A new model for color preference: Universality and individuality

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Abstract

Attempts to develop a universal color preference model have failed to explain individual differences or incorporate physiological factors. Here we propose a new color preference model in which an individual's color preference may be described as the weighted sum of 4 fundamental color-coding components (luminance, red-green, blue-yellow and saturation), all universal across populations. Meanwhile, each individual accords a different set of weights to these components, representing his/her individual color preference. We tested the model with a series of psychophysical experiments. The results reveal that the model explains most of the individual variance in color preference and may therefore be used as a good descriptor for individual as well as group differences. By translating complex color preference results into 4 easily interpreted weights, we also find that the main characteristics of individual color preference do not vary significantly across different color samples and experimental methods, thus allowing us to employ only a small sample of stimuli to reveal color preference across the entire color space. The model's simple format allows easy statistical and quantitative analysis, and provides a reliable platform for future studies on color preference.

Introduction

Studies on color preference extend back to at least 200 years ago [1], yet despite the large number of experiments and observers involved, only recently has a consensus on the phenomenology begun to emerge, although underlying explanations are still lacking [2]. Initially, poorly controlled stimuli and experimental techniques did not permit orderly patterns of individual preferences to emerge [1,3]. But since the mid-1900s, as more and better-controlled experimental studies have been performed, the evidence for a universal pattern in color preference has steadily accrued. The general order of hue preference is found to be unaffected by changes in saturation and lightness [4], and to a considerable extent, is independent of individual variables. For most people, preferences are highest in the region of green to blue and lowest in the region of yellow and yellow-green [5], and early discoveries of a general order of preference, blue, red, green, purple, orange and yellow [6], have been largely supported by subsequent studies [2,4,5,7,9].

As the concept of universality in color preference progresses, some studies have begun to quantify the relative contributions of distinct color attributes to preference [5]; more recently, others have proposed mathematical models which predict the preference value of a given color based on its coordinate location in color space [7]. Nevertheless, the idea of a single mathematical formula which encapsulates color preference for an entire population has a fundamental flaw, in that it assumes that every individual behaves in the same way. Various studies have shown that, although color preference is to a certain degree universal, on the other hand, it is also individual, and is affected by not only sex [10] and age [11], but also geographical origin [12]. By emphasizing purely the universality of color preference, the single-formula-model sacrifices individuality, and is therefore inadequate to account for individual differences.

In our previous studies of hue preference [10,13], we proposed a novel mathematical model for hue preference, in which individual hue preference is described as the weighted sum of two cone-opponent contrast components: S-(L+M) ('blue-yellow') and L-M ('red-green') contrast. Therefore, each individual's hue preference may be reduced to a set of 2 weights, representing individual preferences for the blue-yellow and red-green components respectively. This model is based on the fundamental neuronal mechanisms which encode color, and is universal for all observers, while allowing individual differences in hue preference to be represented by the differential weighting on these components. Consequently, the proposed hue preference model accounts for both individuality and universality of hue preference, and its validity has been tested across sex, culture and age [10,13].

In this paper, we extend the concept of our hue preference model further to cover all color space, and propose an extended model for color preference. Here, individual color preferences may be described as the weighted sum of 4 components: the S-(L+M) contrast component for blue-yellow preference; the L-M contrast component for red-green preference; the L+M+S luminance contrast component for lightness preference; and the saturation component for saturation preference.

The model

An individual's color preference curve $p_{predict}$ is predicted as the weighted sum of 4 independent components: the S-(L+M) and L-M cone-opponent contrast components of the hues, the luminance contrast component, and the saturation component, as shown in Equation (1):

$$p_{predict} = w_1 * S_c + w_2 * LM_c + w_3 * Lum_c + w_4 * Sat_c + a \quad (1)$$

where S_c represents the S-(L+M) (blue-yellow) contrast of the colors, LM_c represents the L-M (red-green) contrast, Lum_c represents the L+M+S (luminance) contrast, all with respect to the background, and Sat_c represents the saturation of the colors. w_1, w_2, w_3, w_4 are the weights given to the S-(L+M), L-M, luminance and saturation components respectively, which, together with the offset *a*, are determined using least-squares regression from the observer's color preference curve measured in the psychophysical experiments. As a result, each observer will have a different set of weights, which represent the individual differences in color preference. The interpretation of the weights is entirely straightforward: a positive w_1 indicates that the observer tends to prefer colors with positive S-(L+M) contrast component, that is, a bias for bluish over yellowish contrast, while a negative w_1 indicates a preference for 'yellows' over 'blues'. Likewise, a positive w_2 weight on the L-M component indicates that the observer prefers hues with positive L-M cone contrast, that is, a bias for reddish over greenish contrast. A positive w_3 indicates that the observer prefers brighter colors, and a positive w_4 indicates a preference for more saturated colors. Note that the endpoints of the cone-opponent contrast mechanisms do not correspond precisely to the primary hues 'blue', 'yellow', 'red' and 'green', we use these terms as shorthand notation only.

To test this model, we performed a series of psychophysical experiments examining the following hypotheses: 1. The proposed model accounts for most of the individual variance in color preference, and provides a satisfactory description of individual color preference. 2. For a group of observers, we may use their average weights on the 4 components to describe their average color preference, and the group difference in preference weights reflects the group difference in color preference. 3. The set of weights obtained for an individual fully explains his/her color preference; therefore, for one observer, the weights obtained from one set of color samples should highly correlate with the weights obtained from another color set, regardless of the experimental method.

Method

Observers

40 observers (20 males, 20 females), aged 18-24, participated in the experiment. All tested normal on the Farnsworth-Munsell color vision test, and were naïve to the purpose of the experiment.

Stimuli

We employed 3 groups of colors as stimuli. Group 1 consists of 90 Munsell colors, with 10 Munsell hues (R, YR, Y, GY, G, BG, B, PB, P, RP) at values 3, 5, 7 and saturations 2, 6 and 8 (excluding those beyond the gamut of our display); this set also includes 5 Munsell grays at values 1, 3, 5, 7 and 9.5, as well as the most typical color for each hue (at the highest value and saturation within the display's gamut). Group 2 stimuli are 20 NCS color samples, with a large range of hue, lightness and chroma, employed in a previous study by Ou et. al [7]. Group 3 contains 24 colors with controlled CIE Luv lightness, hue and saturation values: 8 hues (0.3, 1.09, 1.87, 2.66, 3.44, 4.22, 5.01, 5.8) at one lightness-saturation combination (L80 S0.5); and a subset of 4 hues (0.3, 1.87, 3.44, 5.01) at 4 lightness-saturation combinations (L50 S0.5; L95 S0.5; L80 S0.3 and L80 S0.9).

All three groups are chosen from different color spaces, using distinct principles. Group 1 contains the largest number of colors, and represents best the entire color space; Group 2 colors sample the color space more coarsely, but are more typical colors; Group 3 colors, meanwhile, avoid typical colors, and systematically varies lightness, hue and saturation. By employing distinct sets of stimuli, we were able to test Hypothesis 3.

Experiment Procedure

The color stimuli were presented on a characterized CRT monitor as rectangular patches (2x3 degrees). Observers viewed the monitor from a distance of 57cm, in an otherwise dark room. All the stimuli were presented against a uniform gray background (CIE Yxy = [50 0.3127 0.329]). Before each session of the experiment, observers adapted to the background color for 60 seconds.

The experiment consists of two main tasks. In Task 1, a single color patch is presented two degrees to the right of center, and a horizontal slider scaled from 'Dislike' to 'Like' is displayed on the left. The observer's task is to slide the bar in as quickly as possible to a position that best describes the degree to which he/she likes the color. Here, all three color groups are tested once in one initial session, and then repeated in another session, both with randomized order. We then obtain a color preference curve for each observer for each color group, as a measure of his/her color preference, computed as the observer's ratings of the colors, averaged across both sessions.

In Task 2, a pair of colors is presented simultaneously, 2 degrees above and below the center of the screen. On each trial, the observer's task is to move the mouse pointer to select which of the two color patches s/he prefers. In this task, we test only Group 2 and Group 3 colors. Within each color group, observers pair-wise compare all the color pairs once (190 trials for Group 2, 276 trials for Group 3). These trials are combined in random order, and then divided into two sessions. As all the colors within a color group are compared in the same number of trials, we then compute the color preference curve for this group as the proportion of trials on which each color has been judged as the preferred color, and use it as the measure of individual color preference.

Results

In total, we obtained 5 sets of color preference curves from Task 1 Group 1 colors, Task 1 Group 2 colors, Task 1 Group 3 colors, Task 2 Group 2 colors, and Task 2 Group 3 colors respectively. Figure 1 shows Group 3 color preference, for both tasks. The figure reveals no substantial differences between the pair-wise comparison and the rating tasks, which is confirmed by multiple ANOVA analysis (F(1, 1872)=0.56, p=0.4534). In general, both male and female hue preferences peak in the bluish/bluish-greenish region and fall gradually towards the greenish-yellow region, and both prefer more saturated colors. Nevertheless, there are also notable differences between the sexes. The average female shows higher preference for reddish and reddish blue hues, and less preference for yellowish-greenish hues, than the average male. Moreover, the average female prefers brighter colors over darker colors, whereas the average male's color preference is unaffected by lightness differences. We now apply our color preference model to all sets of color preference data, and obtain 5 sets of predicted color preference curves for each observer. We compute the R^2 (the square of the 2-D correlation coefficient) values between the predicted and actual preference curves, over all observers, to obtain an estimate of the validity of the model for individuals; see 'individual' values in Table 1. We also compute the 5 mean preference curves over all individual observers, and apply the model to obtain the predicted mean preference curves. The R^2 values between these two are also shown in Table 1 ('mean'), indicating the overall performance of the model for a group of observers. For individuals, our proposed model consistently explains approximately 47% of the variance, for Group 1 and Group 2 stimuli. It performs best for Group3 stimuli, explaining approximately 60% of the individual variance. Note that here we have employed a much larger number of stimuli varying in hue, lightness and saturation values, compared with our earlier studies, in which our simpler model based on hue alone explained up to 70% of the individual variance [10]. Moreover, when we look at the overall performance of this model for a group of observers, we obtain a much higher figure, at approximately 70%, for Group 3 stimuli, comparable to models for population preferences proposed by others [7]. Overall, the model's best fit was obtained for Group 3 colors, in which limited numbers of hue, saturation and lightness values were tested, with, consequently, fewer variables.

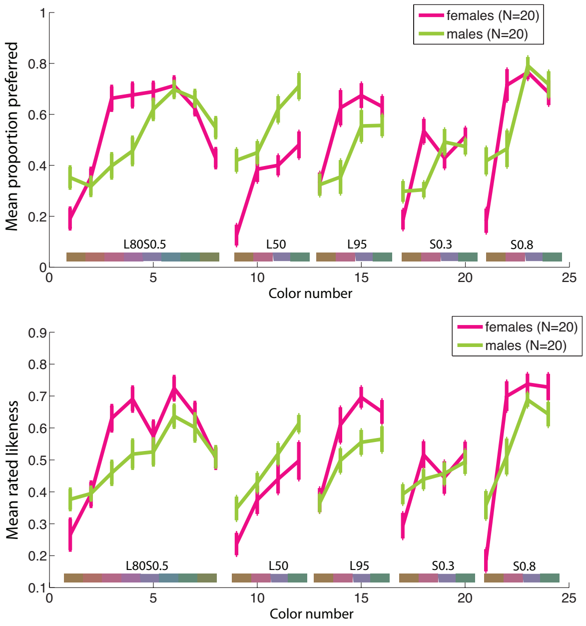

Figure 1. Mean color preference curves for Task2 Group3 colors (Top), and Task1 Group3 colors (bottom); error bars represent s.e.m. Each curve is divided into 5 disconnected sub-curves, representing hue preference at iso-lightness-iso-saturation. The curves for colors 1-8 represent hue preference curves for the 8 selected hues at L80 S0.5; for colors 9-12 and colors 13-16, curves represent hue preference for the subsets of 4 hues at L50 and L95 respectively. The first three hue curves thus demonstrate variations in preference with lightness. For colors 17-20 and colors 21-24, curves represent preference for subsets of 4 hues at S0.3 and S0.8; these curves thus indicates dependence of preference on saturation.

Table 1. Percentage of variance explained (R^2) by the model, for individual color preference curves and the mean color preference curves (N=40).

R^2	Individual	Mean
Task1Group1	0.4837	0.6438
Task1Group2	0.4607	0.4763
Task2Group2	0.4889	0.5328
Task1Group3	0.5700	0.6731
Task2Group3	0.6148	0.7420

Figure 2 illustrates the mean preference weights, for both sexes, obtained from all 5 sets of color preference curves separately. The figure demonstrates that the proposed model explains most of the variance in color preference, and also captures the main characteristics of sex differences in preference. As mentioned previously, both the average male and female most prefer bluish/bluish-greenish hues and more saturated colors. These preferences are represented in the model as positive weights for the S-(L+M) component (female: $p<0.0001$, male: $p<0.01$), negative weights on the L-M component (female: $p<0.0001$, male: $p<0.0001$), and positive weights on saturation (female: $p<0.0001$, male: $p<0.0001$), for both sexes. Meanwhile, the average female gives positive weight to luminance ($p<0.0001$), while the average male gives near-zero weight to this component ($p=0.93$), which, again, agrees with previous findings. Females tend to give larger weights than males to the S-(L+M) ($p<0.0001$) and L-M components ($p<0.05$), explaining the female's distinct preference for reddish and reddish-blue hues compared with the male's. The sex difference is most pronounced for the combination of Task 2 and Group 3 stimuli.

Thus, we have shown that our proposed model explains most of the individual variance in color preference, encapsulates the main characteristics of observers' color preference, and may also be used to analyze group differences in color preference, verifying our first 2 hypotheses. We now examine Hypothesis 3, that the preference weights extracted from different color sets are highly correlated. Table 2 lists the correlation coefficients between all sets of preference weights, obtained from 5 sets of color preference curves separately, over the whole population. The table reveals very high correlations between all sets ($p<0.00001$ for all correlations), and demonstrates that even when we employ completely different color sets and psychophysical methods, the main attributes of observers' color preferences remain the same, and are well captured by the proposed model.

Table 2. 2D correlation coefficient (R) between preference weights obtained from different sets of color preference curves, for all 40 observers.

	Task1 Group1	Task1 Group2	Task2 Group2	Task1 Group3	Task2 Group3
Task1 Group1	1	0.7846	0.8302	0.9018	0.9175
Task1 Group2	0.7846	1	0.8383	0.7557	0.7399
Task2 Group2	0.8302	0.8383	1	0.77	0.8101
Task1 Group3	0.9018	0.7557	0.77	1	0.8926
Task2 Group3	0.9175	0.7399	0.8101	0.8926	1

Conclusion

In this paper, we propose a new model for color preference which incorporates both universality and individuality. An individual's color preference may thus be described as the weighted sum of 4 fundamental color-coding components (luminance, red-green, blue-yellow and saturation), all universal across populations. Meanwhile, each individual accords a different set of weights to these components, representing his/her individual color preference. We tested the model with a series of psychophysical experiments. The results reveal that the model explains most of the individual variance in color preference and may therefore be used as a good descriptor for individual as well as group differences. By translating complex color preference results into 4 easily interpreted weights, we also find that the main characteristics of individual color preference do not vary significantly across different color samples and experimental methods, thus allowing us to employ only a small sample of stimuli to reveal color preference across the entire color space. The model's simple format allows easy statistical and quantitative analysis, and provides a reliable platform for future studies on color preference.

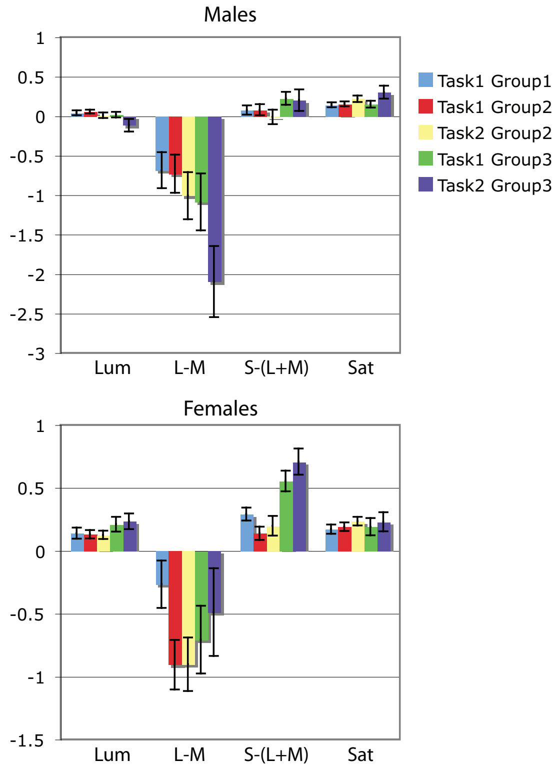

Figure 2. Mean preference weights for females (left) and males (right), obtained from 5 sets of color preference curves respectively. Error bars represent s.e.m.

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