Inferring the Tsimane's use of color categories from recognition memory

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Abstract

Knowledge of color has strong individual, environmental, and cultural differences that may systematically influence performance in cognitive tasks. For example, color knowledge has been shown to influence recall of color (Persaud & Hemmer, 2014). This manifests as a systematic regression to the mean effect, where memory is biased towards the mean hue of each universal color category. What remains unclear is whether differences, such as culture and environment, might differentially influence memory. We tested recognition memory for color in the Tsimane' of Bolivia; an indigenous population with little or no modern schooling, whose environment is very different from industrialized societies. We found that recognition regressed towards the mean of some universal color categories, but for others was systematically biased toward neighboring categories. A cluster analysis suggested that the Tsimane' use five underlying color categories—not the standard universals. This might be shaped by education, language and the environment.

Keywords: Episodic memory; color; Prior knowledge; Expectations; Tsimane'.

Introduction

"The whole world, as we experience it visually, comes to us through the mystic realm of color."**— Hans Hofmann**

Similarities and Differences in Color Knowledge

Color holds social and cultural relevance and people's relationship to color can be both internally (e.g. emotional connections to color) and externally (e.g. through the visual experience in their environment) derived. In addition, color is a ubiquitous domain for research across developmental, social, and cultural groups, as well as across domains of cognition.

Importantly, for investigative purposes people have similar, but also different knowledge states of color. There is an extensive literature characterizing knowledge of color across cultures (e.g., Davies & Corbett, 1997; Regier, Kay, & Cook, 2005; Roberson, Davidoff, Davies, & Shapiro, 2004; Stickles & Regier, 2014; Xu, Griffiths, & Dowman, 2010), and several clear patterns of color universality have emerged. For example, it has been shown that universal tendencies persists in color naming across societies (Berlin & Kay, 1969; Regier, Kay, & Cook, 2005) and that those tendencies are linked to 11 basic color terms (i.e., red, orange, yellow, green, blue, purple, pink, black, white, gray and brown). A possible source of universal tendencies in color naming is similarities in favored color percepts (i.e. best examples) across various languages (Regier, Kay, & Cook, 2005). These color universals are shown to have a subjective perceptual basis, in that they can be used to partition the color space into distinct regions that facilitate color categorization (Webster & Kay, 2012).

While these 11 universal categories are found across most industrialized societies, there are also substantial individual, environmental, and cultural differences in color knowledge (e.g., Palmer & Schloss, 2010; Stickles & Regier, 2014). Internal (e.g., emotional) relationships and preferences to certain colors serve as a candidate source of variation in individual color knowledge as postulated by the Ecological Valence Theory of Human Color Preferences (Palmer & Schloss, 2010). This theory posits that people's emotional response to a color is their cumulative affective response to the objects to which the color is associated. Individuals prefer colors that they have had positive experiences with (e.g. yellow – color of flowers) and do not prefer colors with which they have had bad experiences (e.g. red – color of fire), signifying each person's close and personal relationship to color.

At the group level, a source of variation in subjective color knowledge is the relationship between color and the variability in natural environments. For example, color terms in languages with climates of abundant vegetation (e.g. rainforest) are significantly different from color terms in languages with dry climates (e.g. Savanna), but not in places with relatively similar climates (e.g. rainforest and monsoon) (Stickles & Regier, 2014). The difference in the greenery of the climates presumably accounts for difference in color naming. Thus, it appears that local environmental factors influence color knowledge and promotes variability in color terms across languages.

Cultural differences are a third source of subjective variation that engenders differences in color knowledge. It has been suggested that color category knowledge develop as a function of cultural experience (e.g. Roberson, Davies, & Davidoff, 2000). For example, there are significant differences in perceptual judgments for color between different cultural groups. This has been demonstrated in various groups including Russian, who have two terms for blue (Paramei, 2005; Winawer, Witthoft, Frank, Wu, Wade, & Boroditsky, 2007), Papua New Guinea, who uses 5 color categories (Roberson, Davies, & Davidoff, 2000), and a semi-nomadic South African tribe, who categorizes color based on light and dark (Roberson, Davidoff, Davies, & Shapiro, 2004).

Other theories have been postulated to account for both the universality and cultural differences in color naming across languages. For example, one theory suggests that color naming reflects near optimal divisions of perceptual color space giving rise to both universal tendencies and language differences in color terms (Regier, Kay, & Khetarpal, 2007).

Prior knowledge and memory

In the domain of memory, it has been shown that knowledge of the statistical regularities of the environment exerts strong influences on the information recalled, e.g., the size of objects (Hemmer and Steyvers, 2009a), objects in scenes (Hemmer and Steyvers, 2009c) and the height of people (Hemmer, Tauber, and Steyvers, in press); for a review see Hemmer & Persaud (2014). Memory for color, specifically, demonstrates that recall is influenced by knowledge of the hue distributions over color categories. For example, Persaud and Hemmer (2014) measured bi-directional category knowledge of color, i.e. linguistic categorization (what label describes this color), and category representativeness (generate a color for this label). They found strong agreement in color naming and generation for hue values associated with universal color categories. They also found a hierarchical naming granularity of 7 universals and additional subordinate level labels within those color categories (e.g. light-green, sky-blue). While all participants used labels from the 7 universal categories, there were strong individual differences in the use of subordinate labels. This suggests that people's shared bi-directional knowledge of color may be reflective of their shared environment, but might also reflect expertise and the communicative usefulness of this knowledge.

Furthermore, Persaud and Hemmer (2014) found a regression to the mean effect in free recall, such that studied hue values that were darker shades (above the mean of the color category) were underestimated, while studied hue values that were lighter shades (below the mean of the color category) were overestimated. They modeled this regression effect with a Bayesian cognitive model of memory which assumed recall to be a combination of prior expectations for color and noisy episodic representations. What remains to be examined is whether differences across cultural, social, and developmental groups might differentially influence memory. For example, systematic differences in memory may reflect individuating states of knowledge across cultural groups.

Inferring Color Categories in the Tsimane'

The goal of the current investigation is to examine memory for color in a population that has potentially different expectations for color based on their environment or culture. Specifically, we investigated recognition memory for color in the indigenous Tsimane' group of Bolivia.

The Tsimane' are an indigenous people of lowland Bolivia who inhabit lowland rainforest east of the Andes in the Beni department of Bolivia. They live close to ranching lands and many come to the Bolivian city of San Borja to trade local farmed goods. Otherwise, they have minimal contact with Bolivians and live a traditional lifestyle as "farming foragers", i.e., they are hunter-gatherers who have some agriculture. They have highly variable amounts of education (see table 1) and few manufactured artifacts or even permanent artifacts.

The Tsimane' language is closely related to the Moseten language. In the Tsimane' language color terms are highly variable and morphologically complex—e.g., yellow is called "color-of-the-cuchi-cuchi-tree". Furthermore, while some people know this term, some do not. This holds true for other color terms as well. The high variability in color terms might stem from several sources. The variability in knowledge might be reflective of educational level. The Tsimane' have very little modern education. This includes the use of educational toys employed in modern education that emphasize color naming. Education is known to influence a number of cognitive domains, such as numerical cognition (Piazza, Pica, Izard, Spelke, & Dehaene, 2013),

Figure 1. Tsimane' woman participating in the study. The experiment was conducted in a class and people from the community were watching. The left panel shows a study trial and the right panel the corresponding testing trial.

and education might bias color knowledge and the use of color terms. The lack of a communicative need for referencing certain colors in the Tsimane' environment might also influence development and use of color terms, as evidenced by the findings of Stickles and Regier (2014). Such differences in education, language and environment might result in different influences on memory than those found in U.S. students (Persaud & Hemmer, 2014).

Memory for Color

In the following experiment, we assessed recognition memory for color. The goal of this study was to infer what color categories Tsimane' ascribe to, evidenced by their memory performance. Based on previous work assessing recall for color in U.S. student populations, our predictions for performance were two-fold. First, we predicted a systematic regression to the mean effect where memory is biased towards the mean of the hue range for a color category. Second, based on the high variability in color terms in the Tsimane language, potential differences due to education, and their natural environment, we predict that the specific categories the Tsimane' regress toward will be different than U.S. populations.

The regression effects could then take several forms: Memory could regress towards a smaller number of categories – conjoining neighboring categories, as observed in several cultures using terms to combine categories such as green and blue (e.g., Roberson, Davies, & Davidoff, 2000; Roberson, Davidoff, Davies, & Shapiro, 2004). They could split universal categories – e.g., as observed in Russian where blue has two terms (e.g., Paramei, 2005). Lastly, memory could be non-systematic, i.e., not regress or regress away from the category mean. This would provide support for cultural and environmental factors that influence memory. Alternatively, regression towards the standard universal color categories would suggest that these factors (education, language, and environment) may have little influence on memory.

Method

Participants Twenty-three individuals participated in this study and were compensated with small gift bags of local goods. Participant ages ranged from 18-65 years of age. Self-reports of education levels ranged from no formal education to 10 years of education, and arithmetic skills ranged from 0-11 out of 11 questions correct on an ad hoc field measure (using all addition questions), and highest count ranging from 2-102 (meaning knowing all numbers). Table 1 gives a detailed breakdown of the demographics and skill variables.

Table 1 Participant Demographics *n=23

Age (years)	**18**	**20-28**	**30-34**	**40-48**	**60+**	
	4	8	6	3	2	
Education (years)	**0**	**1**	**2**	**3-5**	**6-9**	**10**
	4	1	3	9	5	1
Spanish (translate out of 11)	**0**	**6-9**	**10-11**			
	1	19	3			
Counting (highest #)	**2**	**5-9**	**15-31**	**46-64**	**93**	**102**
	1	2	5	3	1	11
Arithmetic (out of 12)	**0**	**1**	**2-3**	**4-5**	**6**	**10-11**
	2	3	10	2	2	3

Materials & Design Stimuli consisted of 24 random shapes uniformly filled with 24 unique colors sampled from the hue color space. Colors were sampled such that saturation and luminance were held constant at 100% and 50% respectively. Because saturation and luminance were held constant, the presented hue values did not include black, white, brown or gray. The 24 colors were selected from the remaining 7 color categories and varied in hue by a minimum of 5 units (on a total range of 239). Furthermore, colors were distributed across the hue space such that the colors were selected from the categories based on the size of the categories hue range (e.g., yellow hue ranges only from approximately 35-50, but green ranges from 55-110—See Persaud & Hemmer (2014) for full set of hue ranges used in free recall with undergraduate participants). Thus, hue values were randomly selected from each color category, proportional to the size of the color category (i.e. 2 red, 3 orange, 2 yellow, 6 green, 6 blue, 2 purple, and 3 pink). Study shapes were printed individually on 5.5-by-8 inch cards. For test slides the study hue and shape combination was printed on a 5.5-by-8 inch card along with 5 colors distractors appearing on the same shape as the study shape (See figure 2 for a sample study test pair). The colors of the distractors were chosen such that the hue values of two distractors were greater than the hue value of the target color, two distractors were less than the hue of the target, and the last distractor hue value was either greater or less than the target, but at a further absolute distance from the target than the other distractors (see Figure 2 for illustration).

Procedure Participants were gathered in a communal classroom, and there were a number of onlookers during the administration of the test. Figure 1 shows both the experimental setting and a study-test trial sequence. A translator explained the task, and all participants appeared to immediately understand the procedure. A color shape combination measuring 5-by-5 inch was presented in the center of a white card.

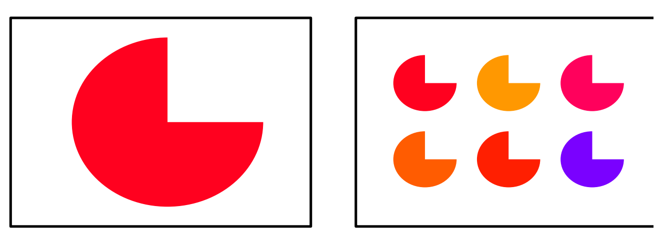

Figure 2. Sample study – test stimuli.

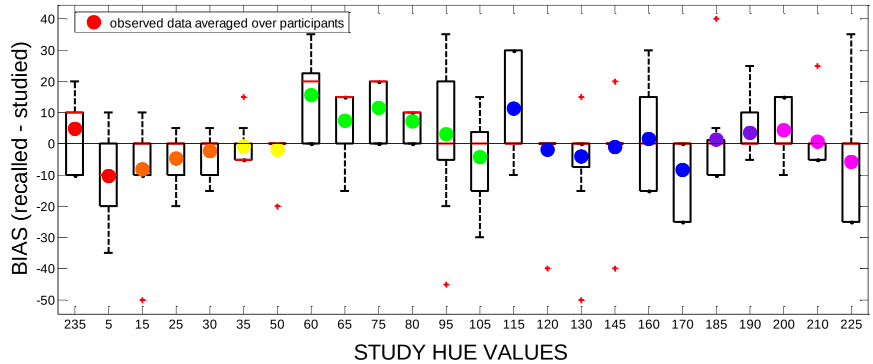

Figure 3. Recognition bias by hue value. Average mean bias (data points) and response ranges (box plots) for each studied hue value. Colors of the data makers indicate the standard universal color categories. Positive bias indicates over estimation and negative bias indicates underestimation. The black line indicates no bias.

Presentation time of the 1-item study card was as close to 1 second as possible. The study trial was followed by a 6-alternative forced choice immediate recognition task. For the 6-way choice, participants had as much time as they needed, but most responded immediately. The response was recorded in a booklet and the experiment proceeded to the next trial. On some trials (approx. 5%) it was not clear where the participant had pointed, and participants were asked to repeat their choice. They were asked to touch, rather than point, to try to alleviate this problem. Total participation time was approximately five minutes per subject. Participants also completed other unrelated tasks (either before or after) for a total of about 20-25 minutes. Trial order was randomized between participants. Due to the field demands, it was not possible to randomize the target/foil locations on the test trials. This means that all participants saw identical test cards.

Results

Prior to any analysis, recognition responses that were more than 6 standard deviations away from the studied hue value were removed. These data points constituted 2.5% of all the data (14 out of 545 data points). This is consistent with the procedure of Huttenlocher et al. (1991) who used an immediate recall task for the spatial location of dots. They removed 2.4% of responses based on trial more than 45 degrees from the study location and an additional 1.5% of responses based on a threshold of 3 standard deviations. Thus, we used a much more conservative criterion and removed only 2/3 the number of trials. After calculating the bias measure described below, individual subject data revealed that there was one participant whose data were very noisy. Performance appeared essentially random in that 50% of this participant's responses were either 6 standard deviations away from the studied hue or were outside of the study color category (studied yellow and recalled red). This data may reflect either impairment in color vision[1] or inattention to the task and was removed from all further analysis.

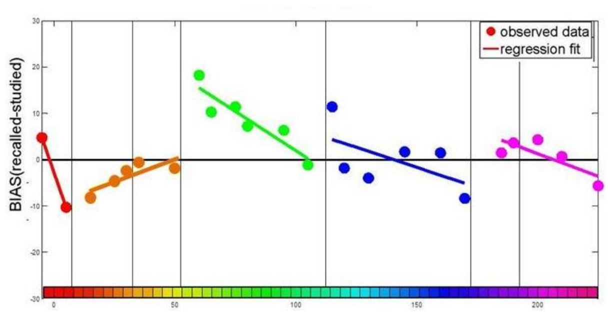

Figure 4. Regression fits to 5 color categories. Categories are partitioned by hue ranges outlined in Persaud & Hemmer (2014) with orange and yellow combined, and pink and purple combined. The black line indicates no bias. The data points are color coded with a hue for that color category. The lines give the regression fits for each of the 5 categories.

Recognition Bias and Regression Memory performance was measured in terms of recognition bias, i.e., the difference between the hue value participants remembered and the hue value studied. First, bias was calculated for each individual participant and then averaged across participants for each studied hue value. Figure 3 shows recognition bias as a function of studied hue values. It should be noted that in all figures the hue range is visualized such that hue values 235 and 5—both red hues—are next to each other on the left side of the graphs. The data appear to show clear regression to the red, green, blue and pink color categories. The data for orange, yellow, and purple is more ambiguous. Based on a this ambiguity, we partitioned the averaged bias into 5 categories – combining orange and yellow, and combining purple and pink— and fit a linear regression model to each of the 5 resulting color categories (Figure 4). The slope of the regression in each category (except for the orange/yellow range) is negative, indicative of a regression to the mean effect. Values below the mean of the category are overestimated and hue values above the mean are underestimated. This is consistent with the findings from recall for color (Persaud & Hemmer, 2014). A one-way

[1] A limitation of this study is that we were not able to conduct a color blindness test. The assessment required naming knowledge of complex shapes which was confounded with education.

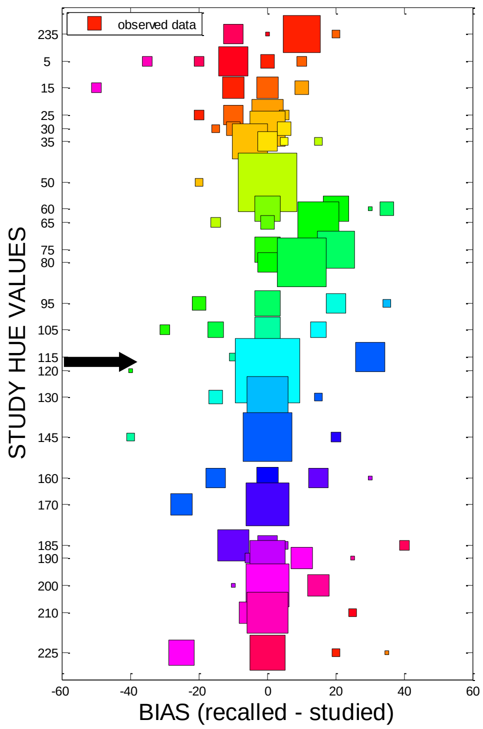

Figure 5. Recognition response bias to studied hue values. All responses for a given study hue value appear in a horizontal row. The response markers are scaled by the frequency at which they were given (larger boxes indicates greater frequency) and colored with the exact hue value chosen.

analysis of variance revealed a significant main effect of intercepts ($F[109]=25$, $p<.001$) across color categories, indicating that each category has a different intercept. However, performance in the orange/yellow range appears to be different from the other categories. In this category, the slope runs in the opposite direction, showing a regression towards orange-red rather than towards yellow. Moreover, there was no significant correlation between recognition bias and the demographic variables (i.e. age, education level, highest count, and arithmetic performance).

All Recognition Responses Next, we examined the hue values remembered for each hue studied. Figure 5 shows all hue responses to each of the study hue values in square boxes scaled by the frequency at which they were given. Correctly recognized hue values lie vertically at the 0-bias line of the x-axis. For each study value, all responses to that value form a straight horizontal line. For example, for study hue 95 (green-blue - indicated by arrow) all responses to fall in line with the black arrow. Responses greater than 95 fall to the right of the 0-bias line and responses less than 95 fall to the left. The squares in each horizontal row are colored by their true response hue value. A visual inspection of this graph suggests that categories may be partitioned differently than observed in Figure 4. For example, red, orange, and yellow hues appear to tightly cluster with no clear diagonal regression line, while a possible light blue category (between green and blue) emerges.

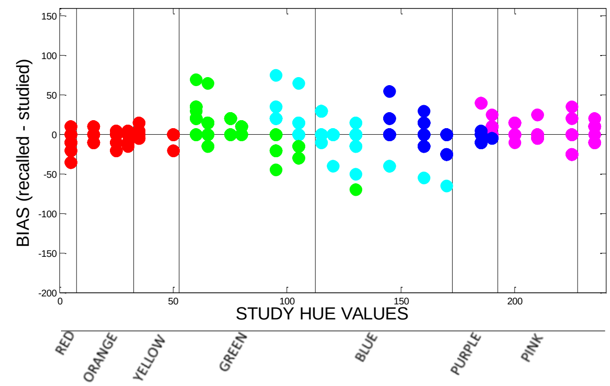

Figure 6. K-means Cluster Analysis. Bias data partitioned into 5 learned clusters from an unsupervised k-means cluster analysis, and color coded with a hue from that category. Vertical lines and color labels on x-axis show the standard universal categories.

Cluster Analysis The visual inspection of figure 5 appears to show interestingly different color categories compared to the universal seven (red, orange, yellow, green, blue, purple and pink). Therefore, rather than manually assigning color categories as seen in figure 4, we conducted a k-means cluster analysis to learn the underlying color categories that participants may have used (Figure 6). We ran 10 iterations of the cluster analysis on four different clusters sizes (i.e., 4, 5, 6, and 7) and found the greatest cluster agreement over the 10 chains for a cluster size of 5. This cluster size was further confirmed by the Calinski Harabasz criterion. Consistent with the regression analysis in figure 4, the cluster analysis also combines colors in the purple/pink ranges and orange/yellow ranges. However, the cluster analysis further combined the orange/yellow category with red, but split the universal blue range into two blue categories.

Discussion

In this paper we sought to infer the color categories of an indigenous population, the Tsimane' of Bolivia, evidenced by their memory for colors. Based on this work, two clear patterns emerged. First, a regression to the mean effect was borne out of the data, such that memory was biased towards some universal color categories. This finding suggests that the regression to the mean effect in memory is a universal cognitive process and is systematic across cultural, environmental, and educational groups. Interestingly, however, the categories regressed toward were different than observed in a standard U.S. population. The standard finding is a regression towards seven universal color categories (i.e. red, orange, yellow, green, blue, purple, and pink). In the Tsimane' population, memory followed this pattern only for red, green, blue and pink, but differed for orange (biased toward red), yellow (no systematic bias) and purple (biased toward pink). Moreover, a k-means cluster analysis further suggests that the Tsimane' segregate blue into two categories, resulting in five inferred categories: red/orange/yellow, green, light blue, dark blue, and purple/pink.

The population specific bias observed in the Tsimane', relative to a U.S. population, might be related to the underdevelopment of category knowledge for some categories. This could be due to low environmental incidence, low frequency in language, limited formal education of color, or little communicative need of certain color terms. For example, if a certain color is not pervasive in an environment, or tied to objects of importance, development of a linguistic label and prototype for that category might be hampered. Even if a that color does exist in the environment, but it is tied to only a few objects and all examples of that object are that color, the color label might not help to disambiguate communication. For example, if all houses were brown, saying "go to the brown house" is not helpful. Instead, other disambiguating features of the object (e.g., "the tall house", "the house with the thatched roof") are needed.

From a memory perspective, the underdevelopment of color categories raises several interesting questions. A color like yellow, which is somewhat rare in the Tsimame' environment, might lead to an outlier (or Von Restorff) effect, where it is better remembered. Conversely, a pervasive color (with a high prior probability in the environment) is also likely to lead to better memory, and might account for the shallow regression line in the blue category (figure 4). Future studies are required to substantiate these intuitions about the Tsimane' population, including an extensive quantification of the color terms found in the Tsimane language. These studies are a part of an ongoing investigation of prior knowledge and memory for this population.

We believe that this study provides important evidence for an experience based mechanism (development and maintenance of prior knowledge) that gives rise to differences in color knowledge. This is consistent with the findings of Stickles and Regier (2014) that environment impacts language (i.e., color words). Furthermore, the study provides strong support for the influence of category knowledge on memory, and the systematicity of memory across groups with varying prior knowledge content.

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