associations.

Data Analysis

The same analysis procedure as in the previous experiments was conducted. For both the working memory and long-term memory sessions, the two factors analyzed with the repeated-measures Bayesian ANOVA were condition (congruent, incongruent, neutral, and abstract) and recall order (color tested first and object tested first). Our dependent variables were recall error for the color delayed estimation task and choice accuracy for the object test.

For color memory, we ran 20,000 iterations (with a burn-in of 5,000 iterations) of the between-item variant of the categorical-continuous mixture model to fit the data of the working memory session and 10,000 iterations (with a burn-in of 2,000 iterations) for the long-term memory session. We increased the iterations in the working memory session to get more stable parameter estimates.

Again, for Session 3, we examined the matching of the object-color associations selected by each participant with the ones assumed in the experimental task and repeated the analysis for the previous sessions only with the items that matched with the experimenters' associations.

Results

Object Recall

On average, each participant responded correctly to 76.42% of the object tests in the working memory session (minimum = 51.25%; maximum = 98.75%). Figure 9A shows the accuracy of the object recall by condition and recall order in the working memory session. The best model of the data included only the condition effect, $BF_{10} = 1.67 \times 10^{461}$. There was very strong evidence against the inclusion of recall order, $BF_{10} = .02$, and against the inclusion of its interaction with condition, $BF_{10} = 1.49 \times 10^{-4}$.

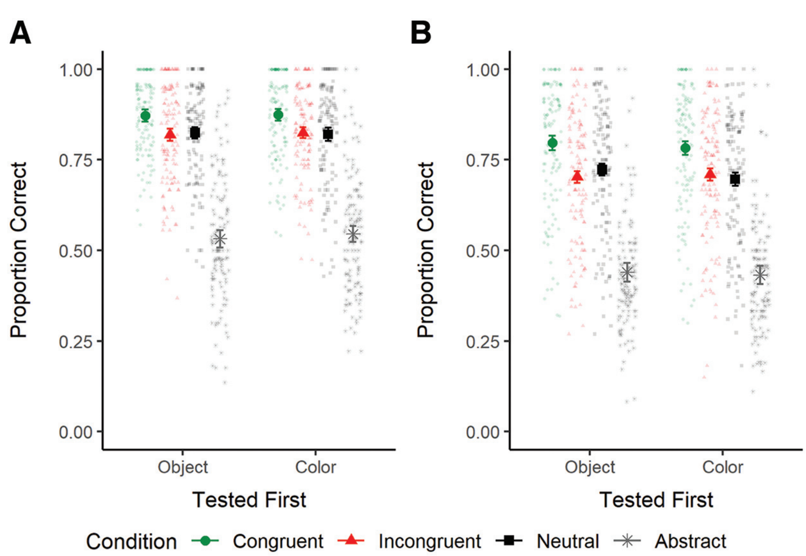
Given that there was no evidence for an order effect, we averaged the data of both orders to follow up on the main effect of condition using *t* tests. Congruent objects were better remembered than incongruent, $d = .49$, 95% CI [.30, .69], $BF_{10} = 7.00 \times 10^{4}$; neutral, $d = .51$ [.31, .70], $BF_{10} = 5.05 \times 10^{4}$; and abstract ones, $d = 2.17$ [2.04, 2.92], $BF_{10} = 2.66 \times 10^{48}$. Abstract objects were remembered more poorly than incongruent, $d = 2.27$ [1.90, 2.63], $BF_{10} = 2.49 \times 10^{46}$, and neutral objects, $d = 2.09$ [1.73, 2.45], $BF_{10} = 1.72 \times 10^{42}$, whereas the latter two did not differ, $d = -.001$ [−.19, .17], $BF_{10} = .10$.

Figure 9B shows the object accuracy in the long-term memory session. Participants responded correctly, on average, to 65.97% of the trials (minimum = 35.42%; maximum = 98.44%). The best model of the data included only the condition effect, $BF_{10} = 1.90 \times 10^{481}$. There was strong evidence against the inclusion of recall order, $BF_{10} = .07$, and extreme evidence against its interaction with condition, $BF_{10} = 9.77 \times 10^{-4}$.

Similar to the working memory session, we averaged across the two recall orders to follow up on the main effect of condition with

Figure 9

Object Recall Accuracy in Experiment 3 as a Function of Test Order and Condition



Note. Congruent objects were recalled better and abstract shapes were recalled worse than in all other conditions. Panel A refers to working memory session. Panel B refers to long-term memory session. The small overlaid dots represent the data of each participant. The larger dots represent the mean of the group. Error bars represent the 95% within-subjects confidence interval. See the online article for the color version of this figure.

t tests. Congruent objects were better recalled than incongruent, $d = .75$, 95% CI [.54, .97], $BF_{10} = 5.29 \times 10^{10}$; neutral, $d = .71$ [.50, .93], $BF_{10} = 1.00 \times 10^{9}$; and abstract objects, $d = 2.14$ [1.77, 2.54], $BF_{10} = 4.39 \times 10^{43}$. Incongruent objects did not differ from neutral ones, $d = -.02$ [−.20, .16], $BF_{10} = .10$. Abstract shapes were more poorly recalled than both incongruent, $d = 1.71$ [1.42, 2.01], $BF_{10} = 1.30 \times 10^{35}$, and neutral objects, $d = 1.78$ [1.47, 2.07], $BF_{10} = 7.07 \times 10^{36}$.

Color Recall

Figure 10A shows the average color recall error as a function of condition and recall order in the working memory session. The best model of the data was the full model including the effects of condition, recall order, and their interaction, $BF_{10} = 3.54 \times 10^{91}$. There was extreme evidence for the inclusion in the model of the effects of condition, $BF_{10} = 3.99 \times 10^{79}$, recall order, $BF_{10} = 1.01 \times 10^{9}$, and their interaction, $BF_{10} = 8.51 \times 10^{2}$. Table 5 presents the effect sizes (Cohen's *d*) for the condition contrasts.

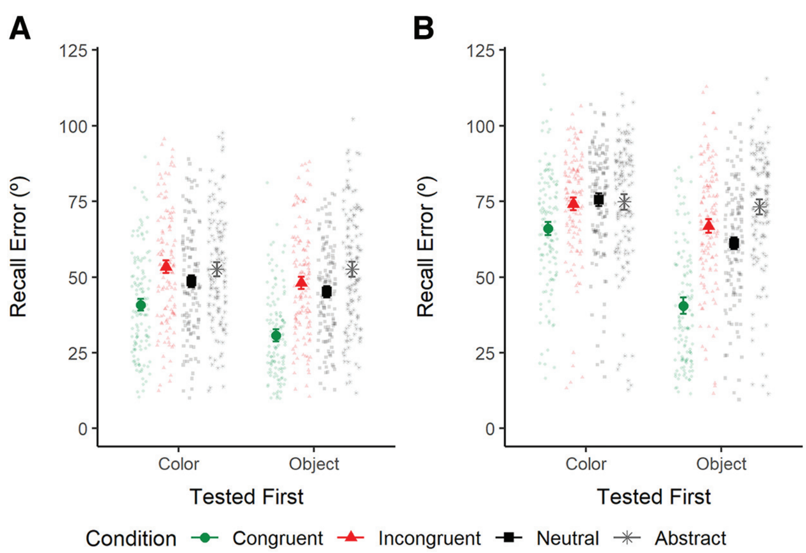
Colors of congruent objects were recalled with lower error than of incongruent, neutral, and abstract objects, both when color was tested first, all $BF_{10} \geq 1.15 \times 10^{5}$, and when object was tested first, all $BF_{10} \geq 2.53 \times 10^{17}$. There was ambiguous evidence against differences in color recall error between incongruent and neutral objects when the object was tested first, $BF_{10} = .88$, but strong evidence for this difference when color was tested first, $BF_{10} = 25.90$. Incongruent and abstract items did not differ when the color was tested first, $BF_{10} = .11$, but there was moderate evidence that incongruent items were better recalled when the object was tested first, $BF_{10} = 3.59$. There was anecdotal evidence for better memory of neutral objects compared to abstract ones when color was tested first, $BF_{10} = 1.96$, and extreme evidence for better recall of neutral than abstract objects when the object was tested first, $BF_{10} = 1.01 \times 10^{3}$.

Regarding the effect of recall order, there was extreme evidence for better color recall when the object was tested first in the congruent, $BF_{10} = 2.71 \times 10^{10}$; and in the incongruent condition, $BF_{10} = 173.76$. There was moderate evidence for a difference in performance as a function of recall order in the neutral condition, $BF_{10} = 3.96$. There was strong evidence against differences in terms of recall order for abstract objects, $BF_{10} = .10$.

Figure 10B shows the average recall error as a function of condition and recall order for the long-term memory session. Effect sizes for the condition contrasts are presented in Table 5. The best model of this data was also the full model, $BF_{10} = 1.82 \times 10^{224}$. There was extreme evidence for the inclusion in the model of congruency, $BF_{10} = 2.24 \times 10^{118}$, recall order, $BF_{10} = 6.38 \times 10^{72}$, and their interaction, $BF_{10} = 5.09 \times 10^{34}$. When color was tested first, recall error was smaller in the congruent condition compared to all other conditions, all $BF_{10} \geq 4587.92$, whereas the remaining conditions did not differ from each other, all $BF_{10} \leq .15$. When object was tested first, recall error was still smaller in the congruent condition compared to all other conditions, all $BF_{10} \geq 3.49 \times 10^{23}$. Recall in the incongruent condition was worse than in the neutral condition, $BF_{10} = 513.23$, but better than in the abstract condition, $BF_{10} = 30.83$.

Regarding recall order, there was extreme evidence for lower recall error when the object was tested first compared to when the color was tested first in the congruent, $BF_{10} = 9.04 \times 10^{29}$, incongruent, $BF_{10} = 9791.26$, and neutral conditions, $BF_{10} = 4.38 \times 10^{14}$, but not for the abstract condition, $BF_{10} = .19$.

Figure 10
Average Error in Reproducing the Colors of the Objects in Experiment 3



Note. The color of congruent objects was better remembered than in all other conditions, and this effect was larger when the object was tested first. Panel A refers to working memory session. Panel B refers to long-term memory session. The small overlaid dots represent the data of each participant. The larger dots represent the mean of the group. Error bars represent the 95% within-subjects confidence interval. See the online article for the color version of this figure.

Table 5
Effect Sizes (Cohen's d) and Their 95% Credible Intervals for the Pairwise Contrast of the Color Recall Error in the Conditions of Experiments 3 and 4

	Working memory Tested first		Episodic long-term memory Tested first	
Condition contrast	Color	Object	Color	Object
Experiment 3				
Con. vs. incon.	−.51 [−.71, −.32]	−1.39 [−1.65, −1.14]	−.84 [−1.09, −.58]	−1.13 [−1.45, −.83]
Con. vs. neutral	−.61 [−.83, −.39]	−1.23 [−1.46, −.97]	−.41 [−.66, −.14]	−.87 [−1.14, −.63]
Con. vs. abstract	−.45 [−.66, −.26]	−1.46 [−1.74, −1.19]	−.59 [−.82, −.36]	−.93 [−1.20, −.66]
Incon. vs. neutral	−.08 [−.26, −.09]	.39 [.21, .57]	.29 [.03, .55]	.11 [−.11, .33]
Incon. vs. abstract	−.03 [−.21, .15]	−.32 [−.51, −.14]	.02 [−.19, .25]	−.13 [−.35, .09]
Neutral vs. abstract	.05 [−.13, .22]	−.64 [−.85, −.43]	−.29 [−.58, −.01]	−.23 [−.46, −.01]
Experiment 4 (Session 2)				
Con. vs. incon.	−.55 [−.85, −.26]	−.93 [−1.26, −.61]		
Con. vs. neutral	−.55 [−.90, −.18]	−.97 [−1.31, −.63]		
Con. vs. abstract	−.28 [−.57, −.01]	−1.26 [−1.62, −.89]		
Incon. vs. neutral	.10 [−.17, .38]	.07 [−.33, .20]		
Incon. vs. abstract	.21 [−.07, .48]	−.45 [−.79, −.12]		
Neutral vs. abstract	.06 [−.20, .35]	−.24 [−.52, .06]		

Note. Con. = congruent; incon. = incongruent.

Finally, we also assessed if the congruency effect, namely the difference between congruent and incongruent objects, was modulated by the color category (i.e., red, green) of the stimulus since the number of stimuli in each color category varied a lot in Experiment 3 (see Figure 1). The online supplemental materials report this analysis. There was no evidence for a main effect of color category or of its interaction with congruency or recall order. These results indicate that the congruency effect was stable across all stimuli used.

Mixture Model for Color Recall

Table 6 presents the evidence for the effects of the manipulated variables in all mixture model parameters.

Figure 11 shows P^M in the working memory and episodic memory sessions. Table 6 shows that for P^M, there was extreme evidence for the main effects of condition and recall order and strong evidence for their interaction in the working memory and in the long-term memory sessions.

In working memory (Figure 11A), colors of congruent objects had a higher P^M than in any other condition, both when the color was tested first, all $BF_{10} \geq 2.06 \times 10^5$, and when the object was tested first, all $BF_{10} \geq 1.92 \times 10^{11}$. Regarding incongruent objects, when color was tested first, they had lower P^M than neutral objects, $BF_{10} = 187.48$, but similar P^M compared to abstract objects, $BF_{10} = .14$. When the object was tested first, incongruent objects had a higher P^M than abstract objects, $BF_{10} = 27.61$, but somewhat lower P^M than neutral objects, $BF_{10} = 1.46$. Neutral objects had a higher P^M than abstract ones both when the color was tested first, $BF_{10} = 1.05 \times 10^3$, and when the object was tested first, $BF_{10} = 4.35 \times 10^4$.

For the working memory session, P^M was higher when the object was tested first compared to when the color was tested first for the congruent, $BF_{10} = 9.51 \times 10^9$, and incongruent conditions, $BF_{10} = 40.73$. There was anecdotal evidence for a difference as a function of recall order for neutral objects, $BF_{10} = 1.12$, and evidence against it for abstract objects, $BF_{10} = .13$. These results suggest that recalling the object first boosted the congruency effect on P^M.

In long-term memory (Figure 11B), congruent objects had a higher P^M than incongruent, neutral, and abstract objects both when the color was tested first, all $BF_{10} \geq 9.19 \times 10^3$, and when the object was tested first, all $BF_{10} \geq 1.99 \times 10^{15}$. When color was tested first, P^M for incongruent objects was not different than for neutral, $BF_{10} = .12$, and abstract objects, $BF_{10} = .14$, and the

Table 6
Evidence (BF_{10}) for the Effects of Condition, Recall Order, and Their Interaction in the Mixture Model Parameters Fit to the Color Recall Data of Experiment 3

	Parameter		
Factors	Probability memory (P^M)	Probability continuous (P^O)	Continuous imprecision (σ^O)
	Working memory		
Condition	5.07×10^9	4.56	4.25
Recall order	2.85×10^6	0.41	0.60
Condition × Recall order	17.92	1.32×10^{-2}	0.48
	Episodic long-term memory		
Condition	2.06×10^{14}	403.80	0.72
Recall order	6.68×10^{25}	0.12	0.44
Condition × Recall Order	2.93×10^5	0.10	0.71

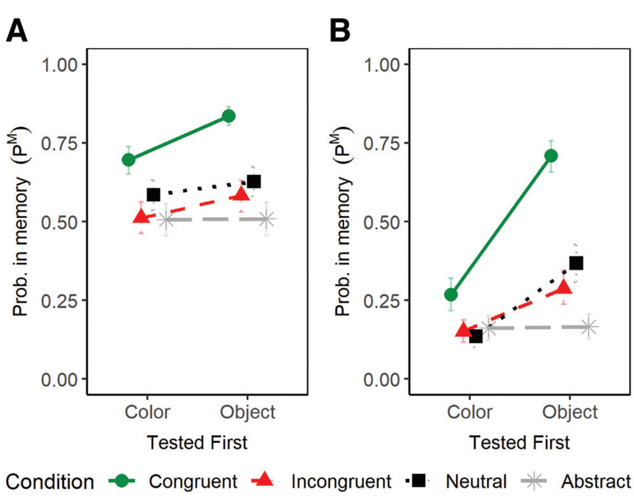
latter two also did not differ, BF_{10} = .46. When object was tested first, there was extreme evidence that P^M for incongruent objects was lower than for neutral objects, BF_{10} = 160.72, but higher than for abstract objects, $BF_{10} = 1.28 \times 10^5$, whereas neutral objects had a higher P^M than abstract objects, $BF_{10} = 9.75 \times 10^9$.

Regarding an effect of recall order, there was extreme evidence for a higher P^M when the object was tested first compared to color tested first for the congruent, incongruent, and neutral conditions, all $BF_{10} \geq 2.06 \times 10^5$. For the abstract condition, there was strong evidence against a recall order effect, BF_{10} = .10. Again, these results are in line with the assumption that activation of the object representation before color recall boosted the congruency effect on this dependent variable.

Figure 12 presents P^O in the working memory and episodic memory sessions. Table 6 shows that the evidence for a condition effect was moderate in working memory and extreme in long-term memory in this parameter. The evidence against an effect of recall order was ambiguous in working memory but strong in long-term memory. In addition, for both systems, the evidence against the Condition × Recall Order interaction was strong.

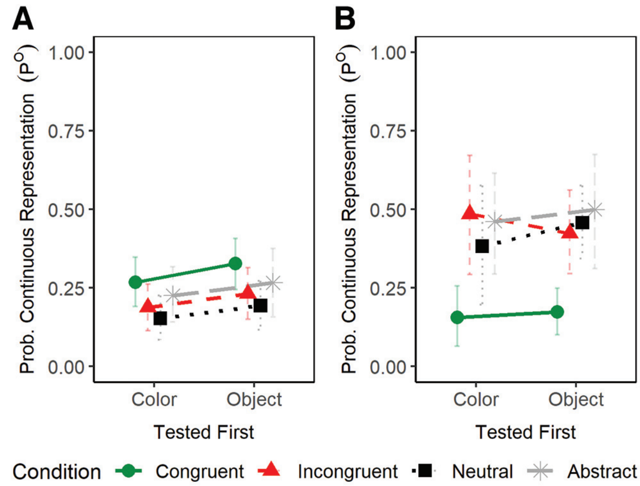
For working memory (Figure 12A), P^O for congruent objects was credibly higher than for neutral objects, both when the color was tested first, BF_{10} = 8.28, and when the object was tested first, BF_{10} = 24.39. In contrast, for long-term memory (Figure 12B), P^O for congruent objects was lower than for incongruent, neutral, and abstract objects, both when the color was tested first, all $BF_{10} \geq 9.03$, and when the object was tested first, all $BF_{10} \geq 205.11$. Therefore, it seems like the large gain induced by the prior knowledge of object-color associations in the P^M parameter for the congruent objects in the episodic long-term memory session was mainly due to an increase in the storage of categorical representations.

Figure 11
Probability in Memory in Experiment 3



Note. Colors of congruent objects had a higher probability (prob.) of being stored in memory, and this effect was stronger when the object was tested first. Panel A represents the parameter in the working memory session. Panel B is from the long-term memory session. Error bars represent 95% credible intervals of the parameter posterior. See the online article for the color version of this figure.

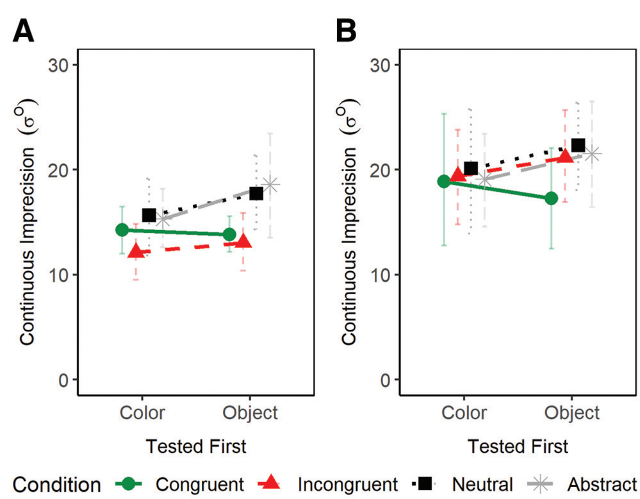
Figure 12
Probability of Continuous Representation in Experiment 3



Note. Continuous representation of colors increased in the congruent condition in the working memory Session A, but it decreased in the long-term memory Session B. Panel A represents the parameter in the working memory session. Panel B is from the long-term memory session. Error bars represent 95% credible intervals. Prob. = probability. See the online article for the color version of this figure.

Figure 13 presents the continuous imprecision parameter for the working memory and episodic long-term memory sessions. Table 6 shows that there was only moderate evidence of a condition effect in working memory (Figure 13A), but not in long-term memory (Figure 13B). There was ambiguous evidence against an effect of recall order and its interaction with condition for both

Figure 13
Continuous Imprecision in Experiment 3



Note. There was only moderate evidence for a condition effect in working memory due to somewhat lower imprecision in the congruent condition compared to the neutral one (when object was tested first). Panel A represents the parameter in the working memory session. Panel B is from the long-term memory session. Error bars represent 95% credible intervals. See the online article for the color version of this figure.

working memory and long-term memory. The only evidence for a difference was between congruent and neutral objects in working memory, but only when the object was tested first, $BF_{10} = 6.25$.

Accounting for Individual Object-Color Associations

When considering all the concrete stimuli, participants responded according to the experimenters' associations, on average, to 88.92% of the objects. We analyzed the responses in the congruent and incongruent conditions of the working memory and long-term memory sessions when considering only tests of the objects that participants associated with the same color as the experimenters. The pattern of results was the same as when all stimuli were considered. These analyses are presented in the online supplemental materials.

Discussion

Experiment 3 had three main objectives. First, it included further control conditions, namely neutral and abstract objects. This allowed us to compare memory for both congruent and incongruent objects against these control baselines. Second, the object was made task relevant so that participants could not ignore this information. Third, we included conditions in which participants could rely only on working memory and conditions in which they had to use episodic long-term memory. This allowed us to compare the effect of prior knowledge for retrieval from working memory and from episodic long-term memory.

In Experiment 3, we observed for the first time that congruent objects were better remembered than incongruent, neutral, and abstract objects in working memory, and this effect was similar in the long-term memory session. By including the object test, we could guarantee that participants were encoding both the object and the color. This seems to have been the key factor in producing an elaboration effect: Congruent objects produced better object and color memory than in any other condition, suggesting that visual working memory can be enriched by previous knowledge.

Unlike studies with verbal memoranda (Bartsch et al., 2019, 2018), we found a benefit of elaboration for both working memory and long-term memory in the visual domain. Yet we also observed that the benefits had different origins in these two memory systems. In visual working memory, congruent colors had higher probability to be in memory (P^M parameter) than in any other condition: incongruent, neutral, and abstract. We also observed a tendency to store more continuous information about a larger number of the congruent objects (i.e., a benefit in the probability of continuous representation, i.e., P^O). For long-term memory, congruent objects also had a higher probability to be in memory compared to the incongruent, neutral, and abstract conditions. In contrast to working memory, however, this gain was mainly due to the storage of more categorical representations as reflected in a reduction of the probability of continuous representation (P^O) for congruent objects in long-term memory.

A further indication that object memory was necessary to produce the elaboration effect was the interaction of condition and recall order. Generally, when the object was tested first, there was a higher probability of recalling the congruent color. Yet it is worth noting that congruent colors were better remembered even when the color was tested first, suggesting that it was the demand to process the object that helped in remembering the associated color.

Although our pattern of results seems to be explained by the requirement to process the object, there are other minor differences to the previous experiments that could explain our findings. First, we included more memory locations (eight instead of four), which may have forced participants to rely more on the object identity to better remember what was presented where. Second, we reduced the pool of concrete stimuli (45 objects in Experiment 3 compared to 64 in Experiment 2 and a 100 in Experiment 1). We reduced the stimulus pool to make sure the objects used were the ones with the largest consensus regarding their association with a specific color category. Third, we included more baseline conditions (neutral and abstract objects). Any of these differences could contribute to the observation of a congruency effect in Experiment 3. To assess if the requirement to attend to and recall the object was the main driver of the congruency effect we observed in Experiment 3, we conducted Experiment 4.

Additionally, after conducting Experiments 1–3, we become aware of a bug in our color wheel program: Due to the way we set up the registering of the responses in the color wheel, the detection of the clicks was relatively imprecise, leading to a slight deviation in relation to the intended response angle location (which resulted in a bias of approximately $-3°$ when recording the responses). This affected all angles in the color wheel. This slight recording imprecision was unlikely to affect our pattern of results because it was a constant across all within-subject conditions in all experiments reported so far. We note that this imprecision did not prevent us from replicating expected effects such as the picture superiority effect, presentation rate benefit, response order effects, working memory versus episodic long-term memory differences, etc. Yet, in Experiment 4, we fixed our code to remove the recording imprecision. Therefore, Experiment 4 also served to replicate our main findings in the absence of this bug.

Experiment 4

Experiment 4 aimed to establish if the requirement to recall both the color and the object was responsible for the congruency effect observed in Experiment 3. To that aim, Experiment 4 replicated the working memory session of Experiment 3 with one exception: In Session 1, participants were instructed to remember the colors presented in each location and were only tested on this information. In Session 2, we instructed participants that they would be tested for both the color and the object presented in each location (as done in Experiment 3).

Method

Participants

Participants were recruited for an online experiment consisting of two sessions (30 min each) in exchange for extra course credits. Data collection occurred between May 6 and June 13, 2022. The links for the sessions were sent across 2 consecutive days. As in the previous experiments, we accepted all submissions completed until the end of the semester.

We initially received submissions from 64 participants, but only 62 completed the two sessions. Participants were adults, first-year students of psychology, and aged between 18 and 52 years old (M = 22.47, SD = 6.83; 48 women, 11 men, three other) and had the same inclusion criteria as in the previous experiments. We further excluded participants based on performance: participants that scored 2 standard deviations below the group mean in the color and/or the object test. In total, two participants were excluded from Session 1 (outliers in the color reproduction) and four from Session 2 (three outliers in the color reproduction and one in the object reproduction).

Materials and Procedure

The same materials as in Experiment 3 were used in Experiment 4 (see Figures 1 and 7). Experiment 4 consisted of two sessions, each consisting of two blocks of 20 trials. Each block included five trials of each condition (congruent, incongruent, neutral, and abstract), which were randomly intermixed. Everything was identical to the working memory session of Experiment 3, except for the test phase in Session 1: Participants were only required to reproduce the color that appeared in each of the four locations, as done in Experiments 1 and 2. In Session 2, participants completed the same procedure as in the working memory session of Experiment 3 (see Figure 8) and were requested to reproduce both the color and the object presented in each location. We did not counterbalance the order of the sessions to avoid any carryover effect of having the object as task relevant.

There was one further difference in the programming of Experiment 4. In Experiments 1–3, we used regions of interest to register clicks on the color wheel. These regions overlapped, creating some recording imprecision. In Experiment 4, we computed the angle between the current *x-y* location of the mouse cursor in relation to the screen center and stored this value when a click was registered. This resolved the recording imprecision from the previous experiments.

Data Analysis

The same analysis procedure as reported in the previous experiments was used. For Session 1, we performed a one-way repeated-measures Bayesian ANOVA for color recall, with condition (congruent, incongruent, neutral, and abstract) as the main predictor. For Session 2, we performed two separate 4 × 2 repeated-measures Bayesian ANOVAs, once for color recall and once for object recall, with condition (congruent, incongruent, neutral, and abstract) and recall order (color tested first and object tested first) as predictors.

We also submitted the color recall data of Experiment 4 to the between-item variant of the categorical-continuous mixture model. For Session 1, we ran 10,000 iterations (with a burn-in of 1,000 iterations). For Session 2, we ran 12,000 iterations (with a burn-in of 2,000 iterations). We increased the number of iterations in Session 2 to obtain more stable parameters.

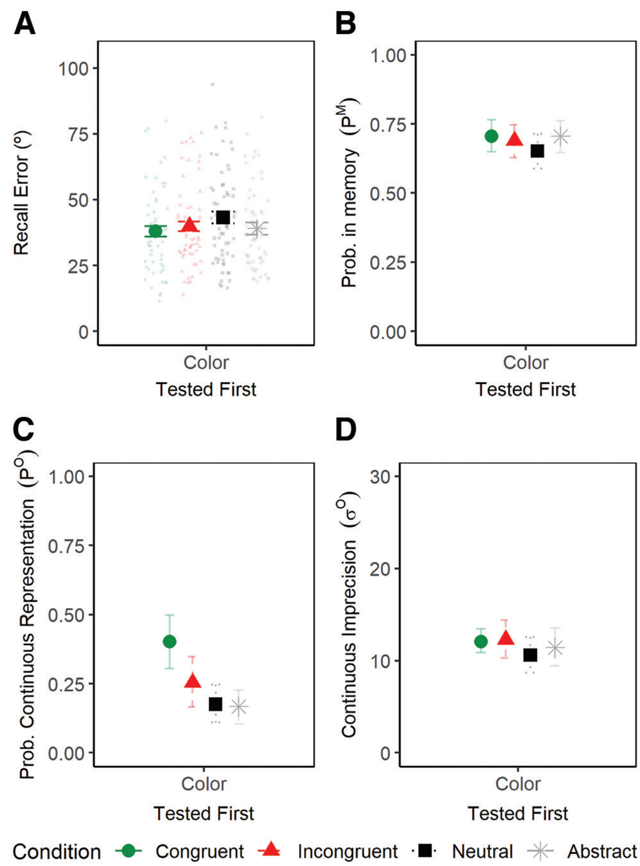
Results

Session 1 – Color Recall

Figure 14A shows the average recall error as a function of condition in Session 1. There was little variation in recall error across conditions, and the ANOVA revealed anecdotal evidence for a condition effect, BF_{10} = 2.47. Replicating Experiments 1 and 2, there was anecdotal evidence against differences between congruent and incongruent objects, d = −.17, 95% CI [−.42, .10], BF_{10} = .35. The only credible effect was of worse recall in the neutral condition compared to the congruent one, d = −.59 [−.88, −.30], BF_{10} = 599.64. Neutral objects were generally worse recalled than in all other conditions, d_{inc} = −.27 [−.54, −.01] and d_{abs} = .31 [.05, .59].

Figure 14

Recall Error (A), Probability in Memory (B), Probability of Continuous Representation (C), and Continuous Imprecision (D) in Session 1 of Experiment 4



Note. Condition had only an ambiguous effect on recall error, yet mixture modeling showed that congruent objects were represented more continuously. In Panel A, the small dots represent the data of each participant. The larger dots represent the mean of the conditions, and error bars represent 95% within-subjects confidence intervals. In Panels B, C, and D, error bars represent 95% credible intervals. Prob. = probability. See the online article for the color version of this figure.

Session 1 – Mixture Model for Color Recall

Figures 14B to 14D show the parameters for the mixture model for Session 1. Regarding P^M, there was anecdotal evidence against a condition effect, BF_{10} = .78. For P^O, there was extreme evidence for a condition effect, BF_{10} = 323.24. More specifically, congruent objects had higher probability to be continuously represented than incongruent, BF_{10} = 16.17, neutral, BF_{10} = 8.08 × 10^3, and abstract objects, BF_{10} = 9.62 × 10^4. There was anecdotal evidence for a higher probability of continuous representation for incongruent items than neutral, BF_{10} = 1.29, and abstract objects, BF_{10} = 2.08. There was moderate evidence against differences between neutral and abstract objects, BF_{10} = .24. Regarding δ^O, there was moderate evidence against the effect of condition, BF_{10} = .32.

Session 2 – Object Recall

Overall, each participant responded correctly, on average, to 70.06% of the object tests (minimum = 38.13%; maximum = 96.88%). Figure 15 shows the individual and group means for object recall across conditions in Session 2. The best model of the data included only the condition effect, BF_{10} = 4.46 × 10^{151}. There was very strong evidence against a recall order effect, BF_{10} = .05, and extreme evidence against an interaction between the two factors, BF_{10} = 5.29 × 10^{-4}.

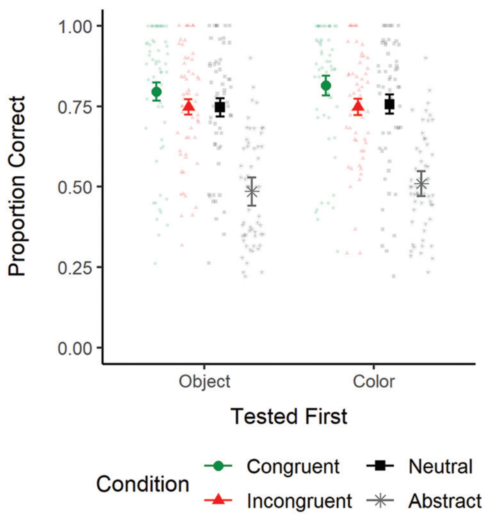
Given the absence of a recall order effect, we averaged across recall orders to follow up on the effect of condition with *t* tests. Congruent objects were better remembered than incongruent, *d* = .51, 95% CI [.21, .80], BF_{10} = 48.51; neutral, *d* = .57 [.25, .91], BF_{10} = 66.83; and abstract ones, *d* = 1.87 [1.32, 2.44], BF_{10} = 8.54 × 10^{15}. Abstract objects were worse recalled than incongruent, *d* = 1.87 [1.37, 2.38], BF_{10} = 1.86 × 10^{16}, and neutral objects, *d* = 1.46 [1.06, 1.88], BF_{10} = 4.82 × 10^{12}, and the latter two did not differ, *d* = −.02 [−.28, .26], BF_{10} = .15.

Session 2 – Color Recall

Figure 16A shows the mean recall error as a function of condition and recall order in Experiment 4. Table 5 shows the effect sizes for the condition contrasts. The best model of the data was

Figure 15

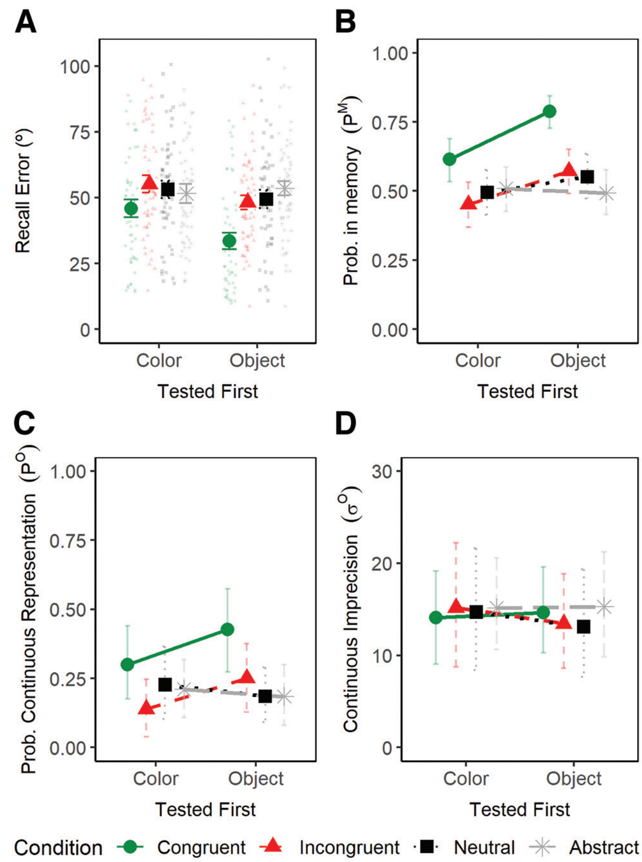
Object Recall Accuracy in Session 2 of Experiment 4 as a Function of Test Order and Condition



Note. Congruent objects were recalled better and abstract shapes were recalled worse than in all other conditions. The small overlaid dots represent the data of each participant. The larger dots represent the mean of the group. Error bars represent the 95% within-subjects confidence interval. See the online article for the color version of this figure.

Figure 16

Recall Error (A), Probability in Memory (B), Probability of Continuous Representation (C), and Continuous Imprecision (D) in Session 2 of Experiment 4



Note. Colors of congruent objects were better recalled than in all other conditions. Congruency increased the probability (prob.) of storage in memory and the storage of continuous information. In Panel A, the small dots represent the data of each participant. The larger dots represent the mean of the conditions, and error bars represent 95% within-subjects confidence intervals. In Panels B, C and D, error bars represent 95% credible intervals. See the online article for the color version of this figure.

the full model, BF_{10} = 1.72 × 10^{27}. There was evidence for a condition effect, BF_{10} = 5.28 × 10^{20}; recall order effect, BF_{10} = 8.34 × 10^4; and their interaction, BF_{10} = 98.11. The colors of congruent objects were better recalled than of incongruent, all $BF_{10} \geq$ 103.25, and neutral objects, all $BF_{10} \geq$ 11.14, irrespective of color or object being tested first. Colors of congruent objects were better recalled than of abstract ones when the object was tested first, BF_{10} = 1.93 × 10^{10}, but evidence was anecdotal when the color was tested first, BF_{10} = 1.08. Colors of incongruent objects were better recalled than of abstract ones when object was tested first, BF_{10} = 4.16, but not when color was tested first, BF_{10} = .39. Neutral, incongruent, and abstract objects did not differ, .17 ≤ BF_{10} ≤ .59, in both recall orders.

Concerning recall order, colors of congruent, BF_{10} = 7.92 × 10^5, and incongruent objects, BF_{10} = 48.64, were better recalled when object was tested first compared to color tested first. For neutral, BF_{10} = .52, and abstract objects, BF_{10} = .25, the evidence was against differences as a function of recall order.

Last, we examined if the congruency effect was modulated by the color category of the stimuli. This analysis is presented in the online supplemental materials. The results showed that there was evidence against the inclusion of the color category and their interaction with condition and recall order.

Session 2 – Mixture Model for Color Recall

Figures 16B to 16D present the parameters of the mixture model for Session 2. Figure 16A shows the results for P^M. There was extreme evidence for main effects of condition and recall order and very strong evidence for their interaction in this parameter (see Table 7). Colors of congruent objects had a higher P^M than of incongruent, neutral, and abstract objects, both when the color was tested first, all $BF_{10} \geq 40.90$, and when the object was tested first, all $BF_{10} \geq 1.48 \times 10^8$. When color was tested first, there was anecdotal evidence against differences of incongruent to neutral, BF_{10} = .65, and to abstract objects, BF_{10} = .90, as well as between neutral and abstract objects, BF_{10} = .22. When object was tested first, incongruent objects had higher P^M than abstract, BF_{10} = 4.79, but not neutral objects, BF_{10} = .30, and there was anecdotal evidence for higher P^M for neutral than abstract objects, BF_{10} = 1.10. Concerning recall order, P^M was higher when the object was tested first compared to color tested first for congruent, $BF_{10} = 5.31 \times 10^5$, and incongruent objects, BF_{10} = 139.03. There was anecdotal evidence for a recall order effect for neutral objects, BF_{10} = 1.04, and substantial evidence against it for abstract objects, BF_{10} = .23.

Figure 16C presents P^O. Table 7 shows that there was moderate evidence for a condition effect and moderate evidence against a recall order effect and its interaction with condition for P^O. Colors of congruent objects had higher probability to be continuously represented than colors of incongruent, BF_{10} = 13.50; abstract, BF_{10} = 42.18; and neutral objects, BF_{10} = 7.13. There was moderate evidence against differences between incongruent and neutral, BF_{10} = .13; incongruent and abstract, BF_{10} = .17; and neutral and abstract objects, BF_{10} = .15.

Figure 16D shows σ^O. Table 7 shows that there was anecdotal evidence against a condition effect and moderate evidence against a recall order effect and its interaction with condition.

Discussion

The main goal of Experiment 4 was to assess the role of testing both the object and the color for the congruency effect observed in Experiment 3. Accordingly, we replicated Experiment 3 while contrasting two scenarios between sessions: (a) only color was test relevant as in Experiments 1 and 2, and (b) both color and object were test relevant as in Experiment 3. Everything else was the same as in Experiment 3.

When only color was test relevant, recall error did not substantially vary between conditions, particularly between congruent and incongruent objects, replicating Experiments 1 and 2. Yet mixture modeling showed that in Experiment 4, participants were able to use congruent objects to store more continuous information about the colors. This was a novel result compared to the previous studies. This novel result could be related to the use of a smaller set of stimuli for which there was a larger consensus regarding the prior object-color association.

Critically, replicating Experiment 3, when both color and object were test relevant, better memory for both the colors and the objects was observed. This was reflected in a credibly lower color recall error and higher probability of reporting which object appeared in a given location. Again, replicating Experiment 3, recall order (color or object tested first) modulated the congruency benefit in color recall: When the object was tested first, color recall was more accurate than when color was tested first. Mixture modeling showed that the benefits of congruency were again reflected in a higher probability of memory storage, with more information being stored in a continuous format. These results suggest that object memory was not simply serving for guessing the color category.

General Discussion

Elaboration is the process of enriching recently encoded information to increase its retention in memory. One way to enrich representations is to associate it with prior knowledge (Bartsch et al., 2019, 2018). In previous studies in verbal working memory, elaboration was found to be an ineffective means to boost performance, although that strategy improved episodic long-term memory (Bartsch & Oberauer, 2021; Bartsch et al., 2019, 2018; Jonker & MacLeod, 2015).

Yet, to the best of our knowledge, no study evaluated the impact of elaboration in visual working memory. Here, we attempted to enrich the representation of color in visual working memory by requesting participants to memorize the color of objects that were either presented in a color congruent (e.g., a yellow banana) or incongruent with their typical state (Experiments 1–4). Additionally, in Experiments 3 and 4, we also presented neutral objects—objects that are not usually associated with a specific color—and abstract objects—new shapes taken from the validated circular shape set (A. Y. Li et al., 2020). Our main hypothesis was that color elaboration at encoding would be facilitated by the

Table 7
Evidence (BF_{10}) for the Effects of Condition, Recall Order, and Their Interaction in the Mixture Model Parameters Considering the Data of Session 2 of Experiment 4

	Parameter		
Factors	Probability memory (P^M)	Probability continuous (P^O)	Continuous imprecision (σ^O)
Condition	4.81×10^4	6.05	0.36
Recall order	4.58×10^4	0.19	0.24
Condition × Recall Order	52.68	0.21	0.17

presentation of congruent colors. In the following, we will discuss our findings and their implication for the use of elaboration as a strategy to improve visual working memory.

How to Best Activate Prior Knowledge?

In Experiment 1, we manipulated congruency and additionally presented the stimuli as words and images. We found that the colors of images were better recalled than the colors of words, yet congruency had no effect on memory, nor did it interact with the format of the memoranda. It has been observed that pictures (compared to words) benefit visual memory for characteristics such as the spatial location and the temporal order of the stimulus in a working memory task (Cattaneo et al., 2007). The results of our first experiment suggest that color might be easier to memorize from images than from words. However, we should note that we made little effort to determine that the colored area was the same for the words and images since our main aim was to evaluate the interaction of format with congruency. Hence, we cannot ascertain that the reason for the image superiority is due to domain of the memoranda.

Our main reason to manipulate the format was to test for the possibility that different formats would have privileged access to representations in long-term memory, thereby being more effective as an elaboration support. According to the *picture superiority effect* (Cherry et al., 2008, 2012; Paivio, 1991), images could be stored in multiple formats, which could be a means to further enrich the representation of the newly encoded stimulus. Alternatively, there is evidence that the meaning of words tends to be processed automatically even if they are not task relevant, as revealed, for example, by the Stroop effect (Lorentz et al., 2016; Stroop, 1935). There is also some evidence that colored words would produce a color interference effect (Cortese et al., 2019). Furthermore, previous work has shown that words tend to activate categories more broadly in long-term memory than category exemplars (Boutonnet & Lupyan, 2015; Edmiston & Lupyan, 2015; Lupyan & Thompson-Schill, 2012). Yet colored words in our study did not facilitate elaboration. If anything, it is possible that the tendency to read the word detracted participants from memorizing the color, leading to the worse performance we observed.

Our study therefore lends little support for any differences between visual versus verbal forms of elaboration support in visual working memory, when considering the activation of prior knowledge about object-color associations. In verbal working memory, there was also no evidence that verbal (e.g., sentence generation) or visual (imagery) strategies would differentially affect the effectiveness of elaboration (Bartsch & Oberauer, 2021; Bartsch et al., 2019, 2018; Jonker & MacLeod, 2015). Future studies will be required to assess if other forms of elaboration could affect differently the retention of information in visual working memory.

Time to Elaborate and Strategy Instructions

In Experiment 2, we presented only colored images since this material was easier to memorize and more commonly used in the visual working memory literature (Oberauer et al., 2017; Overkott & Souza, 2022; Sutterer & Awh, 2016). We manipulated the time to encode the memoranda (1,500 ms vs. 4,500 ms per stimulus) with the hypothesis that longer time would favor the consolidation of the stimulus presented (Ricker, 2015; Ricker et al., 2018; Ricker & Hardman, 2017) and allow for the activation of prior knowledge in long-term memory, thereby facilitating elaboration. Studies by Brady and collaborators (Brady & Störmer, 2021; Brady et al., 2016) suggested that some conditions such as longer time and sequential presentation facilitate encoding of items that have richer semantic content. Based on this, we reasoned that providing more time to encode the memoranda could facilitate the use of elaboration. Longer time was associated with better retrieval from visual working memory, but again, congruency had no effect, and it did not interact with encoding time. The beneficial effect of longer encoding time for sequentially presented items has been observed both in verbal (Mızrak & Oberauer, 2021; Souza & Oberauer, 2018; Tan & Ward, 2008) and visual working memory tasks (X. Li et al., 2020; Ricker & Hardman, 2017; Ricker & Sandry, 2018). Here, we found no evidence that the use of prior knowledge is favored in a condition in which more encoding time is provided, suggesting that the beneficial effect of time is not necessarily due to use of elaboration or the activation of the semantic network.

In another condition of Experiment 2 (Session 2), we provided a long encoding time, blocked the presentation of congruent and incongruent trials, and instructed half of the sample to associate the color to the object in the congruent block (elaboration group). Our reasoning was that blocking the congruency would facilitate the use of an elaborative strategy in the congruent condition, and this effect would be increased by the strategy instruction. We observed no main effect of congruency or group, nor an interaction between them. This is in line with previous results in the verbal domain showing that elaboration instructions do not benefit working memory (Bartsch & Oberauer, 2021; Bartsch et al., 2019, 2018; Jonker & MacLeod, 2015). These results therefore suggest that the lack of a congruency effect was not due to the short time to process the information or a deficit in noticing the availability of the object-color congruency as a potential aid for remembering the colors.

Making Object Information Task Relevant

In Experiments 3 and 4, we made the object task relevant by requiring participants to also recall the objects through a three-alternative forced-choice test. We reasoned that this would favor the encoding of a unified representation of the object and color. Additionally, we included further control conditions consisting of neutral objects (no specific color association) and abstract objects (novel shapes). This permitted us to assess for the likelihood of a bizarreness effect (Geraci et al., 2013; McDaniel & Einstein, 1986; Morita & Kambara, 2022) that could boost memory in incongruent trials and mask the effect of elaboration. Finally, in Experiment 3, we tested memory in conditions in which participants could rely solely on working memory and in other conditions in which they had to use their episodic long-term memory. Our goal was to test if the elaboration support (the object prior knowledge) has a differential impact on working memory as opposed to long-term memory, as has been observed in the verbal domain (Bartsch et al., 2019, 2018).

For both working memory and episodic long-term memory, congruent objects were better recalled than incongruent, neutral, and abstract ones in terms of the probability of remembering the presented object as well as the color associated with it. This result showed, for the first time, a benefit of elaboration support on visual working memory. This was not due to a bizarreness effect since incongruent objects were not systematically recalled better than neutral and abstract ones.

A critical difference between Experiments 1 and 2 and Experiment 3 was regarding the implementation of the object test. It seems like the process of encoding the object and the color together (as opposed to asking participants to focus only on the color) favored the use of the available information about the object-color association, boosting both shape and color memory. One could argue that participants simply used the object to guess the associated color. One piece of evidence against this explanation is that the color boost was observed both when the object was retrieved first and when the color was retrieved first. Additionally, a benefit of retrieving the object first was observed for neutral and incongruent objects as well. This means that when participants had to remember the object in order to place their color responses, object activation facilitated color retrieval. Another piece of evidence against this explanation is that congruency also improved shape memory, and this occurred irrespective of the recall order. It seems unlikely that pure guessing would allow participants to also better remember which shape was presented in which location. Finally, the benefit of congruent objects in working memory translated into a larger proportion of continuous responses about the precise color presented—which would not be possible if participants simply guessed a typical color for that object (which would be reflected in more categorical responses). In long-term memory, however, the results were consistent with an increase in categorical responses in the congruent condition. These results suggest that elaboration may help working memory and long-term memory in different ways, which may explain why the effects of elaboration are usually dissociated across these two systems (Bartsch et al., 2019, 2018; Loaiza & Camos, 2016; Thalmann et al., 2019). The differences in the impact of elaboration on the storage of continuous and categorical representations across visual working memory and visual episodic long-term memory may be related to the different levels of interference present when retrieving information from these systems. In the study by Overkott and Souza (2022), participants verbally labeled the memoranda or performed articulatory suppression. Compared to articulatory suppression, verbal labeling of colors boosted the storage of continuous visual working memory, but labeling only boosted the storage of categorical representations in long-term memory. Indeed, Overkott and Souza observed a large proportion of continuous memory in visual working memory tests than in episodic long-term memory tests. This suggests that the fragility of continuous memory may prevent a benefit of strategies such as verbal labeling and elaboration to appear in this parameter over the long term.

In Experiment 4, we further evaluated the role of testing the object in generating an elaboration benefit by requiring only color recall in one session and both color and object memory in the other session. A congruency benefit was more robustly observed when both the color and the object were test relevant, replicating our previous results. Yet Experiment 4 also showed that even in the absence of object recall, participants were able to use congruency to store some more fine-grained information about the colors, yet this benefit did not translate to a lower overall recall error, suggesting that this boost was much smaller than when participants were forced to process both features.

Why was elaboration more effective when we forced participants to also remember the objects? One possibility is that by focusing on color, participants were highly efficient in filtering out the irrelevant information of the object in Experiments 1 and 2 (Maniglia & Souza, 2020; Shin & Ma, 2016). Remembering both features creates a higher load on working memory (Fougnie et al., 2010; Hardman & Cowan, 2015; Oberauer & Eichenberger, 2013). Indeed, if we compare performance in Experiment 2 (1,500 ms presentation) and Experiment 3, we observe that reproduction error was larger in the later. If we also compare color recall across Sessions 1 and 2 from Experiment 4, we also see that performance was poorer in Session 2 when they had to remember both features compared to Session 1 in which only color was relevant. This may explain why participants refrained from using object information when it was task irrelevant. This may also explain why elaboration is usually not beneficial in working memory: It enriches the representation, making it more robust; however, it also produces a higher load on working memory capacity, and this may cancel out its potential beneficial effect. Since long-term memory is not capacity limited, elaboration does not burden this system, and hence benefits could always accrue in this system. One limitation is that we did not test long-term memory in Experiments 1 and 2; thus, we do not know if the lack of elaboration benefit in visual working memory observed in these experiments would translate in a differential probability of storing elaborated information in long-term memory. This would further support a difference between the creation and retrieval of information in these two memory systems. Future studies should assess for this possibility.

To conclude, our set of experiments indicated that elaboration through prior knowledge of object-color associations can improve the retention of colors in working memory, particularly when the elaborated association is task relevant.

Item Effects

Throughout our experiments, the selection of stimuli was gradually adjusted. For the congruent and incongruent conditions, we started with a pool of 100 images in Experiment 1, reduced it to 64 in Experiment 2, and settled on the most consensual 45 concrete objects in Experiments 3 and 4. The average consensus regarding the object-color associations increased from 66% (100 images), to 78% (64 images), to finally 89% (45 images). Therefore, it seems that we were able to refine our stimulus set to make it more relevant for the study of prior knowledge about object-color associations.

Given that, in Experiment 4, we did observe some effect of congruency with a smaller object set even in the absence of an object test, it seems worthy to consider the impact of the stimulus pool on the results observed in Experiments 1 and 2. It is possible that the refined selection of 45 highly consensual objects in Experiments 3 and 4 was more favorable for the observation of an elaboration benefit. Therefore, we repeated the analysis of the data of Experiments 1 and 2 considering only the subset of 45 objects used in Experiments 3 and 4 (see the online supplemental materials). Yet the same pattern of results remained, namely that congruency had no main effect on recall error. Given that, in Experiment 4, we also did not observe an effect of congruency on the raw recall error scores, but only on the P^O parameter of the mixture model, these results are not divergent from those observed in Experiment 4.

Given the constrains on stimulus selection used in Experiment 1 (i.e., exposition to each stimulus only once), reducing the stimulus pool left us with too few responses per condition for analysis with the mixture model (approximately 22 responses per design cell). For Experiment 2, this set was slightly larger (approximately 38 responses per design cell), and the number of participants was also larger. Hence, we submitted this smaller data subset to mixture modeling. The results are presented in the online supplemental materials. Overall, there was some ambiguous evidence (BFs between 2 and 3.5) in Sessions 1 and 2 in the direction of lower memory imprecision for congruent objects. Although here we observed some ambiguous evidence for a congruency effect on the σ^O, whereas in Experiment 4 the congruency effect was in P^O, these results tend to go in the same direction, namely that congruent items improved the storage of continuous representations. Hence, these findings suggest that congruency could be helpful even when object is task irrelevant provided that the object-color association is very high. Hence, future studies should carefully consider the pool of stimuli used. We should note, however, that these benefits were much smaller (and only visible after modeling) than the ones observed when participants were required to remember both the object and the color (which were also apparent in the analysis of recall error).

Outlook: Further Understanding the Role of Elaboration in Working Memory

Only when objects were relevant for the memory test, we observed substantial benefits of prior object-color knowledge on memory. Furthermore, the congruency effect on color memory was larger when the object was retrieved first, thereby providing an appropriate context to retrieve the color.

These results suggest that manipulations targeting retrieval were more effective than manipulations targeting encoding (memoranda format, time, and instruction) to favor the use of elaboration. This further suggests that elaborated encoding may not be as relevant as previously thought. Rather, elaborative retrieval—that is, which representations are activated at the time we are searching our memory—could be a more serious candidate mechanism for explaining the benefits we observed. It is also possible that changing the task demand at retrieval boosted elaborated encoding by making the association of the to-be-remembered features relevant. We note that this seems to have occurred as a consequence of the retrieval manipulation. As such, we believe future studies should further explore the role of retrieval processes.

These results dovetail with other recent findings from our lab pointing to a critical role of testing to favor the interplay of working memory and long-term memory representations. Souza and Oberauer (2022) observed that the long-term learning of repeatedly presented visuospatial information in a working memory task (i.e., a Hebb-repetition paradigm) depended more on the retrieval conditions (namely, the type of memory test and how many elements of the array need to be retrieved) than on presentation mode (simultaneous or sequential) and encoding time (fast or slow presentation rate). Hence, future studies may need to focus more on the retrieval demands of the task to understand how to facilitate the storage and use of long-term memory representations to bypass the capacity limits of working memory.

Additionally, it is important to assess whether and how other forms of elaboration can boost visual working memory. Here, we used prior knowledge about object-color associations as elaboration support. Another possibility is to foster deeper processing of the memoranda through a levels of processing task (Craik & Tulving, 1975). There is mixed evidence that manipulations of the levels of processing produce a benefit in verbal working memory tasks (Loaiza & Camos, 2016; Loaiza et al., 2011; Rose et al., 2015, 2010; Rose & Craik, 2012). It is unclear if this holds for visual working memory. Finally, a key point that should be focused on in future studies is examining what makes visual working memory amenable to a benefit from elaboration as opposed to verbal working memory. Future studies should directly contrast memory in these two memory systems under comparable conditions. This would further illuminate how working memory and long-term memory knowledge interact and the conditions that serve to facilitate the cooperation between these systems.

Conclusion

In this study, we examined the effect of elaboration support on visual working memory and, to some extent, visual episodic long-term memory. We found that providing support to use prior knowledge of object-color associations at encoding did not substantially boost color working memory. Only when both object and color were made test relevant, prior knowledge favored retrieval of color information from visual working memory and episodic long-term memory. Our results therefore suggest that elaboration can boost visual working memory, especially when associations are activated at retrieval.

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