Bias effects of short- and long-term color memory for unique objects

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Are objects remembered with a more saturated color? Some of the evidence supporting this statement comes from research using 'memory colors' – the typical colors of particular objects, for example the green of grass. The problematic aspect of these findings is that many different exemplars exist, some of which might exhibit a higher saturation than the one measured by the experimenter. Here we avoid this problem by using unique personal items and comparing long- and short-term color memory matches (in Hue, Value and Chroma) with those obtained with the object present. Our results, on average, confirm that objects are remembered as more saturated than they are.

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1.Introduction

In our everyday life color is a property strongly associated with objects and we have all heard and maybe even seen with our mind's eye the "red rose" of Robert Burn's poem or the "green grass of home" sung by Tom Jones. This idea of linking certain objects with a defined color was formalized by Hering and Katz in the early 20 century, as discussed in [1, 2]. Subsequently Koffka [3] and others put forward the specific hypothesis that colors are remembered more saturated, in line with the Gestalt hypothesis of change towards better or the ideal; sometimes identified as a 'positive time error' [4]. A modern formulation of this can now be found as a statement of fact in some image processing [5] and photography books [6]. However in more than 80 years of research into color and memory the evidence to support this has been inconclusive at best.

Hanawalt & Post [2] report 4 studies using different methods to explicitly test for an increase in saturation of remembered colors. They used abstract color stimuli, different task and timings; under none of their tested conditions they find that remembered colors are more saturated.

In Newhall et al. [7] the main experiment is a study using colored lights (2 deg visual field) presented against a neutral background where the authors compared simultaneous color matches with successive. The latter being the memory task, where after a gap of 5 sec. participants were asked to set the colorimeter to the color that had been previously presented also for 5 sec. A comparison between the matches in the simultaneous and the successive condition indicates a consistent increase in Munsell Chroma (and Value to a lesser extent) for the memory matches. In this paper they also describe an older study (their Supplementary Experiment 3) in which participants are asked to select Munsell samples that best represent the recalled colors of a series of unseen objects of highly diagnostic color (brick, sand, grass and dry grass, skin, concrete, pine trees and weathered wood). For some of these objects the memory matches seem to be of higher Munsell Chroma and Value than the 'standards' they compare them to. This latter experiment was re-created by Bartleson [8] using essentially the same methods and arriving at similar results described as remembered colors shifting in the "…direction of the typical or dominant hues commonly associated with the actual objects." A comprehensive review of these and other early studies can be found in [4].

Siple & Springer [9] used a colorimeter and controlled photographs of six fruits and vegetables to study the memory color and preference for them when presented with and without context. Although they also obtained simultaneous matches using the photographs and real fruit as references the memory matches were obtained before participants had seen this particular version of the objects so they were based on some previous internal representation. Across objects and participants they report that memory for Munsell Hue and Value is quite accurate but that Chroma is preferred and remembered as higher.

Another paper often cited as providing evidence of the increased saturation for remembered color is [10]. In this study participants' recollections of the color of 8 common fruit and vegetables were assessed under two illuminants and compared to measurements taken from real examples of the produce. As in other studies participants never saw these measured objects and their matches were reliant on each individuals own interpretation of the color of a given fruit or vegetable that they externalized by selecting one of the 10 possible alternative Natural Colour System papers provided by the experimenter for each object. The author's report their findings in a seldom used color representation space (SVF) and conclude that the color difference found between participants' selection and measurements is due mostly to variation in chroma, rather than hue or lightness.

A part of Jin and Shevell's color constancy study [11] using computer simulated Munsell patches in a simple geometric arrangement the authors also report than when there was no illuminant change between the learning and testing phase (i.e. a color memory task) participants matches deviated, for both durations tested, from the original color but the nature of this variation was not systematic. They indicate that variations in Chroma and Hue for blue and yellow colors were larger than those for red and green ones and not in the same direction. They also report finding larger shifts for the condition with complex background.

In a more recent and sophisticated study [12] that incorporates the polychromaticity of natural objects participants adjusted only the mean hue of 3-dimensional objects that represented fruits and vegetables to settings that were "redder" and "bluer" than the measured values of the unseen exemplars. A common element between this study and other recent ones [e.g. 13] focusing on color memory, many of them using colored patches displayed on monitors, is the decision to reduce the dimensionality of the adjustment or choices available to participants only to the hue dimension of color.

From the summaries above it is clear that a common problem undermines the results of previous studies involving objects with highly diagnostic colors or so called memory-colors. In all cases the experimenters chose **not** to show to the participants the exemplars of the target objects that were later measured to provide a comparison point for the memory matches. In other words there is no way for them to resolve the confound: are discrepancies between remembered and actual colors due to the choice of standard (which might be different to the individual experience each person has of that object) or is there a true memory effect indicative of how we encode the properties of familiar objects.

In our study we avoid this problem by using unique personal items for which the owner has a strong internalized color representation, i.e. they can produce a long-term memory match to this particular object that is very familiar to them. But crucially we also ask them to provide us with a perceptual match when the object is present which provides us with a baseline to compare with the match done from memory. By also presenting the objects to participants other than their owners we are able to study short-term memory effects and compare them to simultaneous matching across all three colour dimensions (Hue, Value and Chroma).

2. Materials and Methods

A. Participants

In total 16 participants (5 females) participated in this study. Mean age was 35 years, with a range between 26 and 61. All but one were members of the Department of Psychology of the University of Gießen and all provided informed consent before taking part. 14 participants were naïve to the purpose of the experiment; two were authors (MB and KRG). All had normal or corrected to normal visual acuity and normal color vision, verified via pseudoisochromatic plates [14]. In the second, short-term memory part of the study, 12 of these participants (4 females) took part, none of them authors. The average age of this sub-group was 31 years with a range between 25 and 42.

B. Objects

Participants brought a personal object (two in the case of KRG) that was well known to them and had a color of which they were confident to have a well-established memory of. Photographs of the 17 objects are shown in Figure 1. Objects had been owned for a median of 3 years with a range of 10 months to 21 years and in most cases seen daily or at least once a week.

Fig. 1. Photographs of the 17 objects brought by our participants. Each object is shown next to the Munsell chip most often selected as a simultaneous (with object present) match. Notice the variety of materials, size and color of objects used in this study. Objects with a black border were only used in the first part of the study.

For the second part of the study we eliminated 5 objects from the collection; 3 because they were too well know by all participants (blue elephant, orange and brown jumper), 1 was no longer available (multi-tool) and 1 was of an overrepresented color (turquoise jumper).

C. Experimental set-ups and procedures

1. Owners long-term memory (O-LTM) and object (O-OM) matches

In a standard office room with grey walls and floor and just one window, the only source of illumination used during the experiments, a table was covered with a grey cloth and 1325 chips from the Munsell Book of Colors (Glossy Collection) [15] were displayed in 40 plastic bins. As part of the 2 minute enforced adaption period participants were asked to order the scrambled bins by hue (see Figure 2). This task allowed participants not only to adapt to the daylight but also to become familiar with the Munsell chips.

After adaptation and in absence of the object (which had been taken away by the experimenter and was not returned to the participant until all experiments were completed) participants selected chips from the Munsell collection that best represented the recalled color of their object. For this purpose, they were allowed to spread the Munsell chips on the grey cloth to compare them and make their final selection. Participants were allowed to select a maximum of three chips, allowing for the possible fact that a single chip in the collection did not precisely represent the exact color of a given object; some owners selected a single chip. All owners performed two long-term memory matches (O-LTM) for their object on two different days. On the second day, after completing their memory match, their object was brought back out and with it present they selected the Munsell chip that best matched the perceived color of their object (O-OM).

Fig. 2. Photograph of the 1325 chips from the Munsell Book of Colors (Glossy Collection) displayed in 40 plastic bins, ordered by hue as participants saw them after completing the adaptation task and before making their selection.

2. Participants short-term memory (P-STM) and object (P-OM) matches

For this task we used a sub-set of 12 objects and 12 participants; participants only evaluated objects brought by others (i.e. not their own objects). This second task was completed in a seminar room that was approximately three times the size of the first room, also only illuminated by daylight that came through three windows and contained six tables, which offered enough space for the short-term memory experiment. Like in the first room, the bins containing the Munsell collection where placed on a table covered with a grey cloth in front of a window. Next to it, another table, covered with the same cloth, was used to present objects, select chips and perform object matches.

After participants adapted while performing the previously described bin-sorting task they turned their back to the bins and the experimenter presented them with one of the objects brought by another participant. For 30 seconds the subject was allowed to handle the object and asked to memorize its color, but not permitted to look at the bins containing Munsell chips. After the 30-second memorization phase, the object was taken away and the subject selected the Munsell chip that best represented the color of the object they had just seen. Each participant performed one short-term memory match (P-STM) per object. Participants were also asked to provide a confidence rating for their match using a 5-point scale, with 5 representing absolute confidence. At the end of the session the experimenter brought out all the objects and participants were asked to select the Munsell chip that best matched the objects' color, these constituted the participants object matches (P-OM). As before, for all matches, participants also provided a confidence rating on a five-point scale.

All experiments were completed between 21 November 2014 and 12 of December 2014 in Gießen, Germany. During this time of the year there is limited daylight hours and experiments were only run between 10 am and 3 pm; half of them during cloudy days and half during sunny days. Regardless of conditions, chips and objects (when present) were never placed in direct sunlight. At the beginning and end of each participant's matching session we measured with a Konica Minolta CS-2000 Spectroradiometer the luminance of a white standard (Photo Research RS2) placed 80 cm along and orientated at 45 degrees from the window normal at a height of 20 cm from the table surface. For the owner matching sessions the luminance measured ranged form 73 to 316 cd/m^2 (mean 185 SD =52 cd/m^2). For participants' sessions mean measured luminance was 261 cd/m^2 (SD = 250 cd/m^2), with a minimum value of 31 and a maximum of 979 cd/m^2.

3. Results

As we used Munsell chips to collect our participants' responses we can directly report our results using the Munsell system [15]. This will have the advantage of allowing straightforward comparison with earlier studies. Although conversion to other systems; for example the CIE 1976 - L*a*b* color space [16], are possible as we have both Munsell chip reflectance data and measurement of average illumination during our experimental sessions this is an unnecessary step that does not add information to the analysis or change the overall conclusions.

In Table 1 we report all matches from object owners; each object shown in the left column corresponds to a different participant. The Munsell chips they selected as long term memory matches (O-LTM) are show in the central columns, one column for each session. The column on the right shows the chips that were picked by the owners as the best match to their object when the object was present (O-OM). For some sessions/objects participants selected more than one chip (up to three) to indicate that the desired match was in between the selected chips. In those cases, and for representations in Figures 3 and 4, the mean is calculated, by averaging each of the three attributes (Hue, Value and Chroma) separately.

Table 1. Owners' long-term memory (O-LTM, 2 sessions) and object (O-OM) matches

Object	O-LTM (1)	O-LTM (2)	O-OM
	2.5BG 6/10 2.5BG 5/10	10G 7/8 10G 6/10	5BG 6/10
	5BG7/8	2.5BG8/6	5BG8/4
	7.5BG 5/10	7.5BG 6/8	10BG 6/6
	5PB 2/8	5PB 2/8	5PB 2/8
	7.5PB2/10	7.5PB2/10 5PB2/8	7.5PB2/10
	5RP 6/7 5RP 7/10	7.5RP 6/12	5RP 6/12
	2.5R 7/6 2.5R 7/8	10RP 7/6	10RP 7/4
	7.5R4/16 5R4/14	2.5R4/14 5R4/12	2.5R4/14
	5R 3/10	5R 3/10	7.5R 3/12
	7.5R 4/16	7.5R 4/14	7.5R 4/14
	2.5YR6/16	2.5YR5/14	2.5YR6/12
	10YR 6/10 10YR 6/12	10YR 7/14 7.5YR 7/14	10YR 7/10 10YR 7/12
	10YR6/4 10YR5/4	7.5YR6/2	2.5Y6/2
	5Y 9/2	5Y 9/2	5Y 8.5/2
	5GY 5/4	5GY 5/4	2.5GY 5/4
	10GY 5/12	10GY 5/10	10GY 5/10
	10GY 6/12 10GY 6/10 10GY 7/10	10GY 6/12 10GY 6/10 10GY 5/10	2.5G 5/8

Figure 3 presents the color attributes of Chroma, indicated by distance from the center with each concentric circle corresponding to a variation of two Chroma steps and Hue which varies along the circumference, with each radial line corresponding to one Hue step as available in the Munsell Book of Colors (Glossy Collection). Each line represents an object, with the origin (dot) located on the average of the object's owner' match with the object present (O-OM) and the end of the line on the average long-term memory match for that object. A cutout of the object is placed at the dot (O-OM) end of the line. In this way the length and orientation of the line indicates the variation in chromaticity between the object and memory matches. If there is no difference between object and memory matches then there is only a dot representing that object. If objects were, for example, consistently remembered more saturated then we would expect all memory matches to be further from the center than their corresponding object match.

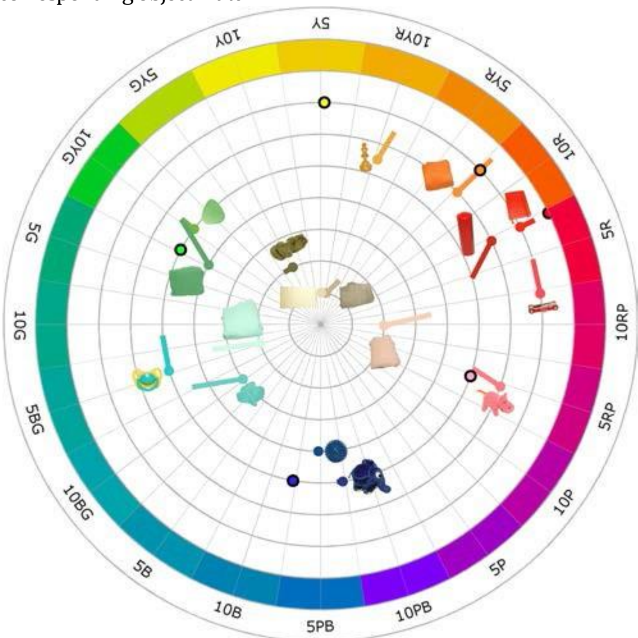

Fig. 3 Radial plot showing Chroma and Hue of owners matches when the object is present (small dot next to object) and average owners long term memory match (end of line). If there is no shift, i.e. object and memory match coincide they are shown as a dot as in the case of the blue spiky ball. Each concentric circle represents 2 Chroma steps and each radial line represents one of the 40 available Hues in the Munsell Book of Colors (Glossy Collection). See Table 1 for list of actual Munsell papers selected in each case. Dots with solid black outline depict color category prototypes [17, 18].

In Figure 4 we show the remaining color attribute of Value along the vertical axis with each division corresponding to one Value step as represented in the Munsell Book of Colors (Glossy Collection) and Hue along the horizontal axis. In this case we have converted Hue notation to degrees by selecting an arbitrary zero point. As before, a cutout of the object is placed at the dot (O-OM) end of the line representing each object and the end of the line is located on the average long-term memory (O-LTM) match for that object. If only a dot is visible for a given object that means that memory and object match are identical.

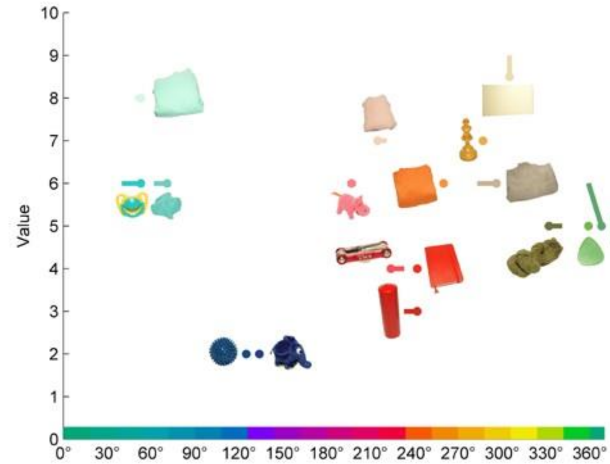

Fig 4 Plot showing Value and Hue of owners' object matches (small dots next to objects) and average owners long-term memory match (end of line). If object and memory match coincide they are shown as a dot with no line. Each available step in the Value dimension is represented in the vertical axis and on the horizontal axis we show all the 40 available Hues in the Munsell Book of Colors (Glossy Collection) converted to degrees with and arbitrarily chosen zero point. See Table 1 for list of actual Munsell papers selected in each case.

In Table 2 we report average and standard deviation of participants matches for objects other than their own. For each object shown on the left column the central column shows the corresponding Hue, Value and Chroma of the short-term memory (P-STM) matches averaged over 11 participants. The column on the right indicates the mean matches made by participants when the object was present (P-OM). As before, each of the three attributes (Hue, Value and Chroma) is averaged separately and the Hue notation was converted to its corresponding angular value (degrees) for calculations.

Table 2. Participants' (N=12) short-term memory (P-STM) and object (P-OM) matches

Object	Mean P-STM ± SD	Mean P-OM ± SD
	H = 69 ± 11 V = 5.2 ± 0.4 C = 9.5 ±0.9	H = 58 ± 5 V = 5.2 ± 0.4 C = 9.8 ± 0.6
	H = 73 ± 13 V = 5.9 ± 0.7 C = 8.5 ±1.5	H = 69 ± 7 V = 6.3 ± 0.5 C = 6.7 ± 0.9
	H = 124 ± 5 V = 2.7 ± 0.6 C = 9.3 ±1.6	H = 125 ± 0 V = 2.6 ± 0.5 C = 8.8 ± 1.3
	H = 208 ± 8 V = 5.8 ± 0.5 C = 11.7 ±1.4	H = 204 ± 7 V = 5.7 ± 0.5 C = 12.4 ± 0.8
	H = 213 ± 16 V = 7.2 ± 0.5 C = 4.8 ±1.0	H = 212 ± 15 V = 7.5 ± 0.5 C = 4.0 ± 0.0
	H = 237 ± 4 V = 3.9 ± 0.2 C = 14.3 ±0.8	H = 238 ± 5 V = 3.7 ± 0.6 C = 13.2 ± 1.0
	H = 242 ± 0 V = 4.2 ± 0.4 C = 15.5 ± 0.9	H = 242 ± 0 V = 4.0 ± 0.0 C = 14.5 ± 0.8

	H = 283 ± 16 V = 6.5 ± 0.9 C = 10.0 ± 3	H = 287 ± 0 V = 6.3 ± 0.8 C = 10.4 ± 2.8
	H = 301 ± 14 V = 8.9 ± 0.3 C = 3.3 ± 1.0	H = 307 ± 15 V = 8.8 ± 0.3 C = 2.7 ± 1.0
	H = 328 ± 10 V = 5.3 ± 0.6 C = 5.2 ± 1.0	H = 320 ± 10 V = 4.7 ± 0.5 C = 4.2 ± 0.6
	H = 356 ± 6 V = 5.5 ± 0.5 C = 11.0 ±1.3	H = 357 ± 4 V = 5.1 ± 0.3 C = 9.5 ± 0.9
	H = 359 ± 8 V = 6.1 ± 0.7 C = 9.0 ±1.8	H = 366* ± 4 V = 5.6 ± 0.7 C = 8.4 ± 0.8

*Due to where the zero value of the hue circle was arbitrarily set this value should be 006 degrees but for ease of plotting in Figure 6 we have used 366 degrees instead.

Figures 5 and 6 are analogous to figures 3 and 4 and illustrate participants' short-term memory and object matches to the objects that were not their own.

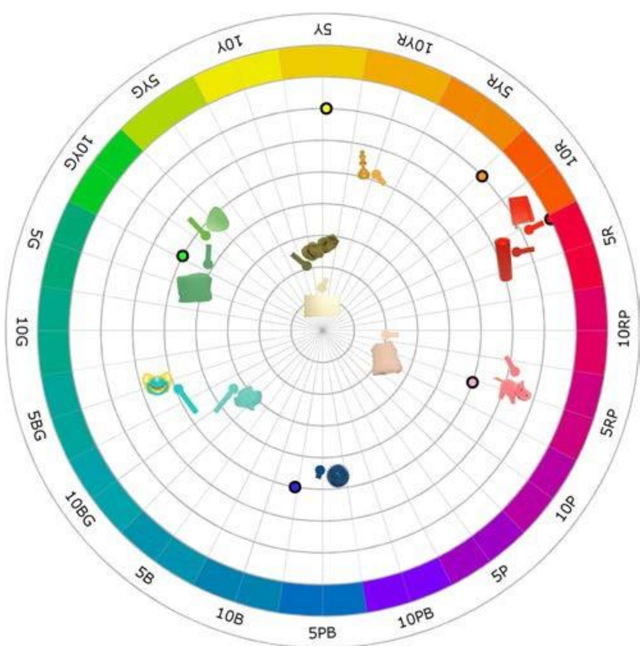

Fig. 5 Radial plot showing Chroma and Hue of average participants object match (small dot next to object) and average participant short-term memory match (end of line). Each concentric circle represents 2 Chroma steps and each radial line represent one of the 40 available Hues in the Munsell Book of Colors (Glossy Collection). Values and SD are reported in Table 2, error bars omitted from plot for clarity. Dots with solid black outline depict color category prototypes [17, 18].

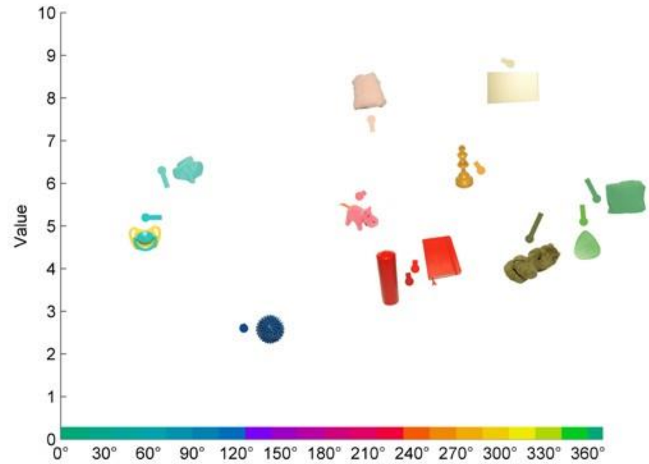

Fig. 6 Plot showing average Value and Hue of participants' object matches (small dot next to object) and average participant short-term memory matches (end of line). If object and memory match coincide they are shown as a dot with no line. Each available step in the Value dimension is represented in the vertical axis and on the horizontal axis we show all the 40 available Hues in the Munsell Book of Colors (Glossy Collection) converted to degrees with and arbitrarily chosen zero point. Values and SD are reported in Table 2, error bars omitted from plot for clarity.

In the case of participants' object and short-term memory matches we also obtained for each match a confidence rating (1 to 5, with 5 being completely confident on their match). When averaged over all objects and participants we find that the average confidence rating for a memory match is 3.4 ± 0.9 and for a match with object present (or simultaneous match) it increases to 4.1 ± 0.9.

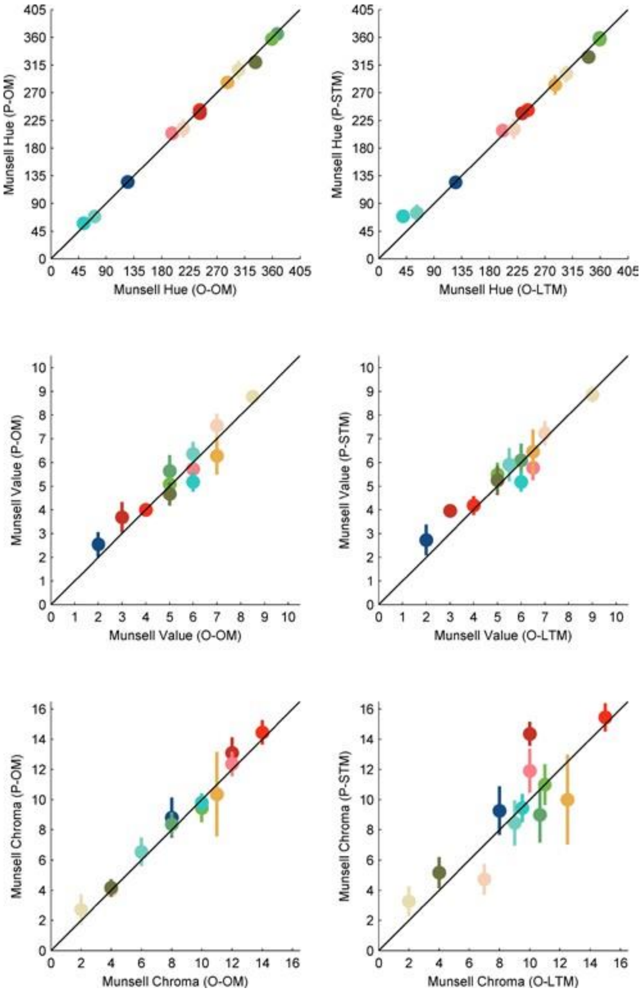

Fig. 7 The three panels in the left column compare owners' (horizontal axes) with participants' matches (vertical axes) in the object present (simultaneous) condition for Hue (top), Value (middle) and Chroma (bottom). The panels on the right hand column show the same comparisons for the memory match condition. Vertical error bars represent SD of participant's matches. The 45-degree line indicates that participants and owners matches are identical. Only the 12 objects used in both studies are illustrated.

A. Analysis

The three panels on the left hand column of Figure 7 show how in the case of simultaneous matches (i.e. with object present) there is no significant difference between how long term owners or participants that have just recently acquainted themselves with them match the object colour. For all three colour dimensions the points lie along the 45 degree line. Two –sided t-tests comparing owners and participants' simultaneous matches show no significant term for Hue: t(11) = .68, p = .51; Value: t(11) = -.55, p = .596 or Chroma: t(11) = -1.72, p= .11. The right hand column of Figure 7 compares the long-term memory matches of object owners with the short-term memory matches of participants for the same object, and the corresponding two-sided t-tests show no significant term for any of the three colour dimensions; Hue: t(11) = -.54, p = .598; Value: t(11) = -.89, p = .39 or Chroma: t(11) = -.51, p=.62 confirming that there is no significant difference on how owners or participants remember the colour of the objects.

To test if there was a difference in any of the Munsell dimensions between long–term memory and simultaneous matches completed by the objects' owners, we conducted one-sided t-tests, comparing owners' mean long-term memory matches with their corresponding object match. For Hue the test showed no significant term: t (16) = 1.18, p = .873, neither did it for Value: t(16) = .16, p = .561. For Chroma, there was a significant effect: t(16) = -2.05, p = .029, indicating that owners long-term memory matches are more saturated than matches made with the objects present.

For effects between the short-term memory and simultaneous matches we conducted repeated measures ANOVA, comparing participants' short-term memory matches with those done with object present. As in the case of the owners' matches we find no effect for Hue: F(1, 11) = .82, p = .384, or Value: F(1, 11) = 3.79, p = .078. As before there was significant main effect for Chroma: F(1, 11) = 13.65, p = .004, suggesting that participants selected more saturated chips in the short-term memory condition when compared to the object present match.

These effects can be seen in Figure 8 where we show owners' matches (left column) and participants' average matches and SD (right column) for Hue (top), Value (middle) and Chroma (bottom). If memory and simultaneous (object) matches were identical they would lie along the 45-degree line, and this is the case for the Hue (top row) and Value (middle row). In the case of Chroma (bottom row) the majority of points are under the diagonal line indicating that the matches from memory tend to be to chips with a higher Chroma than those chosen in the simultaneous (object present) condition.

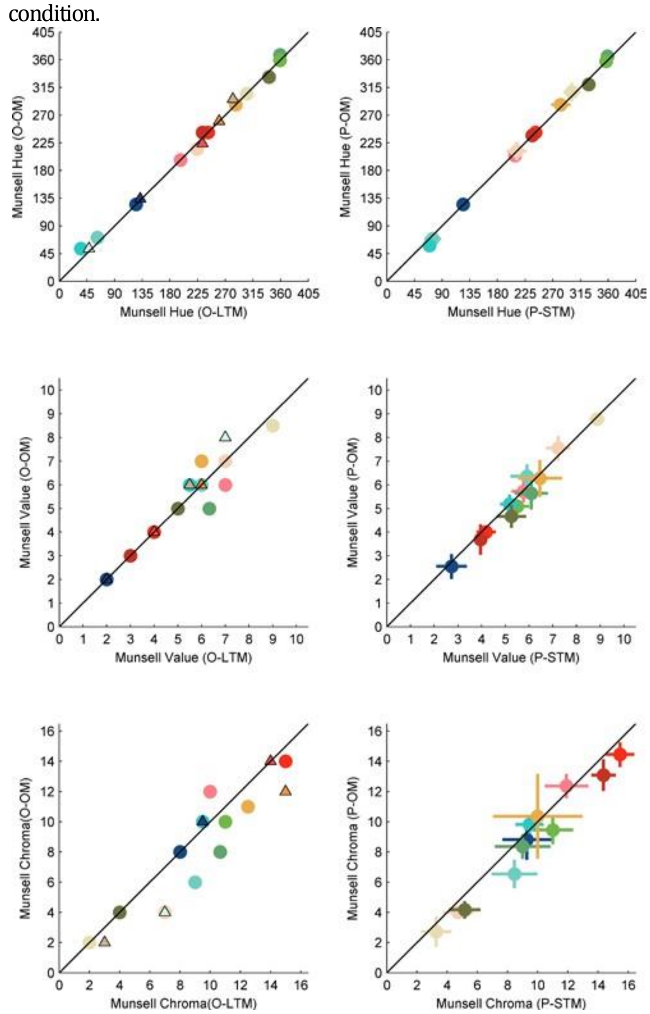

Fig. 8 Left column shows owners' matches for Hue (top), Value (middle) and Chroma (bottom). The triangles represent the 5 objects not used in the short-term memory task, colored disks objects used in both parts of the study. Right column shows mean and SD of participant's (N=12) Hue (top), Value (middle) and Chroma (bottom) matches by color coded crosses. Object matches are shown along the

vertical axis and memory matches along the horizontal. The 45-degree line indicates when memory and object match are identical.

There is a possibility that due to the finite nature of the Munsell collection our study, for some objects, underestimates the increase in saturation. In the case of owners simultaneous matches; four of the objects (candle, animal, ball and dummy) were matched to the chip with highest Chroma meaning that in the memory condition there was no chip available with a higher Chroma for that Hue/Value combination. For the two remaining objects (green scarf, kitchen cabinet) that do not show an increase of saturation with memory, however chips of higher Chroma were available. In the case of the participants matches all three objects for which memory matches were not of higher Chroma than simultaneous ones chips of higher Chroma were available.

In our current study we did not ask our participants to sort the Munsell chips into color categories or to choose the best example for a category (known as prototype or focal colour), however Olkkonen et al.[17] as well as Witzel and Gegenfurtner [18] did exactly this in previous studies. Seven participants across two studies sorted a subset consisting of 320 Munsell chips with maximal Chroma across all Hues and several Value levels into eleven categories that correspond to the basic color terms (red, orange, yellow, green, brown, blue, purple, pink, white, gray, and black) and selected category prototypes in a similar experimental set-up to ours, i.e. office environment with natural daylight from windows. In Table 3 we list the Munsell chip most frequently selected as the category prototype in these studies, and indicate to which category our objects belong to based on the location of the chip most often identified as an object match within the category boundaries from [17, 18].

Table 3: Munsell chip categories and prototypical chips.

Category	Prototype chip	Object
Pink	5RP7/10	
Red	7.5R4/16	
Orange	2.5YR6/14	
Yellow	5Y8/14	
Green	2.5G4/10	
Blue	2.5PB4/10	

The locations of the prototypical Munsell chips are depicted in Figure 3 for owners' matches and in Figure 5 for participants' matches as a dot with a solid black outline. The colour of the dots roughly represents the color category of a given chip.

As participants in [17, 18] only sorted chips with a maximal Chroma, the following analysis only takes Hue of our participants matches into account.

From observation of Figure 3 we can see that for two objects (red book, orange sweater) the Hue of the owners' memory and object matches coincide with the category prototype, and for three other objects (ball, kitchen door, guitar pic) there was no change between the memory match and the simultaneous match. These five objects cannot be analyzed further, because there is no shift between memory and object present match. Seven of the remaining objects were remembered closer to the prototypical colors (turquoise sweater, dummy, potato, elephant, bike tool, green scarf, chess piece), while five others were recalled away from the prototype (brown sweater, pink scarf, candle, animal, t-shirt). Over all 17 objects we found that the Hue of owners long-term memory matches, were no closer to the prototypical colors for each color category than to the simultaneous matches: $t(16) = .95$, $p = .35$, and did not differ significantly from the simultaneous matches: $t(16)= 1.33$, $p = .20$.

In one case the Hue of the participants' short-term memory matches, simultaneous matches and prototypical chip overlapped for one object (red book, see fig. 5). For the remaining 11 objects, short-term memory matches were shifted towards the prototypical colors for 7 objects (candle, pink scarf, ball, green scarf, pic, chess piece), while the remaining 5 were remembered away from the focal color of their category. The Hue of short-term memory matches were no closer to the prototypical colors for each color category than to the simultaneous matches: $t(11) = .68$, $p = .68$ nor did they significantly differ from their simultaneous matches: $t(11) = .51$, $p = .62$.

4. Discussion

Undeniably our ability to remember colors plays an important role in our everyday life. It aids our recognition and identification of objects such as cars in the parking lot and socks in our drawers and contributes to our decision making during shopping for food and clothes. Overall, photographs of natural scenes seen in color are recognized quicker and remembered better than when grayscale is used [19, 20] and even in the case of simple lights, chromatic components are better remembered than brightness ones [21]. Our ability to remember colors has been put to practical use in applications such as color quality metrics for solid-state light sources [22] and to enhance digital images [23] and plays a significant role in color constancy [24-27].

Given this important role of color in visual memory, large biases would be somewhat surprising. However, our results do confirm previous studies in finding an increase in saturation in the memory construct compared to direct viewing. Our study is the first one that uses particular exemplars engrained in the observer's long-term memory, thus getting past potential artifacts of previous studies. We are also able to extend this finding to short-term memory, for which we found an analogous bias towards more saturation for the objects represented in memory. It is interesting to speculate about a potential functional role for such a bias. If the memory trace literally fades with time, then any kind of bias towards more saturation would counteract this tendency.

A notable bias along the saturation axis has also been reported in some experiments measuring the effect of memory colors on perception [28, 29]. Note that in this case it is not the memory that is distorted. Rather, perception itself gets distorted when participants are asked to adjust an object with a typical color to a neutral gray. They adjust the neutral point in the direction opposite to the typical color of the object, when compared to a neutral setting for a neutral object. The image of a banana, for example, would be adjusted more bluish than a random noise patch or an image of a pencil. The most straightforward explanation of this effect is that the memory color is added to the sensory signal in cases of high uncertainty. These results would not predict any bias when viewing objects in their typical color. In this case, there is a strong sensory signal, and the memory color would be quite similar to the sensory signal, too.

There is evidence from carefully controlled computer displayed studies involving 2D patches and a variety of surrounds that patches appear much more vivid and richly colored against low-contrast, gray surrounds than against high-contrast, multicolored surrounds [30]. Systematic exploration of this enhanced contrast or gamut expansion [31] indicates that it is a local effect that can almost be completely eliminated by the introduction of a thin black line between the patch and surround and that its effect is maximal in the case in which the center and surround have the same luminance. Although our chips and objects could be placed against a uniform gray background they remained as 3D objects in a rich and varied context of different luminance that we believe disrupted any contrast or gamut expansion effects.

For the Hue dimension, there does not seem to be any advantage in a memory bias, and in our study we did not find any. A recent study reported a shift in hue towards color category prototypes [13], and earlier studies emphasized the important role of focal colours for colour memory, in particular being remembered better [8] and more precisely [32]. In our current study participants had either a long-term exposure to real tangible colored objects (as in the case of the owners) or an opportunity to familiarize themselves with them over a 30 second period. We collected not only memory matches but also recorded simultaneous matches with the object present. We find no bias effect of either long- or short-term memory for the Hue dimension.

Bae et al. [13], uses computer controlled and displayed stimuli to systematically explore the Hue dimension (while keeping Chroma and Value fixed) in a way that is not possible with our methods and find evidence that memory for Hue of simple colored patches is significantly biased towards prototypical or focal colours. As the authors indicate, this effect would not be noticeable in a sparse sampling of the Hue dimension, such as the one in our study. Our own results show that participants' memory matches of colours associated to an objects do not deviate significantly from their simultaneous (object matches) and do not seem to be biased towards category prototypes.

Different from [7] we do not find a bias in our memory matches towards higher Value although as those authors we do find an increase in Chroma and in the variability of participants memory matches when compared to the object present (simultaneous) condition.

5. Conclusion

In the case of unique singular objects we find, in average, across both the long- and short-term memory tasks a tendency for objects to be remembered as more saturated (higher Chroma) than they are actually perceived (simultaneous match with object present).

We do not find a systematic bias for the other two dimensions in Munsell space, Hue and Value, nor is there evidence for a systematic bias towards category prototypes.

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