Ecological Valence and Human Color Preferences

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Abstract

Why do people like some colors more than others? Why do they have color preferences at all? Recent results from the Berkeley Color Project (BCP) provide intriguing answers based on people's emotional responses to diagnostically colored objects. We report preferences among 32 chromatic colors from 48 adults in the San Francisco Bay area and describe their fit to several color preference models, including ones based on cone outputs, color-emotion associations, and our own ecological valence theory (EVT). The EVT postulates that color serves an adaptive "steering' function, analogous to taste preferences, by biasing organisms to approach advantageous objects and avoid disadvantageous ones. It implies that people will tend to like colors to the extent that they like the objects that are characteristically that color, averaged over all such objects. The EVT predicts 80% of the variance in average color preference ratings from the Weighted Affective Valence Estimates (WAVEs) of correspondingly colored objects, much more variance than any of the other models. We also describe how hue preferences for single colors differ as a function of gender, expertise, culture, social institutions, and perceptual experience.

Introduction

Most people have a favorite color, and more name some shade of blue than any other,[1-3] but there is wide variation in color preferences across the general population. They are important for understanding people's behavior both individually and as an aggregate population, particularly for their impact in the marketplace – what clothes, art, home furnishings, vehicles, and personal electronics we buy – and in the amount of enjoyment we get from using them. Numerous experiments over the last hundred years[1-3] have taught us a great deal about *which* colors people in general like, and this is important for applications such as marketing.

But *why* do people like the colors they do? Somewhat surprisingly, few people have a clear answer to this question, and very little is known scientifically, about *why* they like them. Below we discuss the answers to both the *which* question and the *why* question, but with a goal-oriented emphasis on *why*. First, we discuss several recently proposed theories about the causes of color preferences, and then we present our own alternative to them. Our *ecological valence theory* (*EVT*) assumes that people's color preferences result from an adaptive process whose net effect is to "steer" people toward beneficial objects and situations and away from detrimental ones.

We then present our own color preference data from 48 participants who completed about many perceptual tasks on the 32 colors we studied. When we test the quantitative fit of these data to four theories, we find that our data are clearly most consistent with the EVT: How much people like color-associated objects of the same color accounts for 80% of the variance in average color preferences, substantially more than any of the other theories.[4] We believe that these results constitute a potential breakthrough in understanding why color preferences exist and how they arise.

The Ecological Valence Theory

Although much has been written about which colors people prefer, surprisingly little has been written about why they like the colors they do. Most of the literature consists of psychophysical measurements that merely describe preferences without making any attempt to explain them.[1-3] A few discussions relevant to answering the *why* question have appeared more recently, however.

An important early attempt came from Nicholas Humphrey,[5] who proposed an evolutionary account. He suggested that color preferences arise from the natural "signals" that colors convey to organisms. For instance, the colors of flowers send an "approach" signal to attract pollinating bees, and the colors of poisonous toads send an "avoid" signal to deter potential predators. An organism whose color preferences are consistent with these signals – bees that "like" the colors of the flowers and predators that "dislike" the colors of the toad – will have an evolutionary advantage and tend to be selected as better adapted to their environment. This idea was picked up by Hurlbert and Ling,[6] who used it to explain the color preferences they found in their psychophysical studies.[6-9] They reported that 70 percent of the variance in their color preference data could be explained by linear combinations of the outputs of the three cone types in the human retina: those tuned maximally to short (**S**), medium (**M**), and long (**L**) wavelengths of light.[6] They further found that both men's and women's preferences weighted quite positively on the **S-(L+M)** axis, meaning that colors that were more violet were preferred to colors that were more yellow-green. They also found that on the **L-M** axis, females weighted somewhat positively, preferring colors that were redder, whereas males weighted somewhat negatively, preferring colors that were more blue-green. (A subsequent experiment by Ling and Hurlbert[8] failed to replicate this result, as both males and females weighted negatively on the **L-M** axis, preferring colors that were more blue-green than red, although they did find that females weighted *less negatively* than males on this axis.) Hurlbert and Ling proposed that this gender difference arose from evolutionary pressure in "hunter-gatherer" societies. They hypothesized that females prefer redder colors because their visual systems were selected for finding ripe (red) fruit against a background of (green) foliage. They did not interpret their other results in similar terms, however, failing to explain why males might prefer blue-green colors, or why both genders prefer colors that were more violet to ones that were more yellow-green.

A second approach to the *why* question is based on the "feelings" or "emotions" colors arouse in viewers. Ou et al.[9-10] proposed an account of color preferences based on what they called "color-emotions," which they defined as "feelings evoked by either colours or colour combinations." The implication of this hypothesis for the *why* question is that the valences (positivity-negativity) of the emotions that are evoked by colors might cause people's preferences for the corresponding colors rather directly. For example, if certain colors cause people to feel positive color-emotions (e.g., *clean*, *relaxed*, and *light*), people should tend to like those colors, whereas if certain other colors cause them to feel negative color-emotions (e.g., *dirty*, *tense*, and *heavy*), they will tend to dislike those colors. Ou et al.[9-10] had participants judge their sample of colors on each of nine color-emotion scales (*warm–cool*, *light–heavy*, *modern–classical*, *clean–dirty*, *active–passive*, *hard–soft*, *tense–relaxed*, *fresh–stale*, and *masculine–feminine*) as well as for preference and then performed a factor analysis on the results. They found that 66% of the variance in their preference data could be predicted from three factor-analytic dimensions derived from their nine color-emotions: *active-passive*, *heavy-light*, and *cool-warm* (where the first term is weighted positively). Still, they left many unanswered questions. They did not explain, for example, how color-emotions arise, why some color-emotions predict preferences better than others (e.g., why *happy-sad*, as the most strongly evaluative emotional dimension, is not included as a color-emotion), or even why some color-emotion scales seemed to be weighted in opposition to their valences (e.g., why *cool* is weighted positively whereas *warm* is weighted negatively).

We propose the ecological valence theory (EVT) as an explanatory framework for color preferences that potentially unifies and extends these previous approaches. It is based both on the evolutionary premise that color preferences are fundamentally adaptive[5-6] and on an emotional premise that affective valences underlie them.[9-10] Generally speaking, the EVT posits that people (and other organisms) are better equipped to survive and reproduce if they are attracted to things whose colors "look good" to them and avoid things whose colors "look bad" to them. Color preference thus performs an implicit "steering" function that is roughly analogous to the steering function performed by taste preferences: People are better equipped to survive and reproduce if they eat things that "taste good" to them and avoid eating things that "taste bad" to them. The EVT thus assumes an ecological heuristic that will be adaptive, provided that there is a positive correlation between how "good" vs. "bad" colors appear to the organism and the degree to which things that characteristically have those colors are advantageous vs. disadvantageous to it. In effect, the EVT suggests that the color preferences of an organism provide information about for the adaptive utility of environmental objects within it ecological niche. There is no doubt that modern color technology has, to some considerable degree, subverted the adaptive significance of natural colors, because so many artifacts now can be found in virtually any desired color. Nevertheless, we believe that there is an underlying adaptive significance of color preferences that remains intact in modern society. Indeed, we believe that some aspects of color preferences are specifically social, as we will mention briefly at the end of this article.

The EVT predicts that the average preference for any given color over a representative sample of people should be largely predictable from the average affective responses of a similar group of people to correspondingly colored objects. That is, people should be attracted to colors associated with salient objects that generally elicit positive affective reactions (e.g., blues and cyans with positively valued clear sky and clean water) and repulsed by colors associated with salient objects that generally elicit negative reactions (e.g., browns and olive-colors with negatively valued biological waste products and rotting food). These hedonic statistics about colored objects are assumed to integrate information from *all* objects of a given color, however, since there are also brown things that are likely to be positively valued (e.g., chocolate and coffee) and blue things that are negatively valued (e.g., bruises). We test this central prediction of the EVT in Experiment 2 and compare its predictions for color preferences with the predictions of theories based on cone-contrasts, color-emotions, and color-appearance.

Environmental feedback from the outcomes of color-relevant experiences can influence evolutionary adaptation in at least two ways. First, it could shape genetically-based preferences for evolutionarily advantageous colors over evolutionarily disadvantageous ones. These would presumably reflect universal biases in the ecological statistics of color for the relevant species (e.g., blue skies, red blood, brown feces). Second, environmental feedback could produce and modify preferences based on innate learning mechanisms whose function is to adaptively tune an organism's color preferences during its lifetime to its particular physical and social environment such that it comes to like advantageous colors and dislike disadvantageous ones within its specific ecological niche. To the extent that people have positive emotional responses to more advantageous outcomes and negative emotional responses to more disadvantageous outcomes, they should learn to prefer the colors associated with the former outcomes over those associated with the latter outcomes. Either or both sorts of mechanisms may be involved in causing people to have the color preferences they do.

The best evidence about innate color preferences in humans comes from experiments with infants. Since babies can't tell us what colors they prefer, preferences are inferred from measuring their *looking behavior*: How long do infants spend viewing a given color when it is shown in all possible pairs of colors during series of fixed duration trials and/or which color do they fixate first in such a series of trials? Teller, Civan, and Bronson-Castain[12] studied the looking behavior of 12-week-old infants while viewing pairs composed of six high-saturation colors. Figure 1A shows that the shape of this function, which has a maximum at blue and a minimum around yellow-green. Note that it is roughly the same as the average hue preference curve we find for adults' preference ratings of high-saturation colors (see Figures 1B and 1C). (Similar hue preference functions have been reported by Valdez and Mehrabian[13] and Simmons[14] with adults who evaluated the pleasure and pleasantness, respectively, of colors.) The obvious caveat is that the infant preference functions of 12-week olds might actually reflect learning that has taken place during the first 12 weeks of life. Nevertheless, it is surely possible that these data result from a combination of a strong innate component and some additional learned component.

According to the EVT, innate learning mechanisms modify color preferences from their starting point at birth and eventually lead to the adult preference functions we have measured, presumably reflecting many diverse influences beyond any innate component. As a person interacts with objects in the environment, he or she learns valences (positive or negative affective reactions) to colored objects, depending on the degree to which the

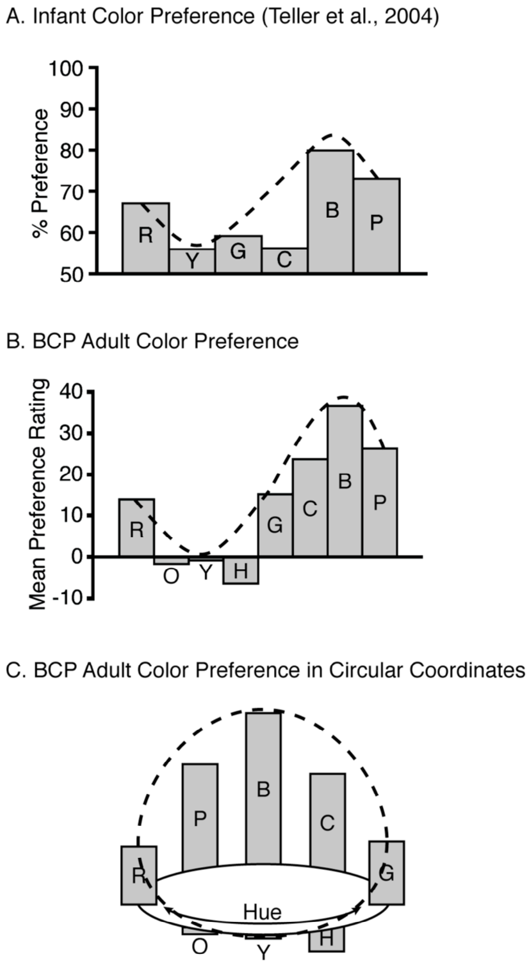

***Figure 1.** Hue preference functions for saturated colors in infants and adults. (A) Infants most prefer looking at blue and least prefer looking at yellow (Teller et al., 2004). (B) Preference patterns in aesthetic ratings for saturated colors by adults in the BCP. (C) Data in B plotted in circular coordinates to highlight the difference between* blue-yellow *vs.* red-green *dimensions. Dashed curves indicate the overall similarity of the functions (A and B) and how they translate into circular coordinates.*

experiences are pleasant or unpleasant. To the extent that the consequences of the interaction are rewarding (e.g., biting into a delicious red apple or diving into a refreshing blue lake), an increment of positive affect is proposed to accrue to the corresponding color. To the extent that the consequences are punishing (e.g., smelling feces or tasting rotten fruit), the associated color accrues a decrement in affect. Colors thus accumulate increments and decrements in affective valence by virtue of their association with correspondingly colored objects. The EVT thus implies that color preferences reflect the overall desirability of things associated with those colors to the given organism.

The EVT further implies there will be different levels of factors that influence color preferences. At the highest level, average color preferences for large, culturally diverse samples of people across the world will reflect universal (but probably species-specific) trends in the valence of colored objects. For example, we presume that virtually all adult humans like clear sky and dislikes feces, but it seems that many dogs and other animals are not nearly so averse to feces. At the more specific level of culture, systematic differences in cross-cultural studies of color preferences should be evident, but should co-vary with corresponding cultural differences in color-object associations (e.g., Japanese observers may associate a certain shade of reddish orange with Shinto shrines, whereas observers from other cultures would not) and/or differences in object valences (e.g., many people in Japan like eel, where it is considered a culinary delicacy, whereas those in other cultures may find eels disgusting).

At a still more specific level, systematic sub-cultural influences may also exert influences on individuals' affinities for colors that are strongly associated with special-interest societal groups, such as sports teams, universities, religions, and/or gangs. The EVT allows for the possibility that positive/negative interactions with members of such groups would result in increments/decrements in people's preferences for the corresponding colors. This is perhaps most obvious for street gangs, where there are overwhelming group sanctions for gang members to like their own colors and to despise their rivals' colors. Other sub-cultural influences may arise from factors other than social institutions, if relevant beliefs are widely held. For example, if a person believes that he or she "looks good" wearing particular colors due to their relation to their own physical characteristics – e.g., skin, hair, and eye color – then he or she may come to prefer those colors in general. At the most specific level, there will be truly idiosyncratic influences, unique to an individual. The color of grandma's rocker, for example, might produce a noticeably positive influence on the preference for that color if the individual was fond of sitting in grandma's lap as a child, but a negative impact if he or she disliked grandma and hated sitting in her lap. It would be impossible to tease apart all such idiosyncratic influences for any given individual, but some of them might be effectively isolated by careful study of the color associations and the object valences individuals have for specific objects that are important to them, as we will later suggest.

Thus far, we been talking as if color preferences were stable over time, at least within individuals, but this is not the case. If learning takes place in color preferences, as we believe that it does, then as people have the positive and negative experiences that cause their color preferences to be adjusted, then color preference are inherently dynamic. Changes may also take place at higher levels. There may be systematic changes in color preferences at cultural and sub-cultural levels that occur over time – from weeks, months, and even years within an individual to seasons, years, decades, and even centuries within a culture. Color fashions in the modern clothing industry change in fairly consistent ways seasonally and in less predictable ways annually. Even more dramatic are cultural changes that have occurred in color preferences over a span of decades to centuries. Perhaps the best documented and analyzed example is changes in cultural preferences for blue.[15] Pastoureau traces its history from a nadir in Roman times, where it was the least favored color, to its zenith in modern times. He also provides an analysis of the complicated factors that seem to have caused changes in cultural associations, which, in turn, seem to have been responsible for the dramatic increase in its popularity. In brief, the Romans apparently disliked blue primarily because it was so well liked by Rome's enemies – especially the Celts to the north, who even painted themselves in ferocious blue symbols to prepare for battle – and it began to scale the preference hierarchy when it became associated with the Virgin Mary in the artifacts of the powerful Catholic Church.

One of the great virtues of the EVT is that all of these factors – universal, cultural, sub-cultural, idiosyncratic, and even dynamic – can potentially be accommodated within its scope. Moreover, carefully selected subsets of these factors can be studied effectively by using the kinds of psychophysical techniques we describe below (see also Palmer and Schloss[4]) with appropriately chosen categories of individuals.

The Berkeley Color Project

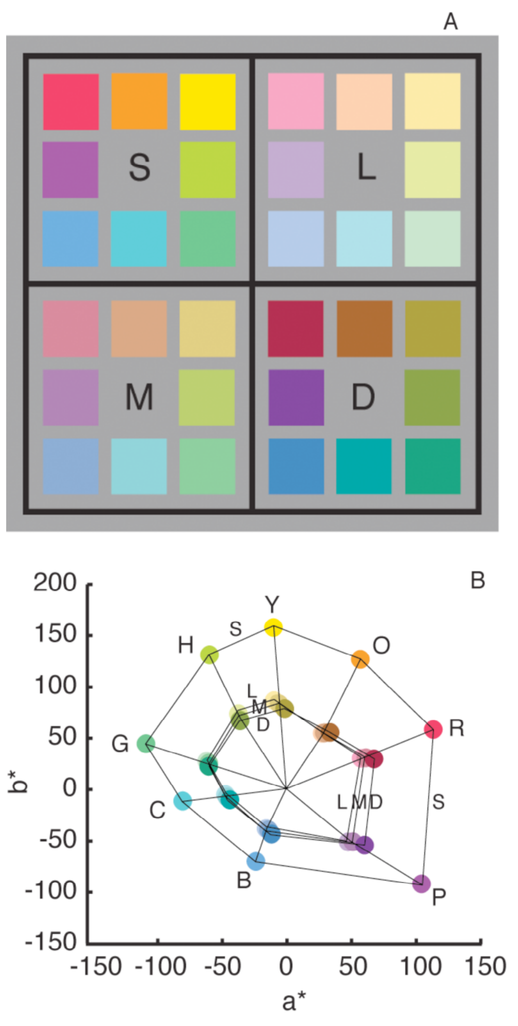

Figure 2*. The colors of the BCP. (A) The 32 chromatic colors of the BCP. (B) The projections of these colors onto an isoluminant plane in CIELAB color-space. (See text for descriptions.) [A printed color version of this figure is available in Figure 1 of Schloss & Palmer (this volume) "Aesthetics of color combinations."]*

The Berkeley Color Project (BCP) is a large, systematic study whose goal is to understand color preferences within the larger context of color vision. There are three key features to the BCP: its massive repeated measures design, its sampling of participants, and its systematic, perceptually motivated sampling of colors.

MRM Design

The first important feature of the BCP is its massive repeated measures (MRM) design, in which the same observers provide data on many different tasks using the same set of colors. We have studied 48 participants performing 30 different tasks on the same 32 colors, requiring more than 12 hours of data collection per participant. MRM designs allow the results for any given task to be related to other results from the same observers and the same colors from some other task. To understand how people's color preferences relate to their color-emotion associations, for example, one needs to collect data of both sorts from the same participants. The same basic logic applies to any number of other aspects of people's preferences for individual colors and color combinations.

The following BCP measurements are most relevant to the present article: aesthetic preference ratings for individual colors, psychophysical ratings of color-appearance (i.e., how *red-green*, *blue-yellow*, *light-dark*, and *high-low saturation* each color appears to be), and ratings of Ou et al.'s "color-emotion" dimensions (i.e., how *active-passive*, *warm-cool*, and *heavy-light* each color appears to be).[10-11] MRM designs provide the important advantages of within-subjects comparisons that are particularly desirable for studying a domain, such as color preferences, in which large individual differences are present.

Participant Sample

A second feature of the BCP is the nature of our participants. Here we present the initial data set collected in Berkeley, California, from 48 adults equally divided between men and women and between high and low color sophistication ranges, where the "high sophistication" group includes professional artists and designers and the low group untrained novices. This sample enabled us to study differences due to both gender and training/expertise. We are currently repeating many of these measurements in Tokyo, Japan, and Guadalajara, Mexico, to obtain information about universal vs. culturally specific features of color preferences. We also plan to collect preference data developmentally with infants and comparatively with macaque monkeys, but have no data from these populations as yet.

Color Sample

The third key feature of the BCP is the set of 32 chromatic colors we used, which were systematically sampled over the three most salient dimensions of color-appearance: hue, saturation, and brightness (see Figure 2). We effectively based our sample structure on the Natural Color System (NCS),[16] although we actually selected the colors from the glossy series of Munsell chips. As described in Palmer and Schloss,[4] the sample included highly saturated colors of the four Hering primaries approximating the unique hues (hues that contain one and only one of the four chromatic primary hues[17]): red (R), green (G), blue (B), and yellow (Y), (Munsell hues 5R, 5Y, 3.75G, and 10B, respectively). We also included four well-balanced binary hues that contained approximately equal amounts of the adjacent pair of unique hues: orange (O) between Y and R, purple (P) between R and B, cyan (C) between B and G, and chartreuse (H) between G and Y (Munsell hues 5YR, 5GY, 5BG, and 5P, respectively). We then defined four "cuts" through color space that differed in their saturation and lightness levels, as follows. Colors in the "saturated" (*s*) cut were defined as the most saturated color of each of the eight hues that could be produced on our monitor. Eight colors in the "muted" (*m*) cut were those that were approximately halfway between the *s* color and the Munsell value of 5 and chroma of 1 for the same hue. Eight colors in the "light" (*l*) cut were those that were approximately halfway between each *s* color and the Munsell value of 9 and chroma of 1 for the same hue. Eight colors in the "dark" (*d*) cut were those that were approximately halfway between each *s* cut and Munsell value of 1 and chroma of 1 for the same hue. The *l*, *m*, and *d* colors within each Munsell hue were equivalent in Munsell chroma (saturation). This set comprised the 32 chromatic colors that were studied. We also included five achromatic colors – white, black, and the three grays whose luminance was approximately the average luminance of the eight hues in the *l*, *m*, and *d* cuts – although we report results for just the 32 chromatic colors in this chapter.

Colors within cuts were not chosen to be constant in saturation and luminance, as Ling and Hurlbert had done, because we wanted to include highly saturated colors of the four unique hues, which are manifestly not equivalent in luminance or saturation. Unique yellow and blue, for example, vary dramatically in luminance, with unique yellow being much lighter. Moreover, our observers made psychophysical ratings of lightness and saturation, and we have the coordinates of the colors in Munsell and other color spaces, so that we could examine the effects of lightness and saturation that varied within cuts, if required.

Experiment 1: BCP color preference ratings

Color Preferences

In both the first and the last testing sessions, each participant rated all 32 chromatic colors for aesthetic preference using a line-mark rating task, in which they moved a cursor to a point along a 400-pixel line (-200 to +200 pixels with a neutral zero-point in the center). The data are normalized to range from -100 to +100 in Figures 3-5. Each participant saw a different randomly determined order of the colors in all tasks. The correlation between average preference ratings indicated high reliability across these two sessions (r=0.92, p<.0001). All subsequent analyses were performed on the data just from Session 1, because it provides the purer measure, uncontaminated by the subsequent tasks each participant completed. Average preference ratings (Figure 3) showed relatively strong effects of hue in the *s*, *m*, and *l* colors (F(7,329) = 9.75, p<.001), producing approximately parallel hue functions with a maximum at blue and a minimum at chartreuse. S colors were preferred to *l* and *m* colors (F(1,47)=9.20, p<.01), which did not differ from each other (F<1). Hue and cut did not interact across *s*, *m*, and *l* cuts (F(14, 658)=1.66, p>.05), but they did interact strongly for the *d* cut versus the other three cuts (F(7,329)=17.87, p<.001). Dark-orange (brown) and dark-yellow (olive) were significantly less preferred than other oranges and yellows (F(1,47)=11.74, 41.06, p<.001, respectively), whereas

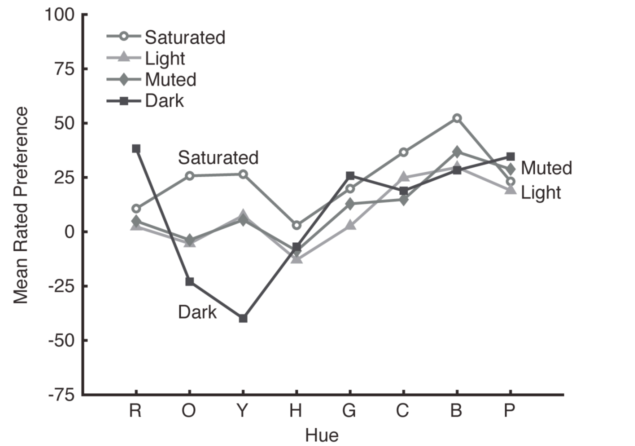

Figure 3. *Color preference ratings as a function of hue for saturated (s), light (l), dark (d), and muted (m) colors.*

dark-red and dark-green were more preferred than other reds and greens (F(1,47)=15.41, 6.37, p<.001, .05, respectively).

Gender and Expertise Effects

The 48 participants were balanced in gender and color sophistication (as assessed by questionnaire), with 12 individuals in each cell of this 2x2 between-subjects design. Figure 4 shows the average preference ratings divided by gender. No reliable differences were present between males and females for the *l* and *d* colors (F<1), but a reliable interaction was evident between males and females for the *s* and *m* cuts (F(1,46)=11.42, p<.01): Males preferred *s* colors to *m* colors (F(1,23)=24.18, p<.001), whereas females trended in the opposite direction.

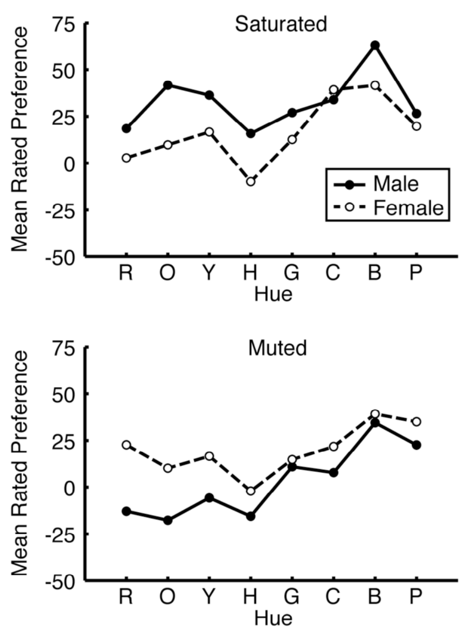

Figure 4. *Gender differences in color preference ratings as a function of hue for saturated, light, muted, and dark colors.*

The cause of this gender difference is not obvious, but it is compatible with a cultural interpretation: *s* colors are bolder and more assertive than *m* colors, fitting the cultural stereotype for males. Supporting this interpretation, the gender difference scores for the 32 colors (male ratings minus female ratings for each color) were highly correlated with the gender difference score in *active-passive* ratings for corresponding colors (r=0.73, p<.001), accounting for 53% of the variance. Some readers may wonder at the seeming conflict between these preferences and male versus female dress patterns, given that males tend to wear more muted colors and females more saturated colors. The data make perfect sense, however, once one realizes that most people dress to attract members of the opposite sex. If the color preferences of gay men and lesbians are similar to those of straight men and women, respectively, then it would be consistent with our interpretation of the relation between dressing patterns and color preferences if gay men tend to wear more saturated colors (because they are dressing to attract other men) and lesbians tend to wear more muted colors (because they are dressing to attract other women). We know of no data on this subject, but it is consistent with cultural stereotypes about how gay men and lesbians tend to dress.

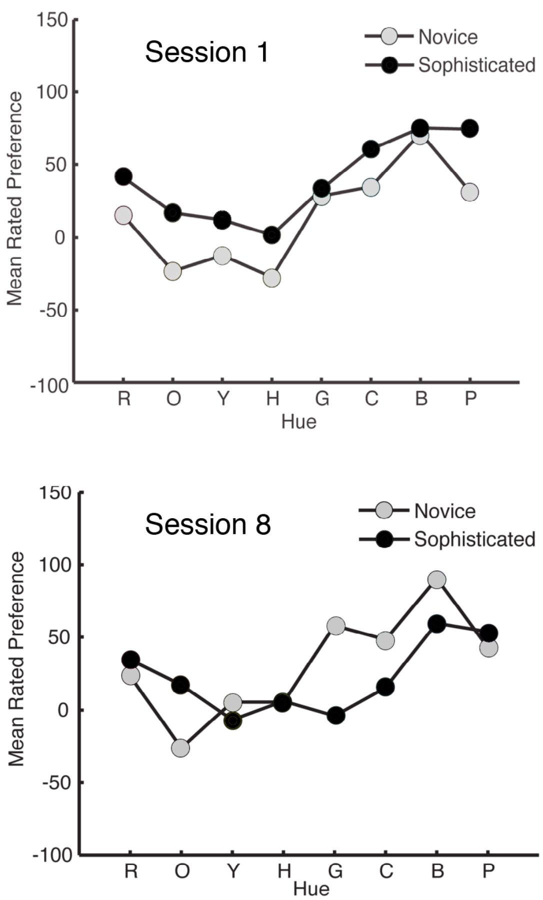

Figure 5. *Color sophistication differences in color preference ratings as a function of hue for sessions 1 and 8.*

Figure 5 shows the hue preference functions from Session 1 for the low versus high chromatic sophistication subgroups. The more sophisticated participants liked chromatic colors more than did their less sophisticated counterparts (F(1,44)=6.22, p<.05). No corresponding difference was present for the achromatic colors (F<1), discounting the possibility that the two groups simply used the rating scale differently. Interestingly, there was an interaction between session (first vs. last) and artistic experience (F(1,44)=11.87, p<.01), such that the difference in preference for chromatic colors found in Session 1 disappeared by Session 8. Preference for chromatic colors increased somewhat over time for the novices (F(1,23)=6.38, p<.05) and decreased somewhat for the sophisticates (F(1,23)=5.84, p<.05), such that they were not statistically different by Session 8 (F<1). These changes are roughly consistent with Berlyne's[18] inverted-U function of aesthetic dynamics, provided that the novices are initially at the low end of the aesthetic exposure spectrum, where their aesthetic appreciation would be expected to increase with exposure, and sophisticates are initially in the middle-to-high end of the spectrum, where their appreciation would be expected to decrease.

Experiment 2: Weighted Affective Valence Estimates (WAVEs)

Experiment 2 was undertaken to test the central prediction of the EVT outlined in the introduction: Color preferences should largely be predictable from the average valences of people's affective reactions to diagnostically colored objects, including ineffable "things" such as sky, water, and clouds. We estimated average affective associations to colors by the following procedure. First, we showed 74 observers each of the 32 BCP chromatic colors and asked them to write as many object-descriptions as they could for each color in 20 sec. The resulting 3874 object descriptions were then filtered to eliminate items that (a) could be any color (e.g., crayons, paint, cars), (b) were abstract concepts instead of objects (e.g., peace, winter, Christmas), (c) were color names instead of objects (e.g., "Cal Blue", "teal"), (d) were very dissimilar to the presented color (e.g., "grass at noon" for dark purple), or (e) were provided by only a single participant for all colors it described.

The remaining descriptions were then categorized to reduce the number of descriptions to be rated in the valence-rating phase of the experiment. Descriptions that were judged to be essentially the same were combined into a single category (e.g., *algae* included the descriptions "algae," "algae water," "algal bloom," "algae filled fish bowl," and "algae floating on top of water"). The resulting 222 descriptive categories were then shown in black text on a white background to 98 different participants, who were asked to rate the affective value of the referent object from positive to negative using the same line-mark rating scale as in Experiment 1.

We presented an additional set of 16 participants with each of the 222 object descriptions together with each of the 32 colors for which it had previously been given as a description, one pair at a time. Participants were asked to rate how well the characteristic color of the described object category matched the color on the screen using a line-mark rating task analogous to those described for the other tasks. These color-object matching ratings, scaled from zero to unity, were used as multiplicative weights in computing the average Weighted Affective Valence Estimate

(WAVE) for each object-color pair, such that the valences of the descriptions that better matched the color on the screen were weighted more heavily.

Fitting the Models

The WAVE data are plotted in Figure 6. Their striking similarity to the corresponding chromatic preference functions (Figure 3) is supported by the high positive correlation between the two data sets (r=0.89), accounting for 80% of the variance with a single operationally-defined predictor. This performance is especially impressive considering that no free parameters were estimated in calculating the WAVE. Even the weighting factor based on object-color match ratings is relatively unimportant, because unweighted average valence ratings are almost as highly correlated with the average color preferences (r=0.84). For comparison, we fit the same chromatic preference data to three other models.

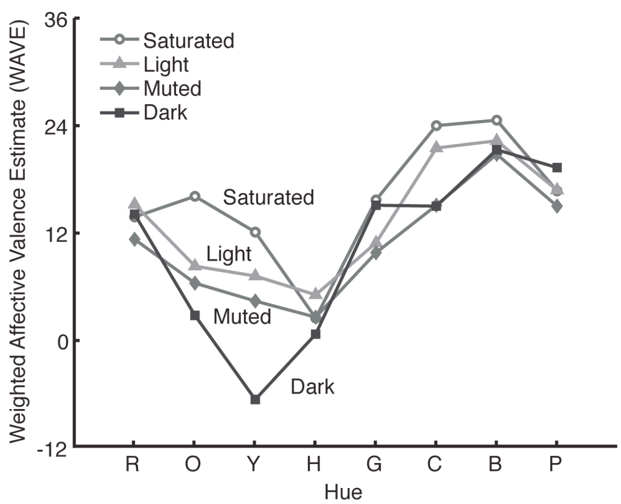

***Figure 6**. WAVE data for the 32 chromatic colors of the BCP.*

First, we fit Ling and Hurlbert's[8] cone-contrast model using multiple linear regression with four predictor variables: the cone-contrasts of the test colors against the gray background for the **L-M**, **S-(L+M)**, and **(S+L+M)** systems, plus CIELUV saturation. This model accounted for 37% of the variance: 21% by **S-(L+M)** output (colors that were more violet preferred), 4% by **S+L+M** output (lighter colors preferred), 8% by CIELUV saturation (more saturated colors preferred), and 4% by **L-M** output (colors that were more blue-green preferred). The model's markedly poorer performance on our data (37%) than on Ling and Hurlbert's own data (70%) is very likely due to the wider gamut of colors in the present sample. Indeed, when their original cone-contrast model (Hurlbert & Ling, 2007) was applied just to the set of eight colors in the present study that are analogous to Hurlbert and Ling's color set in having the same saturation and similar luminance (MO, MY, MH, MG, SC, LR, LG and LP), it was able to explain 64% of the variance, comparable to its performance on Hurlbert and Ling's own data set. When the additional 24 colors in the present sample were included in the analysis, however, the cone-contrast model's fit decreased precipitously.

We also fit an NCS-like color appearance model using multiple linear regression with the four color-appearance ratings made by our own observers as predictors: *red-green*, *blue-yellow*, *light-dark*, and *high-low saturation*. This model accounted for 60% of the variance (multiple-r = 0.774, $p < .01$): 34% by *blue-yellow* ratings (blue preferred), an additional 19% by saturation ratings (high-saturation preferred), and a further 7% by *light-dark* ratings (light preferred). This color-appearance model explains more variance than the cone-contrast model primarily because the hue preferences conform more closely to rated blueness-yellowness than it does to **S-(L+M)**, which is more accurately described as varying from blue-violet to yellow-green; i.e., the higher-level color-appearance space gives a better fit to the rated preferences than does the lower-level cone-contrast space. Nevertheless, even the color-appearance model fails to predict the salient interaction between hue preferences in the D cut relative the S, L, and M cuts. It also fails to explain *why* people prefer the colors they do; it merely provides a better description of the preference pattern than does the cone-contrast model.

Finally, we fit Ou et al.'s[10-11] three-factor color-emotion model using multiple linear regression based on our own participants' direct ratings of *active-passive*, *heavy-light*, and *warm-cool*, including their non-linear transformation of the *active-passive* factor. This model accounted for 55% of the variance: 22% by *active-passive* (active preferred), an additional 26% by *warm-cool* (cool preferred), and a final 7% by *heavy-light* (light preferred). One oddity of this model, at least when interpreted as a causal hypothesis about why people like the colors they do, is that cool colors are preferred to warm colors (akin to the blueness-yellowness differences described in the previous paragraph), but coolness is not preferred to warmness as general "feelings." When asked to rate each of these six words in terms of how "positive/appealing" the feelings they described, our participants rated "warmness" (+127) as higher than "coolness" (+69), on our scale from -200 (least appealing) to +200 (most appealing). The ratings of the other terms were consistent with the expected outcomes, with light (+25) being rated as more positive than heavy (-66) and active (+111) as more positive than passive (-52).

Despite the seemingly different semantics of these three models – cone-contrasts, color-appearances, and color-emotions – they are closely related because of the high correlations among their dimensions. Table 1 shows that the three most important dimensions in the cone-contrast and color-emotion models both have average correlations of 0.85 with the three most important dimensions of the color-appearance model.

In accounting for 80% of the variance in the average preference ratings, the WAVE predictor substantially outperformed the three other models we tested: the cone-contrast model (37%), the color-appearance model (60%), and the color-emotion model (55%). Moreover, it does so with fewer free parameters. It is also better at capturing the primary qualitative features of the color preference functions: the pronounced peak at blue, the trough at chartreuse, higher preference for saturated colors, and the global minimum around dark yellow. Its main deficiencies lie in under-predicting the aversion to dark-orange (largely because chocolate is rated as very appealing) and under-predicting the positive preference for dark-red (largely because blood is rated as unappealing).

Color Appearance	S-(L+M)	Sat (CIELUV)	L+M+S	L-M
Yellow-Blue	**-0.88	0.12	**0.50	**0.56
Saturation	-0.15	**0.77	-0.11	0.27
Light-Dark	-0.30	**-0.48	**0.90	-0.07
Red-Green	0.12	**0.59	-0.16	**0.67

Color Appearance	Warm-Cool	Active-Passive	Light-Heavy
Yellow-Blue	**0.73	0.12	0.15
Saturation	0.35	**0.85	*-0.41
Light-Dark	-0.11	0.29	**0.97
Red-Green	**0.62	0.22	-0.21

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

Table 1. *Correlations between color-appearance and cone-contrasts (top) and color-emotions (bottom).*

Equally important is the fact that the EVT, from which the WAVE is derived, provides a plausible answer to the *why* question: It claims that color preferences are *caused* by average affective responses to correspondingly colored objects. Although the present evidence is correlational, it seems unlikely that causation runs in the opposite direction (i.e., that object preferences for diagnostically colored objects are caused by color preferences) because there are such clear counterexamples. Chocolate and feces, for example, are similar in color but opposite in valence. Some third mediating variable could conceivably be at work, but it is unclear what that might be.

Further critical tests of the ecological valence theory will come from cross-cultural studies of color preferences and their relation to corresponding WAVE data. The theory clearly implies that differences between color preference functions in different cultures should be predictable from corresponding cross-cultural differences in WAVE functions. We are currently collecting such data using the BCP colors in Japan, Mexico, India, and Serbia. WAVE functions in different cultures are likely to be different not only because people in different cultures see different objects and may have different affective responses to the same objects, but because the ecological valence theory implies that socio-cultural variables, such as flags and patriotic color associations, can also affect color preferences.

The EVT also predicts that if people have highly positive (or negative) emotional investments in a social institution with strong color associations – e.g., an athletic team, gang, religious order, university, or even holiday – they should come to like the associated colors correspondingly more (or less) than the rest of the population, depending on the polarity of their relation to the institution. Preliminary results with university colors support this prediction: Among students at the University of California, Berkeley, the amount of school spirit correlates positively with preference for Berkeley's blue and gold colors but negatively with preference for the cardinal red color of Stanford University, a strong rival institution. If substantiated by further evidence of the opposite trends at Stanford, this finding would support the prediction that sub-cultural social institutions influence affect color preferences. Equally important, it would provide further evidence of the direction of causality, because it is wildly improbable that students' attitudes toward universities are caused by their color preferences. Students who like Berkeley do not do so because they like blue and gold; rather, they like blue and gold because they like Berkeley.

We are not claiming that color preferences have *no* influence on object preferences; clearly they do, especially for functionally identical artifacts that come in a wide variety of colors, such as cars, clothes, appliances, and personal electronics (i.e., objects with low color diagnosticity as discussed by Tanaka et al.[19]). Widespread (and presumably effective) market research on color preferences for specific products presupposes that such effects exist. Notice, however, that these effects are also compatible with the EVT: To the extent that people like something that they bought, made, or chose because they like its color, their preference for that color will be reinforced via positive feedback, provided that they continue to value and enjoy that colored object. Color preferences will thus tend to be self-perpetuating until other factors, such as boredom, new physical or social circumstances, and/or fashion trends, change the dynamics of aesthetic response, as indeed they inevitably do.

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