Monte Carlo Simulations of the Farnsworth-Munsell 100 Hue Color Vision Test for Anomalous Trichromatic and Dichromatic Observers

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Abstract: We use a Monte Carlo simulation that considers psychophysical data to replicate experimental results of the Fransworth-Munsell 100 Hue Test for normal and color vision deficient observers.

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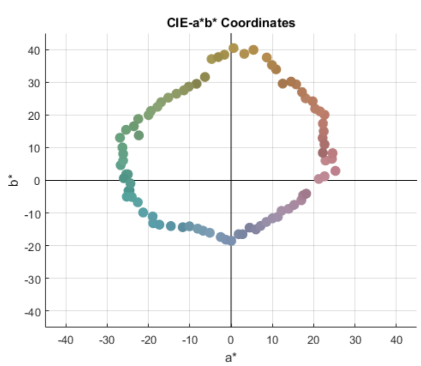
At the retinal photoreceptor level trichromatic human color vision is described by the fundamental cone responses at long, medium, and short wavelengths (respectively L, M, and S cones). Roughly 8% of all men and about 0.5% of all women are color vision deficient [1]. Modifications to the type of proteins that are the building blocks of the photopigments cause variations in the spectral response of the fundamental cones. Color vision deficiency arise when the L (M) spectral cone response is shifted by a few nanometers away from its peak towards the M (L) cone. This is referred to protanomaly (deuteranomaly). The S cone can also be shifted away from its peak spectral response this is called tritanomaly. When an observer is missing an L (M) cone response they are now a dichromatic observer and the deficiency is called protanopia (deuteranopia). The changes in the spectral response of the photoreceptor makes the task of discriminating colors more difficult.

One method to test how well an observer can discriminate colors is the Farnsworth-Munsell 100-Hue test [2]. The test consists of 85 caps each with different hues. All the caps are then divided into four sections where two end caps are fixed. The caps in between are randomized, and the observer is asked to arrange the caps in way that yields a smooth color transition from one end cap to the other. The task is evaluated by calculating the error score which is the sum of the differences between the number (j) of the color cap and the numbers (i, k) of the two adjacent color caps. Here we propose a Monte Carlo simulation of this test and replicate reported experimental results [3].

The reflectance spectrum of the caps is extracted by using a hyperspectral camera (SPECIM IQ). The camera captures the scene and generates a 512x512x204 data cube. The camera has a spectral resolution of 3nm and a spectral range of 400 nm -1000 nm. The spectral data is normalized to a white reference in the scene to account for the detector response and the illumination of the scene. With the reflectance of each caps we can apply any illuminant and calculate relevant colorimetry values. For our simulation we use illuminant D-65 and calculate the corresponding CIE 1931 XYZ and CIE L*a*b* values [ref].



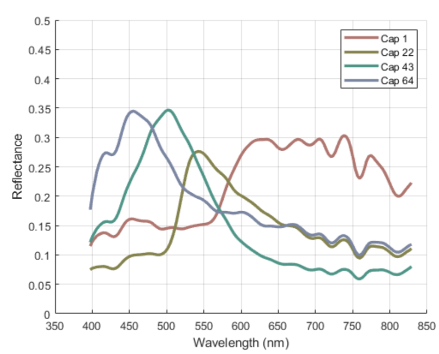


Fig. 1. (a) The CIE a*b* coordinates of all 85 caps of the FM 100 Hue Color Vision test and (b) the reflectance spectrum of the terminal caps.

We designed the Monte Carlo simulation to mimic the actions of an observer attempting to arrange the caps. The experimental setup is equivalent: 4 rows of caps where the terminal caps in each of the rows are fixed. The first step is randomizing all the non-terminal caps in each of the rows. Next, we calculate the ΔE^{*}_{ab}between the first terminal cap in position 1 of the row and cap i up to cap $L - 1$, where L is the number of the second terminal cap in that row. Then, we declare $\Delta E_{threshold} = 3$ to find all the caps whose color difference between itself and the first terminal cap is less than $\Delta E_{threshold}$. To determine the which cap belongs in position 2 we consider a psychophysical model [4,5]. The model introduces the probability that an observer is not able to discriminate to color as function ΔE^{*}_{ab}. [Insert the selection process we decide to use here]. This process yields which cap belongs in position 2 and we repeat this sorting procedure up for all caps up to position $L - 1$ and for all rows. Finally, repeat this simulation N times. To consider color vision deficient observers we shift the individual spectral response of the L and M cones [6]. We consider shifts in both cones corresponding to 5 nm, 10nm, 15nm and the dichromatic cases.

Fig. 2. Averaged results of 200 trials of the FM 100 Hue Color Vision test for (a) anomalous trichromats and (b) dichromats.

Fig.3. Error score distribution of 200 trials of the FM 100 Hue Color Vision test for (a) protanomaly, (b) deuteranomaly, (c) protan, and (d) deutan observes

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