Individual Difference of Color Matching Functions and Its Cause

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Abstract

Using a new colorimeter that can present a color having an arbitrary spectral power distribution, we measured color matching functions for 9 individuals, and analyzed a cause of their individual difference. We found that a main cause of the individual difference is the difference of individual spectral lens density.

Introduction

Recently, several studies showed that CIE standard observer fails to predict individual color-matches[1-2] and it causes serious problem in practical applications such as designing new color display using six-color primaries[3]. There are two possible reasons why standard observer fails to predict color-matches: 1. additivity of color matching is failing, 2. individual color matching functions are different from those of the standard observer. To test these possibilities, we developed a new colorimeter that can present a color having an arbitrary spectral power distribution by utilizing a digital micro-mirror device developed by Texas Instruments as spectrum modulation engine. We first applied this colorimeter to test the additivity of the color matching functions and found its failure is small[4]. In this study, we applied the colorimeter to measure color matching functions for individual observers and analyzed the cause of the individual differences.

Methods

The colorimeter we developed can control the powers of 31 monochromatic lights from 400 nm to 700 nm in 10 nm intervals independently. Color matches were conducted between a test light and a reference light. The test light composed of about 16 monochromatic lights according to 32 bits M-sequence pattern where each bit correspond to one of 31 monochromatic lights, and the reference light composed of three primary colors having the wavelengths of 450, 540 and 610 nm. Observer adjusted powers of three primary colors so as to match the color appearance to the test light for 31 independent M-sequence patterns. RGB color matching functions of wavelength λ were then calculated by solving the following equation,

$$\begin{pmatrix} D_{1,400} & D_{1,410} & \cdots & D_{1,700} \\ D_{2,400} & D_{2,410} & \cdots & D_{2,700} \\ \vdots & \vdots & \ddots & \vdots \\ D_{31,400} & D_{31,410} & \cdots & D_{31,700} \end{pmatrix} \begin{pmatrix} \bar{r}_{400} & \bar{g}_{400} & \bar{b}_{400} \\ \bar{r}_{410} & \bar{g}_{410} & \bar{b}_{410} \\ \vdots & \vdots & \vdots \\ \bar{r}_{700} & \bar{g}_{700} & \bar{b}_{700} \end{pmatrix} = \begin{pmatrix} R_1 & G_1 & B_1 \\ R_2 & G_2 & B_2 \\ \vdots & \vdots & \vdots \\ R_{31} & G_{31} & B_{31} \end{pmatrix}$$

where $D_{i,\lambda}$ represents the spectral power distribution of ith M-sequence pattern, $\bar{r}_\lambda$, $\bar{g}_\lambda$ and $\bar{b}_\lambda$ represent color matching functions, and R_i, G_i and B_i represent the powers of the three primaries matched to the test light by the observer for ith M-sequence pattern.

Results

Figure 1 shows the results of the above measurements and the calculations for 9 observers. The results showed that reasonable color matching functions were obtained compare to the CIE 1931 color matching functions as shown in thick dotted lines except for short wavelength region. Large deviations from CIE color matching functions and large individual differences were observed in the short wavelength region. One of 9 observers was age 42 who showed lowest B color matching function, and the ages of other observers were early 20's who showed higher B color matching functions in the short wavelength region. From this observation, we hypothesized that the main cause of the individual differences were the individual differences of spectral lens density. To prove this hypothesis, we estimated spectral lens density for two observers of age 42 and 22 by comparing dark adapted peripheral sensitivity (rod sensitivity) to the action spectrum of rhodopsin. We found that color matching functions of the two observers become close to each other by compensating individual spectral lens density.

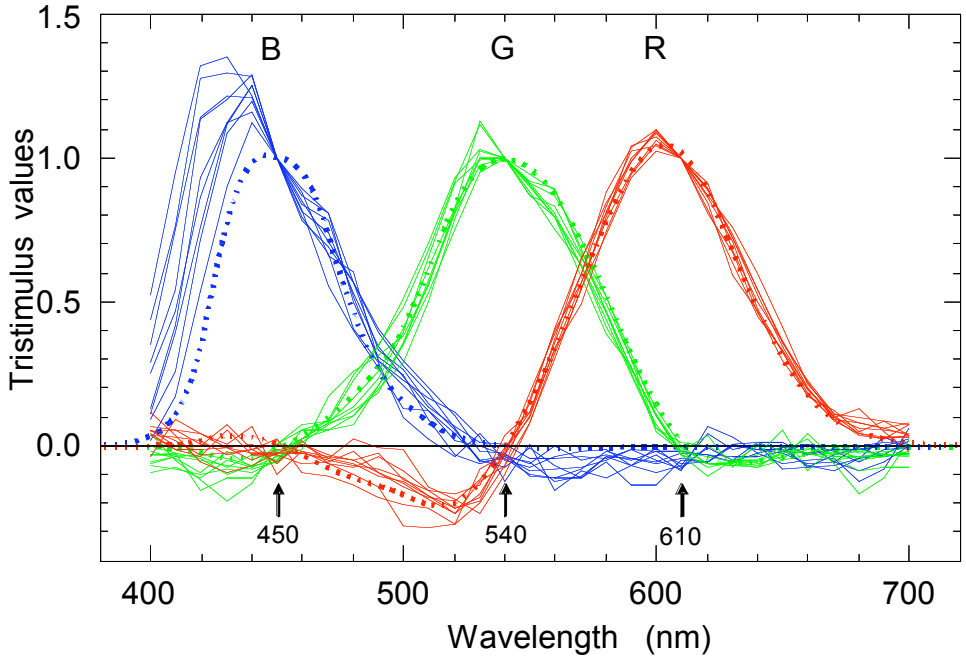

Figure 1. RGB color matching functions for 9 observers (solid lines). Thick dotted lines are the CIE 1931 color matching functions adapted to our RGB primaries.

References

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