An Ecological Valence Theory of Human Color Preferences

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Abstract

Although color preference is an important aspect of human behavior, little is known about why people like some colors more than others. In this paper we probe this issue both theoretically and empirically. First, we discuss Hurlbert and Ling's (2007) cone-contrast theory, which posits a physiological explanation based on opponent cone outputs and gender differences. We then present an ecological valence theory that color preferences reflect people's cumulative emotional responses to environmental objects/events strongly associated with particular colors. Finally, we present data that challenge Hurlbert and Ling's model on multiple counts and support an ecological valence approach.

Keywords: color; aesthetics; preference; ecological valence

Color preference is an important aspect of human behavior. It influences a wide spectrum of decisions people make on a regular basis, including the products they buy, the clothes they wear, the way they decorate their homes and offices, and how they design their personal and professional websites, to name but a few examples. One reason why color preference plays such a prominent role in decision-making is that color is among the most customizable features of man-made objects. Although color is, in some sense, a superficial quality that seldom influences the practical function of artifacts, there is a good reason why clothes, cars, ipods, and carpet come in such a wide variety of colors: most people prefer to surround themselves with colors they like.

There has been much research on which colors the average person prefers, some of which has been published in the scientific literature (e.g., Eysenck, 1941; Granger, 1955; Guilford & Smith, 1959) and some of which is no doubt locked in confidential file cabinets of the corporate world. Until recently, research on color preference has primarily focused on describing *which* colors humans prefer without shedding light on *why* people prefer the colors they do. This level of analysis is sufficient for designers, whose goal is to produce aesthetically pleasing products. For cognitive scientists, however, who are interested in why people have the color preferences they do – and indeed, why people have color preferences at all – simply describing preferences is not enough.

We begin by reviewing Hurlbert and Ling's (2007) cone-based theory of color preference, which argues that it is related to the relative activation of opponent processes derived from retinal cone responses. We then introduce an ecological valence theory, which proposes that color preferences reflect people's cumulative emotional responses to objects, institutions, and events associated with those colors. We then describe the Berkeley Color Project and some results that support our ecological valence theory and challenge Hurlbert and Ling's (2007) cone-contrast theory. In particular, we find that average color preferences in our data are much more closely related to the weighted affective valence estimate (WAVE) of color-associated objects than it is to the retinal cone contrasts proposed by Hurlbert and Ling.

Sensory Physiological Approach

Hurlbert and Ling (2007) recently introduced an explanation for human color preference based on retinal cone responses. They were able to account for a large portion of the variance in average color preference for their set of test colors using linear combinations of cone contrasts – specifically, **L-M** and **S-(L+M)**, where **L**, **M**, and **S** indicate the output of cones that are most sensitive to long, medium and short wavelengths of light, respectively – calculated for the test color relative to its neutral gray background. The **L-M** axis roughly corresponds to a red-to-cyan dimension and the **S-(L+M)** axis roughly corresponds to a purple-to-chartreuse dimension (although Hurlbert and Ling refer to the former as "red-green" and the latter as "blue-yellow"). They found that both male and female preferences weighted highly positively on the **S-(L+M)** axis, because both prefer purpler colors over chartreuser[1] colors. Weights on the **L-M** axis differed as a function of gender, however: females weighted positively, preferring redder colors, and males weighted negatively, preferring cyaner[1] colors.

Hurlbert and Ling suggested that this gender difference in **L-M** (red/cyan) preferences is based on a hardwired biological mechanism that evolved in the context of "hunter-gather" societies. In particular, they argue that females like redder colors because their visual system has specialized to be attracted to ripe berries and fruit against a background of green foliage.

There are both theoretical and empirical problems with their account, however. First, their theory provides no explanation for their most robust finding: that both males and females robustly prefer purpler colors to chartreuser colors. Second, their theory explains why females should like redder colors, but does not explain why males should like cyaner colors. Even if males *never* picked berries and

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[1] Please forgive the odd terminology here. We use "chartreuser" and "cyaner" rather than "more chartreuse" and "more cyan" because of the ambiguity the latter introduces in terms of the number of colors in these categories.

fruit – a dubious assumption, at best – it is unclear why they would be attracted to cyan, especially since the game for which they searched visually would often be seen against a background of green foliage, just like berries and fruit. Third, the data on which Hurlbert and Ling's theory is based come from a narrow color sample that explicitly excludes highly saturated colors, unique hues (red, yellow, green and blue), and other easily nameable colors (orange, purple, white, black, gray, and brown). Indeed, their eight hues form essentially just two classes of colors: 4 variants of pink and 4 variants of green. Although these colors may be good choices for testing a cone-contrast theory of color preference, they do not constitute a representative sample of the full range of colors humans can and do experience. Finally, their model predicts specific constraints on patterns of hue preference due to its opponent-based structure. In particular, it implies that people should never simultaneously prefer redder colors *and* cyaner colors nor purpler colors *and* chartreuser colors, because these pairs lie at opposite ends of the two opponent cone-based dimensions. For all these reasons we felt that different theoretical and empirical approaches to color preference were worth pursuing.

An Ecological Valence Approach

In this paper we propose an ecological valence theory of color preference. It is grounded in people's emotional responses to colored environmental objects rather than on particular hardwired contrasts between cone outputs. The ecological valence theory is perhaps most easily framed by an analogy between color preferences and food preferences. Because humans do not have direct sensory access to the nutritional content of potential foodstuffs, they must rely on the output of genetically evolved taste receptors as a surrogate for actual nutritional value. Through both evolutionarily and individual learning mechanisms, organisms determine what tastes are edible and nutritious (e.g., sweet and/or fatty substances) and what tastes are inedible and/or noxious (e.g., bitter substances) via feedback from the consequences of eating episodes. Just as organisms are more likely to survive and reproduce if they eat good-tasting substances and avoid bad-tasting ones, so too organisms may be more likely to survive and reproduce if they are attracted to objects and situations associated with good-looking colors and avoid objects and situation associated with bad-looking colors. The consequences of color-based preferences are not as strongly drawn as those of taste-based preferences, but it nevertheless seems reasonable that similar evolutionary and associative-learning mechanisms would operate in the color domain.

The ecological valence theory thus assumes that an individual's color preferences at a particular time are determined by their combined affective response to environmental objects and situations associated with each color. Accordingly, people should be attracted to colors associated with objects and situations to which they have positive reactions (e.g., blues with clear sky and clean water) and repulsed by colors associated with objects to which they have negative reactions (e.g., browns with feces and rotten fruit). If this theory is correct, then preference for a given color should be closely related to the affective value of the objects and events that people associate with that color. This hypothesis is easy to formulate, but difficult to test. Nevertheless, we report evidence that provides striking support for it in Experiment 2, where we estimate the ecological valence of color-associated objects and use them to predict the preference data for 32 chromatic colors sampled systematically from the full spectrum in Experiment 1.

The Berkeley Color Project

The Berkeley Color Project (BCP) is a large-scale study aimed at understanding human color preference. (See Palmer and Schloss (in preparation) for a full description.) We used a massive repeated measures design in which the same set of 48 participants were tested on the same 30 tasks using the same set of 37 colors (see below). This allowed direct comparisons across tasks, with each participant serving as his or her own control. Tasks included preference ratings of homogeneous squares of color, preference ratings of colors of objects (e.g., t-shirts, walls), preference ratings of color pairs in concentric squares, ratings of color harmony for color pairs, ratings of color-emotion associations, and ratings of the colors' colorimetric structure (e.g., red/green, blue/yellow), to name but a few. In this paper we focus on preference for 32 single chromatic colors (excluding black, white, and grays) and how they can be predicted from factors such as cone contrasts (Hurlbert & Ling 2007) and colorimetric judgments. We compare these models with a model based on weighted ecological valence ratings in Experiment 2.

Experiment 1: Preference for Single Colors

In the first experiment we obtained preference ratings for 32 single colors presented on a neutral gray background. We then tested several different models to predict average preferences across individuals, one based on cone contrasts, one based on colorimetric ratings (red-green, blue-yellow, light-dark, and saturation).

Method

Participants All tasks in Experiment 1 were completed by 48 participants selected to fill a 2 x 2 design balanced for gender (male, female) and artistic expertise (low, high). All participants were screened for color deficiency using the Dvorine Pseudo-Isochromatic Plates, and none were found to be color deficient. All participants gave informed consent, and the Committee for the Protection of Human Subjects at UC Berkeley, approved the protocol.

Design A massive repeated measures design was employed in which each participant completed all 30 experiments with the same set of 37 colors. Experiments were divided over a series of eight sessions, only a subset of which will be discussed in this paper.

The BCP's 37 colors included four hues approximating the unique hues (red (R), green (G), yellow (Y), blue (B)) and their approximate angle bisectors (orange (O), chartreuse (H), cyan (C), purple (P)), at four saturation/brightness levels (saturated (S), light (L), dark (D), and muted (M)[2]). There also were five achromatic colors including black, white and three intermediate grays. Colors were translated into CIE 1931 xyY coordinates from Munsell space using the Munsell Renotation Table (Wyzecki & Stiles,1967). Figure 1 shows our 37 colors projected onto an equal luminance plane in CIELAB color space.

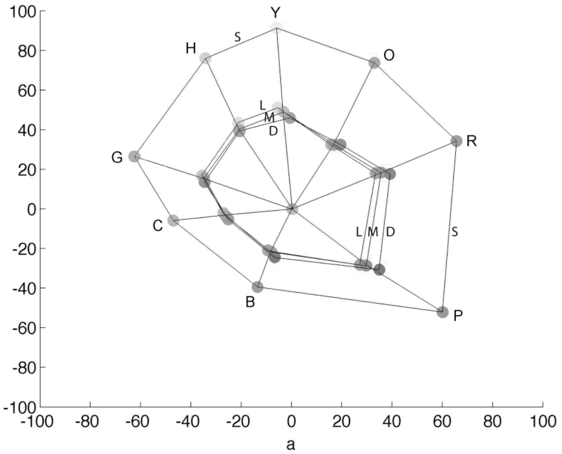

Figure 1: The BCP's 37 colors projected onto a plane of equal luminance in CIELAB color space.

Procedure In all tasks discussed here, participants were presented with a random order of the 37 individual colors on a neutral gray background. Each color remained on the screen until a task-dependent rating was made along a 14 cm (400 px) line. The next trial began 500ms later. For the color preference task, participants rated how much they liked each color on a scale from "not at all" at the left end of the line to "very much" at the right end. For the colorimetric task participants rated how red vs. green, yellow vs. blue, light vs. dark, and saturated vs. desaturated each color appeared to be. Trials were blocked by colorimetric dimension.

Results and Discussion

Color Preference The average results for the color preference task are plotted in Figure 2, which shows preference for the saturated (S), light (L), muted (M) and dark (D) "cuts" in color space as a function of hue. Preferences for the S, L and M cuts produced relatively smooth functions with a peak at blue and a trough at chartreuse. The L and M colors were equally preferred (F < 1), with the S colors at a higher level of preference than the average preference for L and M colors (F(1,47) = 9.20, p < .01). There was no interaction between hue and cut for the S, L, and M colors, showing that the pattern of hue preferences across these cuts was essentially the same (F(7, 329) = 2.02, p > .05). The D cut did, however, interact with the other three cuts (F(7,329) = 17.87, p < .001). Dark orange (brown) and dark yellow (olive) were significantly less preferred than orange and yellow in the average of the other three cuts (F(1,47) = 11.74, 41.06, p < .001, respectively), whereas dark red and dark green were more preferred than red and green in the average of the other cuts (F(1,47) = 15.41, 6.37, p < .001, .05, respectively).

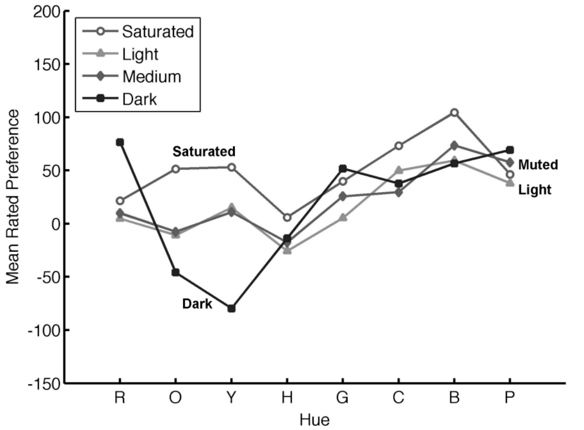

Figure 2: Mean preference for the 32 chromatic colors

Figure 3 shows the average preference ratings separately for male and female participants. The shape of the hue functions do not differ much across genders, and there is no gender difference for either L or D colors (F < 1).

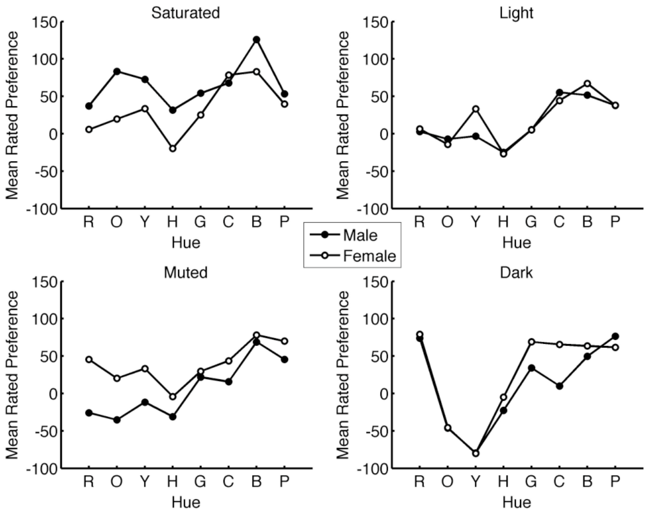

Figure 3: Mean preferences among the 32 chromatic colors for males and females, plotted for S, L, M, and D colors.

There was, however a reliable interaction between males and females for the M and S cuts (F(1,46) = 11.42, p < .01). Males gave S colors higher preference ratings than M colors (F(1,23) = 24.18, p < .001), whereas females liked M and S colors equally. Males liked M colors less than females

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[2] Non-bold S, L and M refer to saturated, light, and muted colors; bold **L, M** and **S** to retinal cone-types.

($F(1,46) = 5.85$, $p < .05$) and S colors more, although the latter difference was not significant.

Modeling Color Preference We first attempted to account for the variance in average preference ratings using Hurlbert and Ling's (2007) cone contrast model. We calculated the contrasts for the **L-M**, and **S-(L+M)** opponent systems (see Figure 4) using equations provided by Eskew, McLellan, & Giulianini (1999). Consistent with Hurlbert and Ling's findings, there was a significant correlation between preference for our 32 chromatic colors and the output of the **S-(L+M)** system ($r = .44$, $p < .05$). No additional variance was accounted for by the **L-M** system however. A multiple linear regression model using all three factors as predictors accounted for only 19% of the variance in our color preference ratings. This contrasts dramatically with Hurlbert and Ling's (2007) finding that these variables accounted for 70% of the variance in their preference data. This discrepancy is almost certainly due to the salient differences between our stimuli, which included unique, highly saturated, nameable colors, and theirs, which avoided unique, highly saturated, nameable colors.

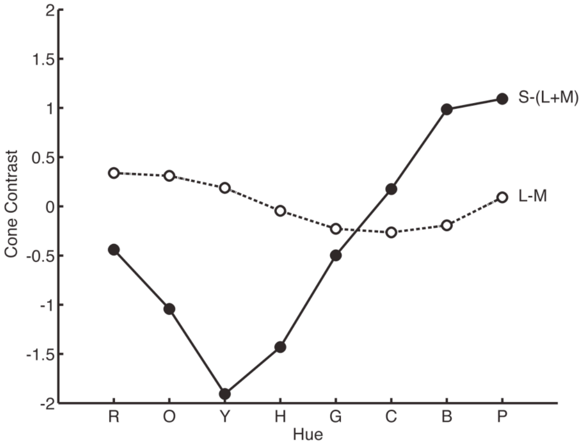

Figure 4: Cone contrasts for the **L-M** and **S-(L+M)** axes as a function of the 8 hues of the Berkeley Color Project.

We conducted the same analyses for males and females separately to see whether our data replicated their finding that females weighted positively on the **L-M** axis and males weighted negatively. Both males and females in our study weighted negatively on the **L-M** axis, with small negative correlations for both genders ($r = -0.12, -0.12$, $t(23) = -2.44, -2.40$, respectively, $p < .05$), showing that both genders among our participants prefer cyaner to redder colors, to the extent that they have any preference over this dimension.

In the second model we attempted to predict our average color preference ratings from our average colorimetric ratings: red/green, yellow/blue, light/dark and saturation. Although these dimensions are not rooted in a known biological system, as the **LMS** cone contrasts are, they are based explicitly on salient dimensions of perceptual experience (i.e., the Hering-based dimensions of the Natural Color System (NCS) color space; Hård & Sivik, 1981). This model performed much better than the cone contrast model, accounting for 57% of the variance in our preference ratings: 34% for blueness-yellowness (similar to the **S-(L+M)** dimension of the cone contrast model), an additional 17% for saturation, and a further 6% for lightness-darkness. Redness-greenness was not included in the model.

Although this model explains substantially more variance than the cone contrast model, it does not predict the striking difference in hue preference for the colors in the D cut, relative the S, L and M cuts. It also does not provide any explanation of *why* people prefer the colors they do; it only describes an approximation to the pattern of preferences we found. We will address both points in Experiment 2.

Individual differences were further examined using cluster analysis to separate participants into subgroups based on similar hue preferences (see Figure 5). The input to the cluster analysis was obtained by correlating preference ratings for the eight hues (averaged over cuts) for each pair of participants. These pair-wise correlations were then used as distance metrics in the cluster analysis (Carroll, 1976).

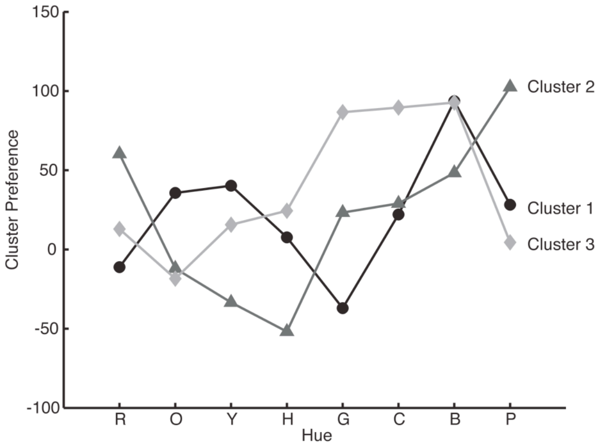

Figure 5: Hue preferences (combined across cuts) for three clusters of participants based on similar hue preferences.

We examined these three hue functions separately to determine whether color preferences always vary in opposition as the cone-contrast theory requires. Following Hurlbert and Ling (2007), we computed the correlation between each observer's data and the cone-contrasts (Eskew et al., 1999): the colors' coordinates on the two opponent axes (**L-M** and **S-(L+M)**), which vary in opposition as the cone-contrast theory requires, and the absolute value of these same coordinates (|**L-M**| and |**S-(L+M)**|), which vary conjointly in conflict with the cone-contrast theory. Table 1 shows the results. The data show modest, but highly reliable conjoint variation as well as opponent variation. This finding casts doubt on the viability of cone-opponency as the primary determinant of color preference.

Cone Contrast	$r_{\text{cluster 1}}$	$r_{\text{cluster 2}}$	$r_{\text{cluster 3}}$
L-M	-0.05	-0.02	-0.63***
S-(L+M)	0.17	0.66***	0.30*
|L-M|	-0.07	0.12	-0.03
|S-(L+M)|	0.23*	-0.38***	-0.30**

* p<.05, ** p<.01, ***p<.001

Table 1. Average of each participant's correlation between cone contrasts and hue preferences for Clusters 1, 2, and 3. Significance levels are based on t-tests comparing individuals' correlations within each cluster to zero.

Experiment 2: Weighted Affective Valence Estimates (WAVEs) of Colors

Experiment 2 was conducted to test a key prediction of the ecological valence theory outlined in the introduction. The theory postulates that color preference is determined by the cumulative valence of people's affective responses to "things" that are strongly associated with colors. In this section we outline how we calculated the WAVEs for verbally described physical objects and test how well they predict color preferences.

Method

Participants There were 74 participants in the object-description phase of this experiment and 98 in the valence-rating phase, none of whom participated in both tasks or in the color preference task of Experiment 1. All were students in psychology courses, participated to fulfill a partial course requirement, and gave informed consent. The experimental protocol was approved by the Committee for the Protection of Human Subjects at UC Berkeley.

Procedure In the object-description phase, participants were presented with each of the 37 colors on a computer screen as a square on a neutral gray background, one at a time in a random order. Each color remained on the screen for 20 seconds, during which participants wrote verbal descriptions of as many "things" as they could that they associated with that particular color. Participants were instructed to name objects whose color would be generally known (e.g., not the color of some particular music album) and not to name objects that could be any arbitrary color (e.g., T-shirts, crayons, or paint).

All of the 4744 object descriptions were filtered by the following exclusion rules: A description was eliminated if it (a) could be any color (e.g., crayons, cars), (b) was an abstract concept instead of a physical object (e.g., peace, winter), (c) was a color name instead of an object (e.g., "Cal Blue", "teal"), (d) was clearly dissimilar to the color on the screen (e.g., "grass at noon" for dark purple), or (e) was provided by only a single participant for the given color.

The remaining 1062 descriptions were then categorized to reduce the number of items to be rated in the valence-rating phase. Descriptions that referred to the same object were combined into a single category (e.g., the category "rain clouds" included descriptions such as "storm clouds," "clouds before rain," and "clouds (on rainy days)"). In addition, descriptions were combined into a superordinate category plus exemplars when many exemplars referred to the same type of object. For instance, "purple flowers (e.g., lavender, violets, lilacs, irises)" was used instead of separate categories for each type of purple flower. The final list contained 280 categories of object descriptions.

In the object-valence phase, participants were presented with each of the 280 object descriptions one at a time in black text on a white background on the computer screen. Their task was to rate how positive/appealing each object was on a scale from "negative" to "positive." The same line-mark rating task was used as in Experiment 1.

Results and Discussion

The WAVE value was calculated for each color by multiplying the mean affective rating of each object description by the frequency with which that object description was reported for that color, and then taking the average of these weighted valences across all object descriptions for that color. The correlation between the WAVE and color preference was very high (r = 0.82), accounting for 67% of the variance with a single predictor. It thus outperformed the cone contrast model (36%) and the colorimetric model (57%), each of which included three predictors.

Not only is the WAVE the best single predictor of average color preference, but it nicely captures many of the key features of the color preference data. The WAVE captures the peak at blue, the trough at chartreuse, the higher preference for saturated colors, and the large dip around dark yellow (see Figure 6).

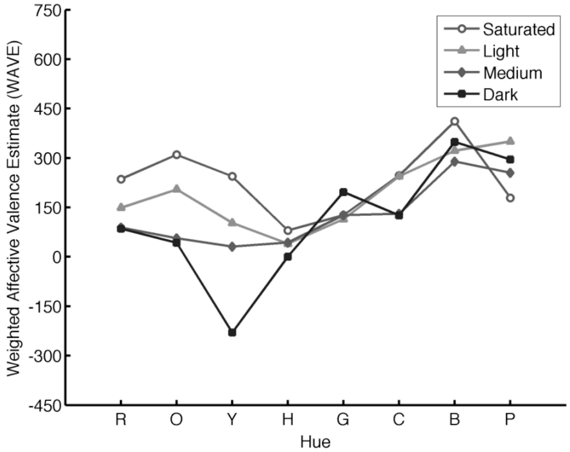

Figure 6: Weighted Affective Valence Estimates (WAVEs) of objects associated with the 32 chromatic colors.

Even more important, it provides an explanation of color preferences that goes significantly beyond merely re-describing the data; it implies that people's particular aesthetic responses to colors are *caused* by their affective responses to objects and situations associated with that color. Although the present evidence is purely correlational, it seems unlikely that causality runs in the opposite direction. If color preferences caused object preferences (rather than vice versa), affective ratings of same-colored objects (e.g., chocolate and feces) should be highly similar. Clearly, this is not necessarily true. It is also possible there is some mediating factor that influences the relationship between color preference and WAVE, but this also seems unlikely. Future experimental work will be conducted to rule out these alternative explanations.

The most obvious shortcoming of the WAVE predictions is that they fail to capture the increased preference for dark red relative to saturated, light, and muted reds. This occurs largely because blood was very frequently reported for dark red and because blood had a negative valence.

Conclusions and Future Directions

In this paper we showed that, as predicted by an ecological valence theory, people's emotional responses to objects they associate with particular colors are highly and positively correlated with their aesthetic preferences for those colors. This suggests that, due to evolutionary and/or individual learning, people like colors that are associated with objects and situations that are affectively positive for them and dislike colors that are associated with objects and situations that are affectively negative. This is an advantageous mechanism in that it tends to maximize people's affective state, biasing them to seek objects and situations they like and to avoid objects and situations they dislike.

We also found evidence against Hurlbert and Ling's (2007) cone-contrast model as a complete theory of color preferences. Not only does it account for a much smaller portion of the variance than the WAVE data, but one of its key predictions (opposition between preferences for colors at opposite poles of the **L-M** and **S-(L+M)** axes) does not hold for a significant fraction of our participants. Moreover, we failed to replicate their finding that females prefer red to cyan, whereas males prefer cyan to red. Nevertheless, it is possible that a simple, innate cone-based mechanism plays a role in a full explanation of color preferences, since associative learning and innate biases are not mutually exclusive. Within the ecological valence theory, an innate initial bias towards some colors and away from others is possible given sufficient evolutionary pressure. This might be implemented in the **S-(L+M)** cone-opponent system if the consequences for interacting with objects colored towards the **S** pole of the axis are more positive.

Thus far we have found that average color preference reflects average affective valence of color-associated objects. This is an important result, but we also find large individual differences, probably depending on innumerable personal experiences accumulated over a lifetime, many of which are idiosyncratic. The ecological valence approach to color preference suggests effective ways to test this account: identify a subgroup of people who are likely to share experiences with particular colors, measure the affective valences for their associations to those colors, and find out whether the predicted correlations hold. For example, members of athletic teams at UC Berkeley develop strong positive feelings about Berkeley and strong negative feelings about Stanford, Berkeley's arch-rival. Members of athletic teams at Stanford develop the opposite emotional connections. The ecological valence theory makes the clear prediction that these emotional responses will become associated with their corresponding school colors (blue and gold for Berkeley; red and white for Stanford) and cause particular interactions between color preference and educational institution: Berkeley athletes should show increased preference for blue and gold and (perhaps) decreased preference for red and white whereas Stanford athletes should show increased preference for red and white and (perhaps) decreased preference for blue and gold. In future work we plan to test such predictions by studying various such sub-populations whose positive (or negative) associations with particular colors should allow numerous tests of the ecological valence theory of color preference.

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