Independent storage of real-world object features is visual rather than verbal in nature

Platon A. Tikhonenko¹, Timothy F. Brady², & Igor S. Utochkin¹

¹HSE University, Russia

²University of California San Diego, USA

Corresponding author: Igor S. Utochkin

Address:

Psychology Department, HSE University

101000, Armyansky per., 4

Moscow, Russian Federation

E-mail: isutochkin@inbox.ru

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Abstract

Previous work has shown that semantically meaningful properties of visually presented real-world objects, such as their color, their state/configuration of their parts/pose, or the features that differentiate them from other exemplars of the same category, are stored with a high degree of independence in long-term memory (e.g., are frequently swapped or misbound across objects). But is this feature independence due to the visual representation of the objects, or because of verbal encoding? Semantically meaningful features can also be labeled by distinct words, which can be recombined to produce independent descriptions of real-world object features. Here, we directly test how much of the pattern of feature independence arises from visual vs. verbal encoding. In two experiments, during the study phase we orthogonally varied the match or mismatch of state (e.g., open/closed) and color information between images of objects and their verbal descriptions (Experiment 1) or between images of two exemplars from the same category (Experiment 2). At test, observers had to choose a previously presented image or description in a 4-AFC task. Whereas in Experiment 1 we found quite a small effect of visual-verbal mismatch on memory for images, the effect of mismatch between exemplars in Experiment 2 was dramatic: memory for a feature was reasonably good when it matched between exemplars, but dropped to chance otherwise. Importantly, this effect was observed both for color and object state independently. We conclude that independent, feature-based storage of objects in long-term memory is provided primarily by visual representations with possible minor influences of verbal encoding.

Keywords: visual memory, long-term memory, verbal encoding, objects and features

Visual long-term memory can store thousands of real-world objects (Standing, 1973) with a lot of detail including specific states or poses (Brady et al., 2008). Even when there are multiple semantically similar objects encoded in long-term memory, they still can be visually recognized with reasonable accuracy (Konkle et al., 2010). However, the representational format underlying successful retrieval of multiple objects from visual long-term memory is still highly debated. How is the information about each individual object represented so that it can be distinguished among thousands of other individual objects? Does the observer encode each object as a single holistic pattern and then discriminate it from other such patterns? Or does the observer encode each item as a collection of independent features (colors, shapes, object parts, etc.) and decide whether an object looks familiar or not for each feature separately? Both views on the representational format of visual long-term memory can be found in the literature.

The idea of relatively independent feature storage implies that the information about objects can be stored in such a way that makes it possible to recognize some of its features without the need to remember other features. This was illustrated by Brady and colleagues (2013) who found that various features of real-world objects (e.g. specific features underlying exemplar discriminations, object states, or colors) could be forgotten at different rates. That is, when one feature of an object was lost, another feature could often still be in memory. The researchers also observed independent memory performance for different features after a long delay (people might remember state, but not remember exemplar and vice versa). Another strong consequence of feature independence is binding errors when observers tend to recognize never presented objects that combine familiar features from different objects (Reinitz et al., 1992; Utochkin & Brady, 2020). For example, Utochkin and Brady (2020) had participants remember a set of objects from various basic-level categories represented by

different exemplars in various states (e.g., two mugs, one full and one empty). Utochkin and Brady (2020) found that their participants had reasonably good recognition rates for exemplars (which mug?) and states (were both mugs full or empty?) they had studied, but they frequently confused which state went with which exemplar. In another line of experiments, Utochkin and Brady (2020) asked participants to remember exemplars, each presented in a certain state, and to recognize these exemplars against new exemplars when the states were manipulated at test (for example, when the old exemplar went with a new, unfamiliar state and the old exemplar went with the old state originally presented with the old exemplar). The observers showed very little interference in this task which suggests that changing state features did not impair an ability to independently recognize exemplar features.

The opposing view on visual long-term memory for objects is that they are represented as integrated, holistic entities (Balaban et al., 2020; Bastin et al., 2019). In this account, all features of the same object are stored or forgotten together (Ceraso, Kourtzi, & Ray, 1998) or, in a different scenario, forgetting of some features necessarily entails forgetting of other features but not vice versa (Balaban et al., 2020). Although the independent-feature framework and the integrated-object framework look absolutely opposing, they both are based on relative evidence of feature independence or boundedness that appears to depend on additional circumstances like retrieval delay (Balaban et al., 2020; Brady et al., 2013) or observer's emotional state (Spachtholtz & Kuhbandner, 2017). Therefore, the existing evidence about the extent to which objects are stored as bundles of somewhat independent features vs. in a more holistic, integrated format is complicated and gives rise to viewpoints suggesting that both representational formats might co-exist (Kuhbandner, 2020).

While focusing on the independent vs. bound character of object representations in visual long-term memory, the researchers usually do not discuss another fundamental question also related to the representational format: How *visual* are these representations? In most of the aforementioned studies on that topic, their authors used visual images of objects to answer some questions about the visual subsystem of long-term memory. However, there is a possibility that these representations are not only visual or visual and semantic, but are also affected by another powerful system, namely, verbal long-term memory. Given that these visual experiments generally use nameable real-world objects or features (often basic colors or simple shapes), verbal encoding can become a strong tool to support storage and retrieval. Applying verbal encoding to memorizing visual images can potentially affect whether these images are recalled as whole objects or as independent features. It is easy to imagine that, if an observer can name relevant features of a visual object with separate words (e.g., “red full coffee mug”), then it would favor an independent-feature memory pattern because separate words can be forgotten separately or migrate independently between descriptions of other objects. Items whose relevant features are harder to name with separate words (either because they are not easily nameable, or because the observer does not know which features are relevant), might give rise to a more whole-object memory pattern. Therefore, it is possible that the previous conclusions about the representational format of visual memory in fact reflect the way things are encoded verbally. Some of the previous studies have attempted to diminish intentional verbal encoding by introducing a concurrent verbal interference task (Utochkin & Brady, 2020) or using a filler task to make participants not suspecting of a subsequent memory test (Brady et al., 2013). However, the verbal interference task in these studies was not very demanding, making it possible that participants were able to generate names for studied objects in parallel (Toppino & Pisegna, 2005).

Similarly, using a filler task did not completely preclude observers from unintentional verbal or conceptual encoding. Therefore, the question that needs to be resolved is how much of the object and feature representation addressed by the previous literature are genuinely visual and not verbal.

Views on the representations of verbal and visual codes

Of course, the importance of the question about the roles of visual and verbal codes in representing objects and features in long-term memory is not limited to methodological issues of a specific research field. It is related to more general questions about the roles of modal-specific (e.g. visual) and conceptual or verbal representations in the organization of knowledge and cognition. The translation of visual input into a verbal code is considered by some researchers a default process for various visual tasks and sometimes an unavoidable tendency (Simons, 1996; Postle, D'Esposito, & Corkin, 2005; Postle & Hamidi, 2007). This view is consistent with an idea that mental representations are necessarily multidimensional (Wickens, 1973) and supported by neurophysiological data suggesting that visual representations might be fastly augmented with verbal and semantic representations (Lewis-Peacock, Drysdale & Postle, 2015).

There are different views of the interaction between verbal and visual representational formats in building long-term memories. For example, the representational shift account (Lupyan, 2008) assumes that verbal labeling of familiar objects may induce the augmentation of their representations with conceptual information. This account is based on findings that verbal labels effectively activate conceptual knowledge in quite an abstract, decontextualized form (Edmiston & Lupyan, 2015) and do it better than non-verbal sounds (Lupyan & Thompson-Schill, 2012). Another framework, a two-mental-representations view (Schuler, 2015) based on the dual coding theory (Paivio, 1990) assumes that verbally and visually

encoded traces of the same object or episode constitute an integrative memory consisting of two separate but connected representations, verbal and visual. Another view postulates the single mental representation that also integrates visual and verbal information but in an abstract, conceptual form (Schuler, 2015; Mayer, 2009; Schnotz & Bannert, 2003). The idea of visual and verbal integration is supported by numerous studies that have found evidence for unidirectional or bidirectional interference between picture memory and text memory when their contents were related but conflicting in some details (Arndt et al., 2015, 2019; Gentner & Loftus, 1997; Pezdek, 1997; Schuler et al., 2015). Another set of evidence for the possibility of such integration comes from eyewitness memory when visually encoded episodes can be affected by the verbal survey (Loftus & Palmer, 1974) or by the eyewitness' own language (Fausey & Boroditsky, 2010). It is noteworthy that the interaction between the visual and verbal sources of memories of these kinds comply with binding errors that are central to the debate about the representational format for visual objects described above (e.g., Utochkin & Brady, 2020; Balaban et al. 2020).

The current study

Thus, the basic motivation of the current study lies at the intersection of two questions about object representation in long-term memory: Whether the objects are stored in a unitized format, or as independent features (the representational format question), and whether the representational format (whichever it is) is genuinely visual or mediated by verbal codes. We created a test of these questions in two experiments where we measured recognition memory for real-world objects while independently manipulating their features (colors and states) and presenting these objects as visual images or as verbal descriptions. Measuring both the feature and modality effects was based on testing how people remember paired items (exemplars) from the same basic category when their target features match vs.

mismatch. This paradigm was originally used to distinguish between the independent-feature vs. unitized-object representations (Utochkin & Brady, 2020) and has a major benefit over other approaches that have been used in that it does not depend on the details of the model of memory used (unlike e.g., Balaban et al. 2020; Brady et al. 2013).. For example, suppose an observer is shown a red closed backpack A and a red closed backpack B and then has to choose the exact color and state of each backpack out of four combinations of correct and incorrect colors and states (e.g., open red backpack A, open green backpack A, closed red backpack A, closed green backpack A; the same four options are available for backpack B). Since both backpacks are red and closed, it is sufficient that the observer remembers this fact to correctly choose the correct color and state for both backpacks without the need to remember which of the backpacks had which color or state. But if the backpacks differ in one of the features (e.g., red closed backpack A vs. green closed backpack B) or even in both features (e.g. red closed backpack A vs. green open backpack B), this can serve as a test of whether the information about the backpacks is stored in holistic units or as independent features. If the objects are stored and forgotten in an all-or-none holistic manner, then recognition accuracy for the exemplar pairs with different colors or/and states should not differ from accuracy for the exemplar pairs with the same features. But if the features are independent, then it should be harder to recognize exemplars with different features than exemplars with the same features, since the former requires not only remembering these different features but also which exemplars these features went with. For example, one can remember that one backpack was red and another was green (or more generally, that their colors were different) but fail to remember which color belonged to which of the backpacks. This logic of the method was implemented by Utochkin and Brady (2020, Experiments 1A-B) who found evidence for feature independence. Moreover, using this logic will allow

testing another set of alternative scenarios. If features are independent then we can expect that feature manipulations will affect recognition memory in a feature-specific way. For example, if the colors are the same but states are different, then it should be harder to recognize the states of the paired exemplars but not their colors, and vice versa. Alternatively, if objects are stored unitized then changing one of the features can affect the integral discriminability of the objects, which implies that a second feature would be affected as well.

Having explained the meaning of the same-different feature manipulation in paired objects for testing the hypotheses about the representational format, we can now explain how it can be used for testing the potential role of verbal encoding in representing visual objects and their features. We accomplish this in our current Experiment 1 by modifying the paradigm so that the paired items from the same category are presented in two different forms, visually (as a picture) and verbally (as a typed description), and observers have to remember them in that specific form. For example, an observer can be shown a picture of a red open backpack and also shown the text “green closed backpack”. The observer is then tested with various pictorial instances of the backpack having different colors and states and with various verbal descriptions. The effects of verbal descriptions on memory for visually presented objects and their features can be estimated using the same logic of analysis as described in the previous paragraph. In Experiment 2, we tested object and feature memory for paired objects, all presented visually, to see how strong the interaction between object features can be when no intentional verbal encoding is required and when all the stimuli are to be remembered in the same modality. This allows us to get the comparative picture of visual-verbal interaction vs. visual-visual interaction to evaluate the role of verbal encoding in shaping the format of visual object representations in long-term memory.

Experiment 1

Methods

Participants

To determine the necessary sample size, we used the “pwr” package for R software. Our sample size calculations were based on the previous work by Utochkin and Brady (2020, Experiments 1A-B) with a similar paradigm. They tested 19-20 in each experiment and found large effects ($d_z = 1.09-1.25$) of the relevant feature manipulations (same state vs. different states) on recognition accuracy. We increased the sample size from Utochkin and Brady (2020) to thirty observers considering possible technical problems and a lessened control for external conditions in an online format of the experiment. This sample size allowed us to detect even weaker effects than those reported by Utochkin and Brady (d_z of about 0.5-0.6) with a power of .8 and significance level of .05. Therefore, 30 participants (11 females; mean age = 31.14, $SD = 11.41$) reporting to speak English as their mother tongue took part in the experiment. The observers were recruited through Prolific (<https://prolific.co>) and participated in the experiment on Pavlovia (<https://pavlovia.org>) online-platform for £5. All participants reported having no vision deficiency. At the beginning of the experiment, they electronically gave informed consent.

Stimuli

Images were taken from a stimulus set used by Brady et al. (2013) and modified in accordance with experiment purposes. The image set consisted of 480 images of 120 basic object categories. Each category included four images of the same object exemplar in two states and two colors. Both colors for a category were chosen randomly from eight possible options (red, pink, blue, yellow, green, orange, cyan, or purple). Then, images were sorted into color categories and re-colored in Adobe Photoshop CC 2019 (20.0.5). The verbal

stimuli were 480 descriptions of images containing the information about the color, state, and category of an object (for example, “red opened plastic bottle”). The list of categories was the same as in the image set. All descriptions were created by the authors and verified in an additional online experiment (see Supplementary).

Procedure

The experiment consisted of two phases: study and test. In the study phase (Figure 1A), participants were sequentially presented with images or verbal descriptions at a rate of one item per 2.5 sec with a 0.5-sec intertrial interval. The total number of presented items was 240: Half of the items were images of objects from 120 categories and another half were verbal descriptions of objects from the same 120 categories. The order of item presentation was completely randomized, so that the two instances of the same category (description and image) could be separated by a random number of other items and did not have a fixed order (the description could be presented earlier than the picture and vice versa). The image and the description within each category could be same or different in terms of color and state which was manipulated orthogonally. Therefore, there could be four combinations of feature matching within a category: (1) “same colors - same states”, (2) “same colors - different states”, (3) “different colors - same states”, and (4) “different colors - different states” (Figure 1B). Each such combination was represented by 30 categories (60 image-description pairs). The categories were randomly assigned to the feature-matching combinations in each participant.

At the beginning of the study phase, the participants were instructed to memorize all 240 presented items as accurately as possible. They were not given any specifications about focusing on any particular features. Also, they were warned that both visual and verbal memory would be tested to encourage them to memorize both types of stimuli.

The test phase (Figure 1C) followed immediately after the study phase. It consisted of 240 trials, each testing memory for one of the items from the study phase. In each trial of the test phase, participants were shown four picture instances (2 colors x 2 states) of the same object or four verbal descriptions (also 2 colors x 2 states) of the same object category (Figure 1). These four options were arranged in two rows and two columns. The participants had to perform a four-alternative forced choice (4-AFC) clicking on an option that they thought they had seen in the study phase. The order of test trials was pseudo-random: Those items that were presented in the second temporal half of the study phase, also appeared in the second half of the test phase. But importantly, the order was randomized within the two temporal halves. The reason for such a restriction was to make an interval between the presentation and test of the same item at least as long as six minutes. The spatial arrangement of the response options in each test trial was chosen randomly, so that the options with the same color or state could be located in the same arbitrary row, column or in different rows and columns.

Figure 1. The procedure of Experiment 1. (A) In the study phase, participants were instructed to memorize presented items (images or descriptions). (B) Feature match or mismatch was orthogonally manipulated between the two items of the same category: the image and the description could be same or differ in color and/or state information. (C) In the test phase, participants performed a 4-AFC, where they had to choose an image or a description with correct color and state.

Data analysis

Since our 4-AFC test displays contained one correct and one incorrect option for color and for state and these options were orthogonally distributed across the options, we could measure recognition accuracy for each of the features independently. For example, a color response on a given test trial was counted to be correct if a participant picked any of the options with the correct color, regardless of whether it was correct in terms of state. The proportions of correctly reported colors and states were calculated for each feature match/mismatch combination and for each stimulus modality (visual and verbal). The effects of feature match/mismatch were tested with repeated-measures ANOVA separately for each reported feature (color and state) and for each modality.

Results and discussion

One participant was excluded from analysis due to chance performance in all conditions of the experiment. Therefore, the data of 29 participants were analyzed.

Figure 2. Recognition memory for object features of (A) visual images and (B) verbal descriptions in Experiment 1. Error bars denote 1 *SEM*. Dashed lines show the chance level.

Memory for visual images. The effects of feature match/mismatch between image and description on recognition accuracy were small, though significant both for color choices ($F(3, 84) = 3.164, p = .029, \eta^2 = 0.07$) and state choices - ($F(3, 84) = 4.98, p = .003, \eta^2 = 0.06$). However, post-hoc tests corrected for multiple comparisons (6 comparisons) failed to reach significance for color choices. For state choices, accuracy was lower in the “different color - different state” ($M = 0.65$) condition compared to the “same color - same state” ($M = 0.73$, comparison: $t(28) = 3.66, p = .001$, Bonferroni corrected alpha = 0.008, Cohen’s $d_z = 0.68$) and the “different color - same state” ($M = 0.73$, $t(28) = 3.44, p = .002$, Bonferroni corrected alpha = 0.008, Cohen’s $d_z = 0.64$) conditions. That is, state reports were slightly selectively impaired when the image and descriptions differed in both states and colors compared to both conditions with the same state (Figure 2A).

Memory for verbal descriptions. We found medium-size significant effects of feature match/mismatch between images and description on description recognition accuracies for both state choices ($F(3, 84) = 10.41, p < .001, \eta^2 = 0.19$) and color choices ($F(3, 84) = 9.79, p < .001, \eta^2 = 0.18$). Overall, accuracy was higher for features that matched between paired items than for features that mismatched (Figure 2B). For color names, there were more correct reports in the matching-color conditions (“same color - same state” and “same color - different states”, $M = 0.58$ and 0.59 , respectively) than in the mismatching-color conditions (“different colors - same state”, “different colors - different states”, $M = 0.48$ and 0.50 , respectively); comparisons: t ’s(28) > 3.4, p ’s < 0.002, Bonferroni corrected alpha’s = 0.008, Cohen’s $d_z > 0.30$. Similarly, state reports were more accurate for items with matching studied states (“same color - same state” and “different colors - same states”, $M = 0.59$ and 0.59 , respectively) than for items with mismatching studied states (“same color - different states” and “different colors - different states”, $M = 0.48$ and 0.48 , respectively);

comparisons: $t's(28) > 3.2$, $p's < 0.003$, Bonferroni corrected alpha's = 0.008, Cohen's $d_z > 0.24$. It can be noted that verbal feature reports were around chance (0.5 correct) when the feature of interest unmatched between the image and the description (“different colors - same state” and “different colors - different states” for color choices, “same color - different states” and “different colors - different states” for state choices; one-sample $t's(28) < 1.3$, $p's > 0.18$, $d_z < 0.25$), whereas the reports were fairly above chance when the feature of interest matched between the image and the description (all other conditions; one-sample $t's(28) > 4.40$, $p's < 0.0001$, $d_z > 0.82$). Our results are consistent with a limited effect of feature manipulations between images and verbal descriptions on memory for features of visually presented objects.

Although verbal memory is not our main subject in this study, our analysis of the description recognition tests tells us two important things. First, we can rule out the lack of memorization of verbal stimuli as a cause of the small verbal effects on visual memory. Indeed, if our observers had been focused on memorizing the visual stimuli and had not tried to memorize the verbal stimuli, we would have expected either chance recognition of all descriptions (in case of simple guessing), or the mirror symmetry for “same” vs. “different” trials (in case of informed guessing based on image memories: e.g., 63% correct state reports for “same state” vs. 37% correct state reports for “different states”). Our pattern of results showed that participants were at chance only when the features were different and they were above chance when the features were same. This specific pattern is more consistent with existing feature memory but difficult binding (Utochkin & Brady, 2020) rather than with the absence of any memory. The second important note follows this one. It appears that in our experiment visual features interfered more with verbal descriptions (18-19% accounted variance) than vice versa (6-7% accounted variance), suggesting the possibility of an

asymmetric interaction between visual and verbal memories. Definitely, the nature of this influence should be investigated more thoroughly and is not the subject of the present study.

Experiment 2

Experiment 1 showed an effect of verbal descriptions of objects and their features on memory for the features of visually presented objects, but this effect was relatively small (as compared to the very large effect found by Utochkin & Brady, 2020 for pairs of objects). This suggests that visual memories for object features may be only weakly dependent on verbal memory. To compare this effect more directly with the interfering effects of feature manipulations within the visual modality, we ran Experiment 2 where verbal descriptions were replaced with other exemplars from the same object categories. In part, this design repeats the design used by Utochkin and Brady (2020, Experiments 1A-B). However, while Utochkin and Brady (2020) manipulated only state matching information between studied exemplars, in the present experiment we manipulate both color and state information which provides a more correct comparison with Experiment 1.

Methods

Participants

Thirty observers (19 females, mean age = 35.73, $SD = 13.75$) reporting to speak English as their mother tongue and recruited via Prolific took part in the online experiment hosted on Pavlovia.org. The sample size was determined based on the same criteria as in Experiment 1. The participants were compensated £5 for task completion. All participants reported having no vision deficiency. At the beginning of the experiment, they electronically gave informed consent.

Stimuli

Image stimuli for Experiment 2 were also taken from Brady et al.'s (2013) set. This time, each object category was presented by images of two distinct exemplars, each having two states and two colors. Sets of states and colors were identical for each exemplar (for example, if coffee mug A could be empty or full, red and green, then coffee mug B also could be empty or full, red and green). Since not every category from the original image set had pictures of two exemplars, we reduced the number of used categories from 120 (as in Experiment 1) to 92. Second visual exemplars replaced verbal descriptions from Experiment 1.

Procedure

Procedure and design were the same as in Experiment 1 with the only important difference that observers had to learn only visual images of two different exemplars in each category rather than one visual exemplar and one verbal description (Figure 3A-B). Consequently, in the study phase, they had to choose a correct combination of color for each exemplar (Figure 3C).

Figure 3. The procedure of Experiment 2. (A) In the study phase, participants were instructed to memorize presented objects. (B) Feature match or mismatch was orthogonally manipulated between the two exemplars of the same category: they could be same or differ in color and/or state information. (C) In the test phase, participants performed a 4-AFC, where they had to choose a correct color and state of each exemplar.

Data analysis

Data analysis was the same as in Experiment 1 with one difference. Since there was only one stimulus modality, we collapsed data from memory tests of first and second exemplars to get visual memory accuracy.

Results

The effects of feature match/mismatch between paired exemplars were large-size and significant both for color and state memory (respectively, $F(3, 87) = 31.95$, $p < .0001$, $\eta^2 = 0.41$ and $F(3, 87) = 56.82$, $p < .0001$, $\eta^2 = 0.56$). Post-hoc test showed clear feature specificity: Color match/mismatch of the studied items affected only color choices but not state choices at test; the same held true for the state matching manipulations and state choices (Figure 4). In color choices, the accuracy in the “same color - same state” ($M=0.64$) and the “same color - different states” ($M=0.65$) conditions were greater than in the “different colors - same state” ($M=0.49$) and the “different colors - different states” ($M=0.50$), $t's(29) > 5.7$, $p's < 0.0001$, Bonferroni corrected alpha = 0.008, Cohen's $d_z > 1.04$.

In state choices, the accuracy in the “same color - same state” ($M=0.74$) and the “different colors - same state” ($M=0.71$) conditions were greater than in the “same color - different states” ($M=0.49$) and the “different colors - different states” ($M=0.51$), $t's(29) > 7.4$, $p's < 0.0001$, Bonferroni corrected alpha = 0.008, Cohen's $d_z > 1.36$. Noteworthy, in all conditions, where a feature of interest mismatched between studied items, the choice accuracy for that feature was at chance (one-sample $t's(29) < 1.07$, $p's > 0.29$, Cohen's $d's < 0.19$), suggesting strong feature interference in these conditions.

The results of Experiment 2 are rather clear and consistent. We found that the observers were reasonably accurate when they reported features that matched between two exemplars but the observers were at chance when the features mismatched between the

exemplars. This finding perfectly replicates the pattern reported by Utochkin and Brady (2020). Furthermore, our results showed the specific correspondence between the manipulated feature and the accuracy of reporting this but not the other feature. Taken together, these results suggest that the visual information about colors of objects is represented independently from the visual information about states, and together they are represented independently from the visual information about exemplars.

We see that the effects of feature manipulations on visual recognition in Experiment 2 were much stronger than in Experiment 1, which is clear from a simple comparison of the effect sizes across the experiments (Figure 4 compared to Figure 2A). To recapitulate, feature manipulations accounted for 6-7% variance in accuracy in Experiment 1 and 41-56% variance in Experiment 2. This suggests that direct verbal encoding has much less effect on visual memories of objects and features than encoding of other objects and features within the same visual modality. In particular, the comparison between the experiments shows that verbally encoded descriptions are less capable of producing the pattern of feature independence in visual memory than other visually encoded objects.

Figure 4. Recognition memory for object features visual images in Experiment 2. Error bars denote 1 *SEM*. The dashed line shows the chance level.

General discussion

Our main novel finding from this study was that explicit verbal descriptions of objects and their features showed minimal but reliable interference with visually memorized objects (Experiment 1), whereas the features of two visually presented exemplars of the same basic category tended to very strongly interfere with each other (Experiment 2). In fact, we found that an ability to recognize the features of visual objects dropped to chance level when the exemplars had different features. This finding replicates the finding made by Utochkin and Brady (2020, Experiments 1A-B). Another important addition to Utochkin and Brady's (2020) study was that we orthogonally manipulated two features, color and state, attached to each exemplar or description, whereas Utochkin and Brady manipulated only the state features. This gave us another strong piece of evidence for feature independence for visually presented objects, as we found high feature specificity in recognition performance: Color mismatch between the exemplars impaired color but not state recognition accuracy, and vice

versa; and finally, when both colors and states differed between the exemplars then the recognition rates suffered for both these feature dimensions. Taken together, our results suggest that at least some of object features significant for object recognition and discrimination (such as color and state features) are stored independently in long-term memory. This finding is in line with other data about visual long-term memory (e.g., Brady et al., 2013; Reinitz et al., 1992; Utochkin & Brady, 2020). Most importantly in the present context, this feature independence pattern cannot be ascribed to the use of verbal encoding strategies that might transform the visual image into discrete, flexibly combined independent words.

Implications for the representational format

The fact that remembering visually presented objects is not affected by verbal encoding implies that there should be a strong visual component in it. However, we do not necessarily imply that the representations of these objects are entirely visual. The problem of thinking about object features as purely visual entities is particularly obvious when we look at such a feature dimension as state. Elsewhere, we have discussed in detail that state features (such as “openness-closedness”, “fullness-emptiness”) are definitely not the same thing as conventional basic visual features (such as color, orientation, size, spatial frequency, etc.), although the state information in an image is conveyed by complex combinations of these basic features (Brady et al., 2013; Markov et al., 2021; Utochkin & Brady, 2020). It is possible that the features of this sort can reflect semantically meaningful transformations that can occur to real-world objects independently (in the real world, a coffee mug can be full, empty, or half-full independently of its color, size, shape, or viewpoint). Therefore, our results are not inconsistent with the semantic component in object and feature representations in long-term memory. What our results show is that there can be a direct link between

semantics and visual appearance of objects and features without any strong need for verbal encoding. For example, the semantically meaningful and independent representations of features can be experienced in a form of a visual image of a prototypical object from a category with some color and another prototypical image in a certain state that are referenced at recognition, when particular exemplars are presented in a variety of colors and states. This is what we mean by the visual nature of object and feature representations.

One more important note about feature independence should be made in the light of other research claiming that feature independence can be not absolute (e.g., Balaban et al., 2020; Kuhbandner, 2020). Balaban et al. (2020) suggest that the information about different object features can be stored in a hierarchically dependent manner rather than as completely independent representations. In particular, they propose that exemplar features can be stored in a representation superior to some other features such as the exemplar's state, viewpoint, or material that this exemplar is made of. In support of this idea, Balaban et al. (2020) showed that forgetting any of the latter features given a forgotten exemplar is substantially more frequent than vice versa. In other words, it is less likely that an observer remembers the state or material of an object if they forgot the object's identity (specific exemplar), but it is more likely that the observer remembers the object's identity but fails to remember its state or material. Our findings are not inconsistent with Balaban et al.'s (2020) conclusions. In our paradigm, we manipulated colors and states, features that can be represented as separate, independent “branches” of the hypothetical feature hierarchy, both subordinate to exemplar features. (Note that we used exemplars only as a “basement” to attach variable and testable colors and states but we did not directly test any contingency between exemplar recognition and color/state recognition). So, we agree that features that are mutually independent can be a part of a bigger hierarchical structure (Brady et al., 2011). What both feature independence

and hierarchical representations are inconsistent with is the idea of strongly unitized object representations.

Given the previous literature showing various interactions between visual and verbal memories (Arndt et al., 2015, 2019; Gentner & Loftus, 1997; Pezdek, 1997; Schuler et al., 2015), we should say that our current findings and conclusions can be limited to certain research conditions. First, our results reflect storage and retrieval processes that take place within minutes or tens of minutes after learning. Although longer storage periods tend to increase feature independence in long-term memory (Brady et al., 2013) the role of verbal long-term memory in this process is yet to be investigated. For example, it is imaginable that verbal distortions conceived at a study phase do not influence at short delays but yield their effects later (Arndt et al., 2015). Also, in our study we focused on how people remember individual objects presented one by one, without a context, whereas the previous studies of visual-verbal interactions were focused on more complex scenes and events (Arndt et al., 2015, 2019; Gentner & Loftus, 1997; Pezdek, 1997; Schuler et al., 2015). The complexity of such stimuli, as well as their specific requirements to object-context binding (e.g., Bastin et al., 2019; Davachi, 2006; Diana, Yonelinas, & Ranganath, 2007, etc.) can also make more active, verbal encoding involved. Finally, in our experiments (as well as in many other visual-verbal experiments) verbal and visual stimuli that were pre-generated by the authors and shown in different encoding episodes, whereas the most straightforward strategy of verbal encoding in visual tasks is using self-generated labels and descriptions during visual image presentation (Bertsch et al., 2007). In theory, such a strategy could have a stronger effect on visual memory (but note that Utochkin & Brady, 2020 diminished the availability of such a strategy by verbal interference and still got the feature independence pattern). These and other interesting questions should be addressed in further research.

In summary, our research one more time demonstrated that real-world objects, even though they can be introspectively unitized, are not necessarily stored in a unitized manner in long-term memory. Instead, meaningful features of the objects (such as features of particular exemplars, colors, states) are represented in quite an independent manner. Critically, in addition to the previous demonstrations of feature independence, we provide clear evidence that this pattern is related to the visual format of feature storage and cannot be explained by the use of verbal coding of objects and their features. That is, we conclude that visual long-term memory itself stores the information about real-world objects in an independent manner. Our research contributes to the understanding of representational formats of memory, as well as to understanding of interaction between memory systems.

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Open Science statement

The experimental data are publicly available via Open Science Framework at:

<https://osf.io/kygmd/>. Experimental scripts and stimuli are available at:

https://gitlab.pavlovia.org/HSE_CogLab/VisVerbMem_Exp1 (Experiment 1) and

https://gitlab.pavlovia.org/HSE_CogLab/VisVerbMem_Exp1 (Experiment 2).

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Supplementary

Experiment 0: Verification of picture-description correspondence

The main goal of Experiment 0 was to verify that verbal descriptions we created are indeed appropriate to describe the pictures from naive observers' viewpoint. Additionally, we expected to filter out categories or states of objects that are hard to verbalize.

Method

Participants

40 participants (20 female; age: $M = 32$ years, $SD = 11.4$) reported to speak English as their native language and to have normal or corrected-to-normal vision. The recruitment of participants was implemented with the Prolific recruitment platform. Each participant was paid £1.3 and participated in the study hosted on Pavlovia website (<https://pavlovia.org>). Before the experiment, they gave informed consent.

Stimuli

The stimulus set of images consisted of 528 pictures from 132 categories. Each category contained 4 pictures in two colors and two states. The stimulus set of descriptions included 528 verbal phrases for objects from 132 categories. All verbal descriptions contained information about color, state and object category (e.g., “red open backpack”).

Procedure

The overall number of trials was 132. In each trial, each participant was one of four images from a category combined with two descriptions (the color and state of each image category was randomized across participants). Descriptions were always opposite in terms of state information, but had the correct color information. We did not manipulate color

information because we did not expect that our set of more or less basic, discriminable colors would cause any big discordance in naming.

Participants were instructed to choose the most suitable description of the presented image. If the best description was on the right, the participants had to press a right arrow key, and vice versa. If both descriptions were not suitable for the image, the participants were asked to press a down arrow button to enable a field where they could type in their own suggested description (see Figure S1).

Figure S1. An example trial of Experiment 0. Observers had to choose a correct description between the two suggested ones or answer that there is no suitable description. If the observers choose one of the suggested descriptions, the trial is finished; If they choose “nothing suitable”, an field appeared where they could type in their own his description.

Data analysis

We analyzed how often participants considered our pre-generated descriptions to be suitable for the images. An agreement metric was calculated for each category as a

percentage of responses that matched the pre-generated descriptions. We set a 75% agreement level as a minimum threshold of an appropriate description.

Results

Three participants were excluded from analysis due to their systematic inconsistency with other participants. Whereas the median percentage of categories where the pre-generated descriptions were considered correct was about 90%, those participants agreed with less than 30% of categories.

Twelve out of 132 tested categories had agreement level less than 75%, so we decided to exclude these categories from our stimulus set in the main experiments.

“Nothing suitable” responses were quite rare - only two participants suggested their own descriptions. Overall, there were 3 suggested descriptions for 3 categories from two participants. However, we did not replace our descriptions because of high agreement for these categories demonstrated by the rest of participants.