

Simulation of EnChroma Technology

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- [Introduction:](#)
- [Background:](#)
- [Methods:](#)
 - [Simulation of Color Vision Deficiency](#)
 - [EnChroma Glasses Notch Filter](#)
 - [Simulation of Color Appearance of Color Vision Deficiency \(CVD\)](#)
- [Results:](#)
 - [Examples of Color Vision Deficiency Simulation](#)
 - [Retina Images with and without EnChroma Glasses](#)
- [Conclusions:](#)
- [References:](#)
- [Appendix:](#)

Introduction:

Human color vision enables an ability to perceive differences between light composed of different wavelengths independently of light intensity [1]. It is mediated by a complex process between neurons that starts with differential stimulations of different types of photoreceptors (cone cells) by light entering the eye. Those cones then emit outputs that are propagated through many layers of neurons and then ultimately to the brain. Humans have three types of cone cells (S-, M-, and L-cones), which contain different forms of pigment protein and have different spectral sensitivities, resulting in trichromatic color vision.

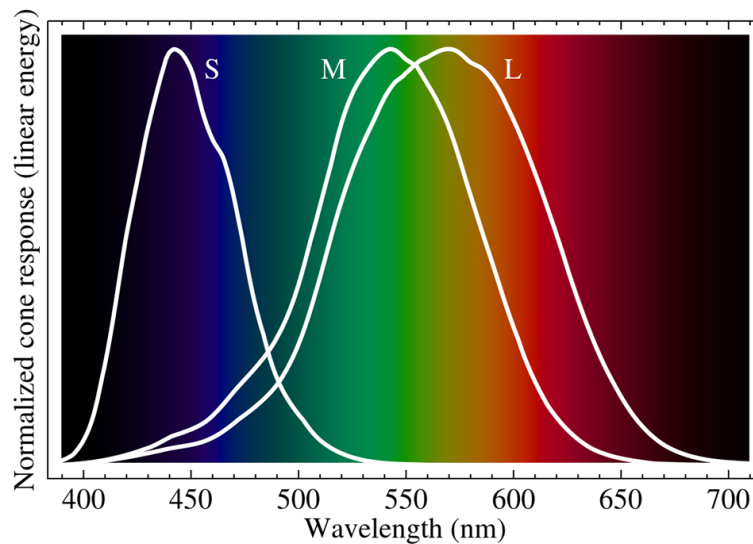


Figure 1. Normalized response spectra of human cones to monochromatic spectral stimuli, with wavelength given in nanometers [2].

Color blindness includes a wide range of causes and conditions. Usually when people talk about color blindness, they are referring to the most common form of red-green color blindness which can be broken into two main types: Protan-type (disorder of L-cones) and Deutan-type (disorder of M-cones). Other than red-green color blindness, there are Tritan color blindness (blue-yellow color blindness, disorder of S-cones), Monochromacy and Achromatopsia (partial or total color blindness, missing one or two types of cones).

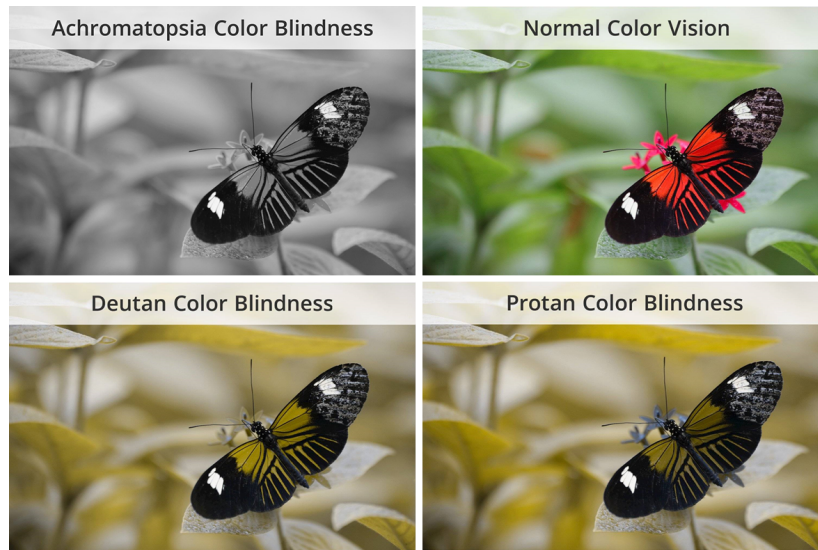


Figure 2. Color appearance of different color vision conditions.

EnChroma glasses technology is marketed to help with anomalous trichromacy color blindness (~80% cases of color blindness) and help increase contrast between the red and green color signals [3]. In this project, my goal is to simulate the EnChroma technology for the cases of normal color vision and different cases of color blindness, and see how this technology would make a difference.

Background:

EnChroma glasses were first invented by an accident [4]. Don McPherson, a Ph.D. glass scientist, who was known for designing protective eyewear for surgeons who were using a certain laser in the operating room. His friend Mike borrowed those tinted protection glasses one day on a Frisbee field. And when he put them on, he saw something he's never seen before – orange color. Don's surgeon glasses accidentally helped his friend see orange color. This led to the starting of a new company EnChroma.

EnChroma lenses focus on the most common color vision deficiency which is caused by the red and green retinal cone cells that, when responding to light, coincide. To eliminate the overlapping of the wavelengths of light, there is an optical material called a notch filter, which is capable of removing the exact wavelengths of light in the location where it overlaps, getting a simplified differentiation of colors. The glasses block specific wavelengths to create a clearer separation of different color signals so that they can be better calculated by the brain. The separation of signals allows most people with color blindness to distinguish colors, but the glasses will have little to no effect on the 20% of color blind people who have severe color impairment. [5][6]

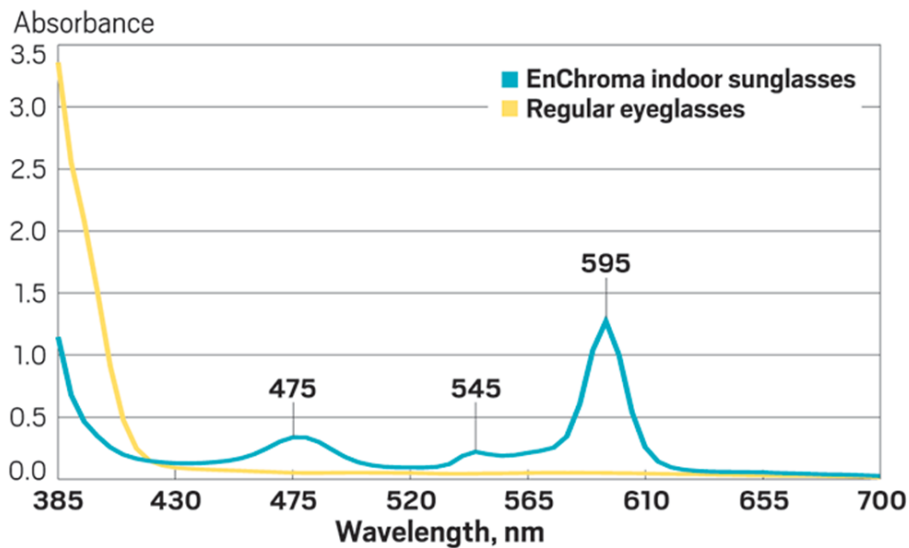


Figure 3. Ultraviolet-visible absorption spectra of EnChroma's indoor sunglasses suggest it would block a band of light centered on 595 nm [7].

Methods:

Simulation of Color Vision Deficiency

In a case of protan-type color blindness, the L-cone is shifted towards that of M-cone, as shown in Figure 4. As for deutan-type color blindness, the spectral sensitivity of the M-cones is shifted towards that of the L-cone.

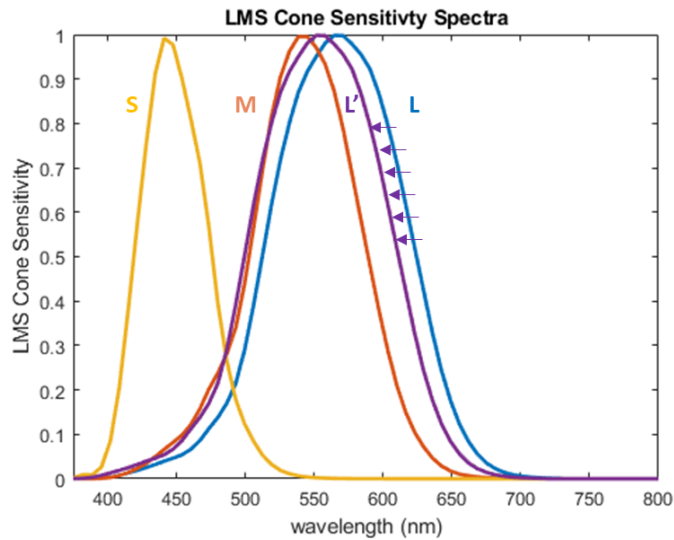


Figure 4. Relative spectral sensitivities of the L,M,S cone types involved in normal color vision. The purple curve is the hypothesized (shifted) sensitivity of the protanomalous L' cone for an intermediate value of the shift.

The cone excitations associated with normal color vision, L_c , M_c , and S_c are calculated by integrating the product of a spectral power distribution and the cone sensitivity over the relevant wavelength region. The shifted spectral sensitivities are captured by multiplying a 3x3 matrix D [8].

$$\begin{pmatrix} L'_c \\ M'_c \\ S'_c \end{pmatrix} = D \begin{pmatrix} L_c \\ M_c \\ S_c \end{pmatrix}$$

With different matrix D , we are able to simulate different degrees and types of color blindness (shown in Figure 5). In case of protan-type color blindness,

$$\begin{pmatrix} L'_c \\ M'_c \\ S'_c \end{pmatrix} = \begin{pmatrix} 1 - d & d & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} L_c \\ M_c \\ S_c \end{pmatrix}$$

In case of deutan-type color blindness,

$$\begin{pmatrix} L'_c \\ M'_c \\ S'_c \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ d & 1 - d & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} L_c \\ M_c \\ S_c \end{pmatrix}$$

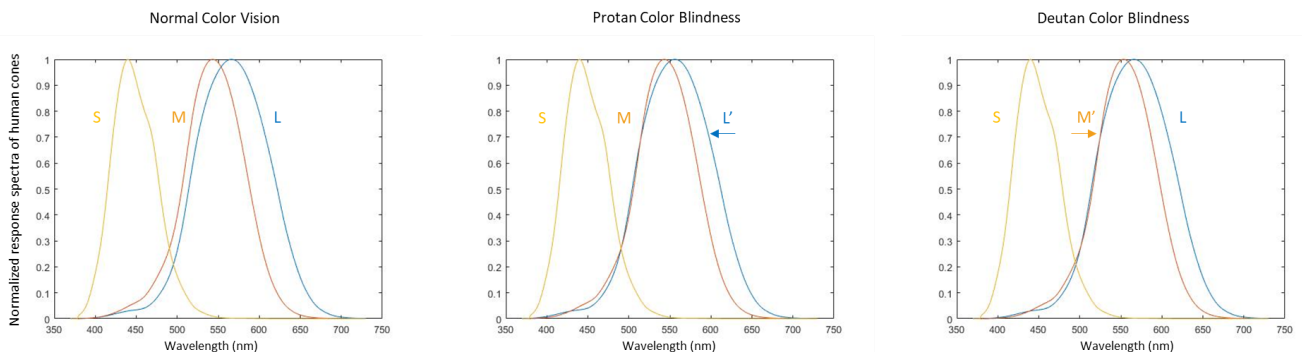


Figure 5. Spectral sensitivity of LMS cones for Normal color vision, protan-type, and deutan-type color blindness.

EnChroma Glasses Notch Filter

The EnChroma glasses block specific wavelengths to create a clearer separation of different color signals so that they can be better calculated by the brain. EnChroma lens transmittance data is from ISETBio.

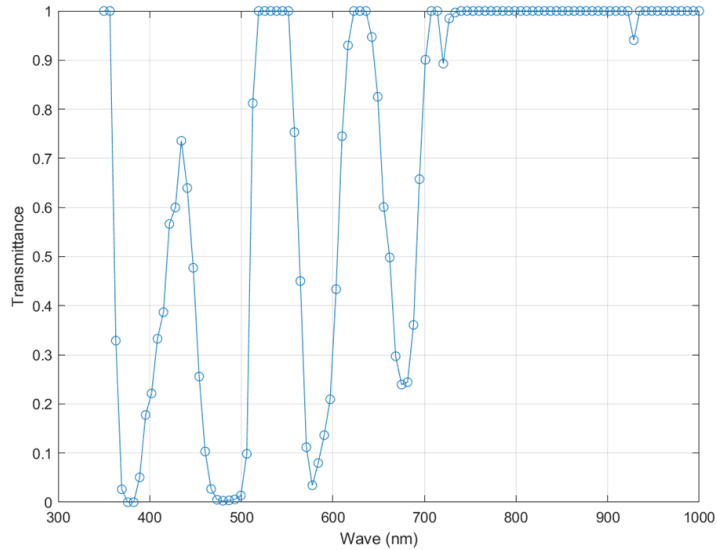
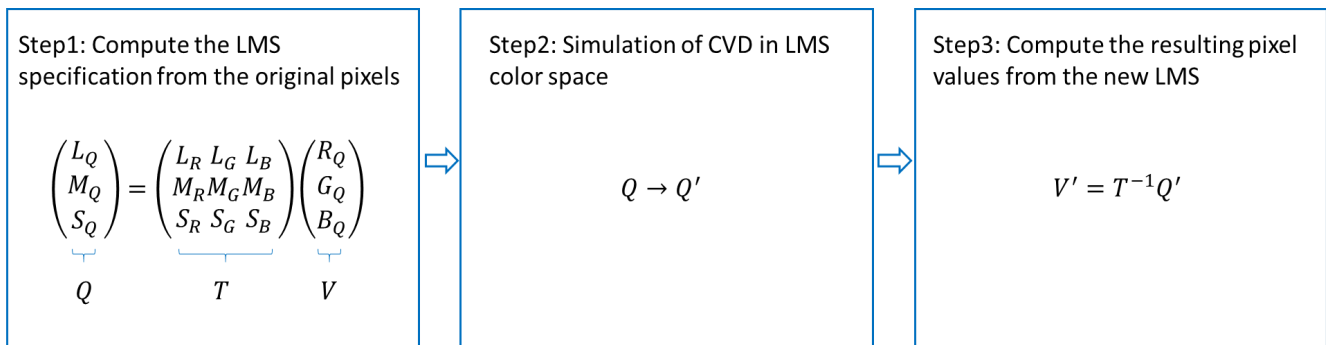


Figure 6. Transmittance of EnChroma glasses.

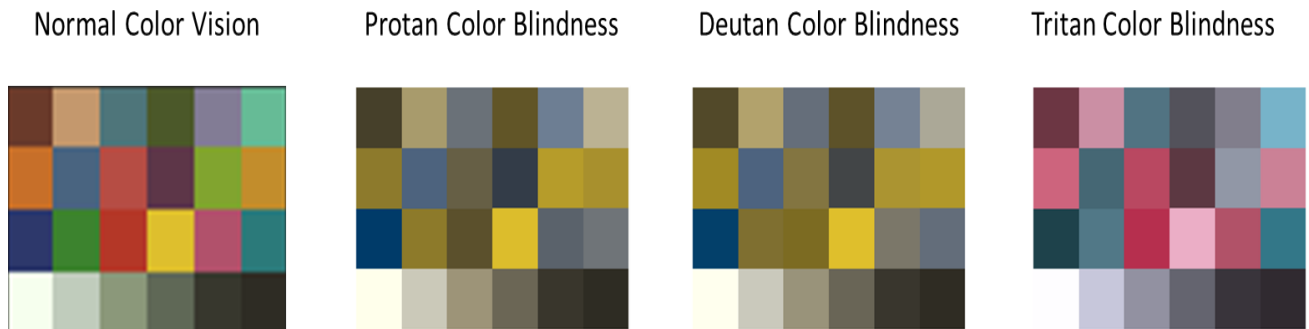
Simulation of Color Appearance of Color Vision Deficiency (CVD)

The Algorithm of color appearance simulation for color vision deficiency was first developed by Brettel et al [9]. it is also available in ISETBio (s_humanColorBlind.m).



Results:

Examples of Color Vision Deficiency Simulation





Retina Images with and without EnChroma Glasses

	Normal Color Vision	Protan Color Blindness	Deutan Color Blindness	Tritan Color Blindness
Retina Image without EnChroma Filter				
Retina Image with EnChroma Filter				

Conclusions:

EnChroma glasses can improve color separation to some extent, however, whether EnChroma glasses can recover color vision for different types and levels of color blindness is still pending investigation. It will be interesting to simulate different degrees of color blindness (mild, medium, and severe), and the effect of EnChroma filter. Also, a simulation of different notch filters and its impact on different types of color blindness might be meaningful.

References:

ISSET Bio:

<https://github.com/issetbio/issetbio/wiki>

[1] https://en.wikipedia.org/wiki/Color_vision

[2] <https://commons.wikimedia.org/wiki/File:Cone-fundamentals-with-srgb-spectrum.svg#/media/File:Cone-fundamentals-with-srgb-spectrum.svg>

[3] <https://EnChroma.com/pages/how-EnChroma-glasses-work>

[4] <https://www.npr.org/2018/07/13/628907277/how-universities-and-businesses-are-trying-to-engineer-more-accidental-genius>

[5] Diane, Kelly; Maddie, Stone (11 July 2015). "Can These Glasses Help the Colorblind? We Put EnChroma to the Test". *Gizmodo*. Retrieved 29 November 2018.

[6] Bettenhausen, Craig (6 February 2017). "Experimenting with EnChroma's color-blind assistance glasses". *Chemical & Engineering News*. **95** (6): 80. Retrieved 30 November 2018.

[7] Photo credit: C&EN/University of Maryland, College Park

[8] Marcel Lucassen & Johan Alferdinck, Dynamic Simulation of Color Blindness for Studying Color Vision Requirements in Practice, CGIV 2006 Final Program and Proceedings.

[9] Brettel et al., Computerized simulation of color appearance for dichromats, Vol. 14, No. 10/October 1997/J. Opt. Soc. Am. A.

Appendix:

Code: [EnChromaTechnologySimulation_v4.m](#)