# Observer Function Database

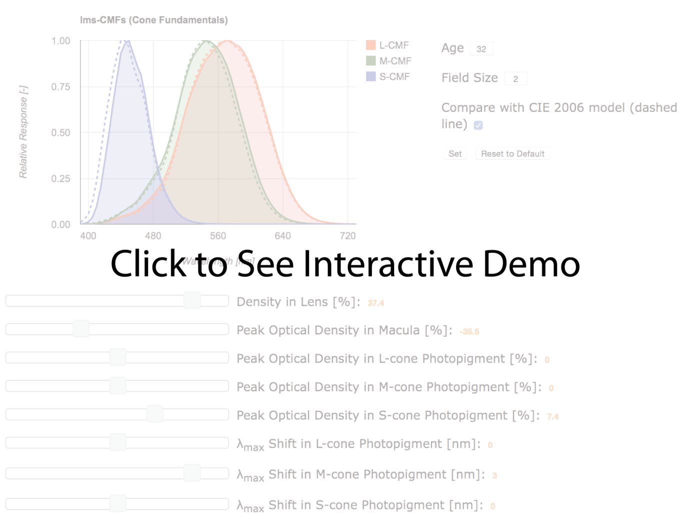
### Individual Colorimetric Observer Model

The individual colorimetric observer model is the first complete function aimed to model color matching functions (CMFs) of color-normal individuals (not the average such as the CIE 1931, 1964, 2006 observers).

The model is an extension of the CIE 2006 physiological observer function and incorporates eight physiological parameters in addition to “age" and "field size" inputs of the CIE 2006 model. The equation is shown below.

$$lms\text{-}CMFs = f(age, fs, d_{lens}, d_{macula}, d_L, d_M, d_S, s_L, s_M, s_S)$$

age: age of an observer (as in CIE 2006 model)
fs: field size (as in CIE 2006 model)
$d_{lens}$: deviation [%] from an average for lens pigment density
$d_{macula}$: deviation [%] from an average for macular pigment density
$d_L$, $d_M$, $d_S$: deviations [%] from averages for peak optical densities of L-, M-, S-cone photopigments
$s_L$, $s_M$, $s_S$: deviations [nm] from averages for $\lambda_{max}$ shifts of L-, M-, S-cone photopigments



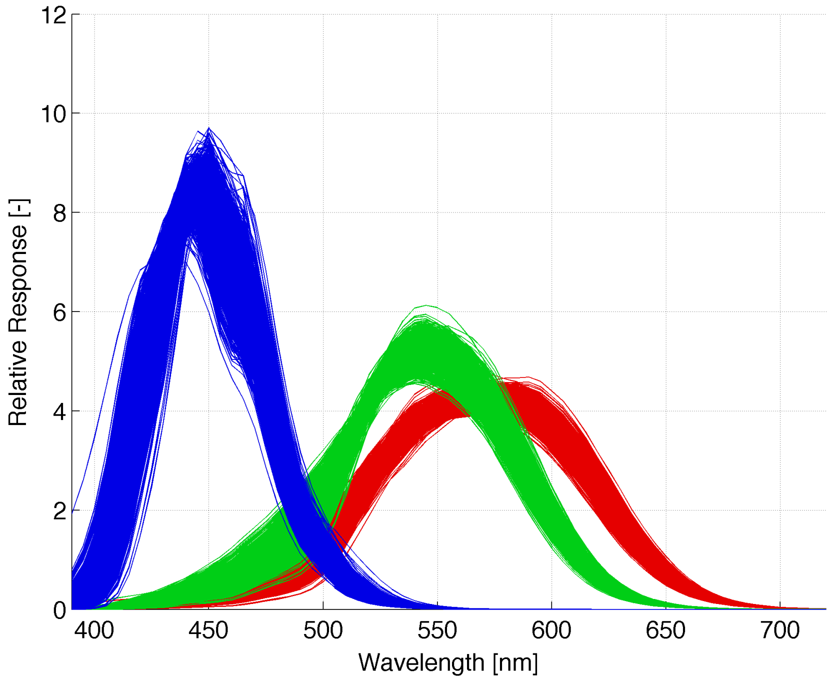

Combined with Monte Carlo simulation technique, the individual colorimetric observer model can generate thousands of observer functions that represent color-normal populations for a given age distribution and a given field size.

The probability density functions for the eight physiological parameters were normal distributions with standard deviations obtained from numerous past studies (a table shown below).

| Standard Deviations for 8 Physiological Parameters | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lens [%] | Macula [%] | Density in L [%] | Density in M [%] | Density in S [%] | Shift in L [nm] | Shift in M [nm] | Shift in S [nm] |
| 18.7 | 36.5 | 9.0 | 9.0 | 7.4 | 2.0 | 1.5 | 1.3 |

The model was validated using three different datasets: a traditional color matching dataset, an applied color matching dataset, and a Rayleigh match dataset. The model would be beneficial to assess ranges of color matches instead of a single average match in many color-critical applications such as color grading and soft proofing. The figure below shows the generated 1000 cone fundamentals (or lms-CMFs) for 2-degree field size with an age distribution taken from the US Census 2010. The response functions are area-normalized.

Matlab codes for the individual colorimetric observer model and 1000 CMFs generated from the Monte Carlo simulation are available for download.




### Categorical observers

Categorical observers are observer functions that would represent color-normal populations. They are finite and discrete as opposed to observer functions generated from the individual colorimetric observer model. Thus, they would offer more convenient and practical approaches for the personalized color imaging workflow and color matching analyses. Categorical observers were derived in two steps. At the first step, 10,000 observer functions were generated from the individual colorimetric observer model using Monte Carlo simulation. At the second step, the cluster analysis, a modified k-medoids algorithm, was applied to the 10,000 observers minimizing the squared Euclidean distance in cone fundamentals space, and categorical observers were derived iteratively. Since the proposed categorical observers are defined by their physiological parameters and ages, their CMFs can be derived for any target field size.

Categorical observers were ordered by the importance; the first categorical observer vas the average observer equivalent to CIEPO06 with 38 year-old for a given field size, followed by the second most important categorical observer, the third, and so on.

The color matching analyses showed that ten categorical observers are good for general use and convenience to represent color normal populations. On average, the prediction error improvement was small after adding tenth categorical observers, and the prediction errors became one-third by introducing ten observers. Nevertheless, readers should be aware that the number of required categorical observers varies depending on an application (a pair of spectra viewed by observers). For example, the simulation revealed that as many as 50 categorical observers would be required to predict individual observers' matches satisfactorily when a laser projector is viewed.

Matlab code for the categorical observers and CMFs as well as model parameters for ten categorical observers are available for download below.

### 151 color-normal observers

CMFs of 151 color-normal observers were estimated by combining the individual colorimetric observer model and the color matching proposed in Asano's PhD dissertation. The color matching consisted of five color matches aimed to highlight and detect inter-observer variability among color-normals. To obtain a set of CMFs for a given human observer, at first, the observer performed the five color matches with three repetitions. Then, his/her eight physiological parameters (used in the individual colorimetric observer model) were estimated from the color matching results by a non-linear optimization. The objective function was to optimize the eight physiological parameters such that the color differences between the human observer results and model predictions were minimized. Finally, the CMFs were reconstructed from the estimated physiological parameters and the observer's real age.

The estimated CMFs for 151 color-normal human observers, the corresponding model parameters, and other information such as gender, experience in color-related subjective experiments, ethnic origin, color deficiency in family, diabetes, and intra-observer variability (Mean Color Difference from the Mean using CIEDE2000) for each of the 151 observers are available for download.

### Downloads and Demonstrations

Matlab code for individual colorimetric observer model and categorical observers
Matlab code for simulating three different colormatches (Stiles and Burch's experiment, Asano's five color matches, and Rayleigh matches by Rüfer et al.)
1000 CMFs generated from individual colorimetric observer model with Monte Carlo Simulation [xls]
CMFs, ages, and physiological parameters for 10 categorical observers [xls]
Estimated CMFs and other information (e.g. model parameters, genders, ethnic origins, etc.) for 151 color-normal human observers [xls]

Here is an interactive demonstration showing the spectral responsitivities resulting from varying the model parameters.

Note that all the CMFs have wavelength ranges from 390 nm to 780 nm at 5 nm interval. CMFs are available in four different forms: field size of either 2-degree or 10-degree and xyz- or lms-primaries (lms-CMFs are area-normalized). xyz-CMFs were obtained by a linear transformation from corresponding lms-CMFs using a 3x3 matrix. The 3x3 matrix was obtained performing a linear regression between the average lms-CMFs and the CIE 1931 2-degree observer (or the CIE 1964 10-degree observer).

For 2-degree, the 3x3 matrix is:

$$M_{3x3} = \begin{matrix} 0.4151 & -0.2424 & 0.0425 \\ 0.1355 & 0.0833 & -0.0043 \\ -0.0093 & 0.0125 & 0.2136 \end{matrix}$$

For 10-degree, the 3x3 matrix is:

$$M_{3x3} = \begin{matrix} 0.4499 & -0.2630 & 0.0460 \\ 0.1617 & 0.0726 & -0.0011 \\ -0.0036 & 0.0054 & 0.2291 \end{matrix}$$

### More Information

For more information, please refer to the PhD dissertation of Yuta Asano.

If you have any questions regarding the observer function database, please contact YutaAsano1986@gmail.com