Vision Science II – Monocular Sensory Aspects of Vision

Lecture 30 – Anomalous Color Perception

REVIEW BASICS of COLOR VISION ANOMALIES (Lecture 30)

- Color vision anomalies affect about 4.5% of the general population—1 out of 20 patients
- Most color anomalies are hereditary.
- Hereditary anomalies predominantly affect males. About 8% (1/12) of men are affected.
- Most hereditary color anomalies are of the red-green type (protan L anomaly or deutan M anomaly)
- A small percentage of women have hereditary color anomalies
- Acquired color anomalies can affect males as well as females

Q. Name some characteristics that would help you differentiate between a hereditary versus acquired color vision anomaly?

Q. What kind of hereditary color anomaly is most common?

Q. Why are acquired color anomalies usually more of a concern?

ANOMALOUS COLOR PERCEPTION

V(λ) function

The V(λ) or luminous efficiency function may be altered in a person with anomalous color vision. Recall that the luminance efficiency function, or V(λ) curve, is bell-shaped with a broad peak at about 555 nm. The V(λ) curves for a protanope, dueteranope and trichromat are shown in Schwartz Fig. 6-3.

- The protanope (missing erythrolabe) curve is shifted toward shorter wavelengths. The shift is due to the absence of input from erythrolabe, which is sensitive to longer wavelengths.
- The deuteranope (missing chlorolabe) curve is nearly normal, since the M-cone (chlorolabe) input is not as important in the V(λ) function as the L-cone input.

Since protanopes have reduced sensitivity to long wavelengths, compared to normal trichromats, red lights appear dimmer or less saturated to them than to normal trichromats. Protanomalous trichromats show a similar change as a protanope, though less pronounced. Deuteranomalous trichromats have a nearly normal V(λ) function.

One student, who is a protonope, told me that he has difficulty seeing red lights. When he comes to a traffic light, he can't tell if the red light is on or off, so he depends on other cues to decide whether if it's safe to proceed or not. For example, if the green and yellow lights are not on, then the red might be on. If the traffic going the other way begins to move, he knows it's red for his direction.

Wavelength discrimination

Wavelength discrimination for a color anomalous person is illustrated in Schwartz Fig. 6-4. The normal wavelength discrimination function (ability to detect small changes in wavelength) has a W-shaped curve, with best sensitivities at about 500 and 600 nm. Protanopes and deuteranopes both show significantly altered wavelength discrimination (Fig. 6-4A).

- Only one minima (wavelength of best wavelength discrimination).
- Much worse wavelength discrimination at other wavelengths (higher values).
- No wavelength discrimination (essentially monochromatic) above about 545 nm.

Relate this to the spectral absorption characteristics of the cone photopigments (Figure 1 below). If a person is missing either the L or M-cones pigments, then he is essentially monochromatic beyond the range for the S-cones (about 545 nm). Monochromats are incapable of discriminating wavelengths based on wavelength information alone. (See Schwartz Fig. 6-5.)

Tritanopes show an abnormal wavelength discrimination function (Fig. 6-4B), but at long wavelengths it is relatively good, since they are still dichromats (normal) in that range. They are also dichromatic at shorter wavelengths, but at about 500 nm, the spectral sensitivities of the M and L cones are nearly identical, so wavelength discrimination is poor in that range.

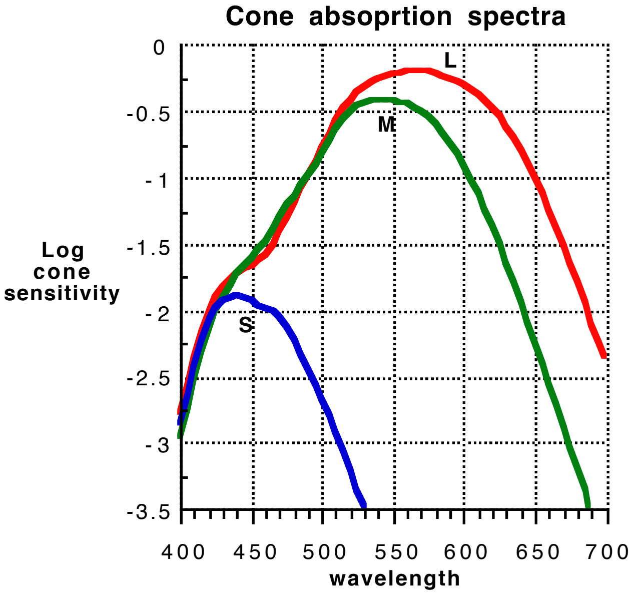

Figure 1. Normal sensitivity spectra for L, M & S

Color confusion

Because of their limited wavelength discrimination, dichromats confuse certain colors. A specific pattern of color confusion characterizes each of the different dichromats. This is illustrated by the **color confusion lines** on the CIE chromaticity diagram shown in Figure 2 and Schwartz Fig. 6-6.

All colors falling on the same line appear to be the same color. Note that the color confusion lines converge to a **copunctal point** (points P, D and T on Figure 2)

- The protanope confuses colors such as blue-green (492 nm) with red (700 nm).
- The deuteranope confuses blue-green (498 nm) with reddish-purple (See Schwartz figures.)

Since protanopes and deuteranopes are essentially monochromatic above 545 nm, they both share a color confusion line that runs from 545 nm through red (600-700 nm) to the copunctal points. Since protanopes and deuteranopes easily confuse reds and greens, both anomalies are sometimes referred to as red-green color blindness.

The tritanope confuses violet (400 nm) with yellow (570 nm). They are sometimes referred to as being blue-yellow color blind.

Note which colors appear the same as white for the different dichromats: about **492 nm for protanopes, 498 nm for deuteranopes, 569 for tritanopes.** These wavelengths are known as **neutral points**.

Q. Can you see a problem in designing a traffic light with the following dominant wavelengths: Red (650 nm), yellow (570 nm), green (550 nm)?

The most common color anomaly is **deuteranomaly**. Why then would it be better to make the green traffic light blue-green rather than pure green?

Color confusion helps us understand how to create a color vision test, such as a pseudoisochromatic plate test. Just create a figure made of dots in a background of dots. The dots that make up the figure and background should be made up of colors that lie on a color confusion line.

Q. Why are these tests referred to as "pseudo isochromatic" tests?

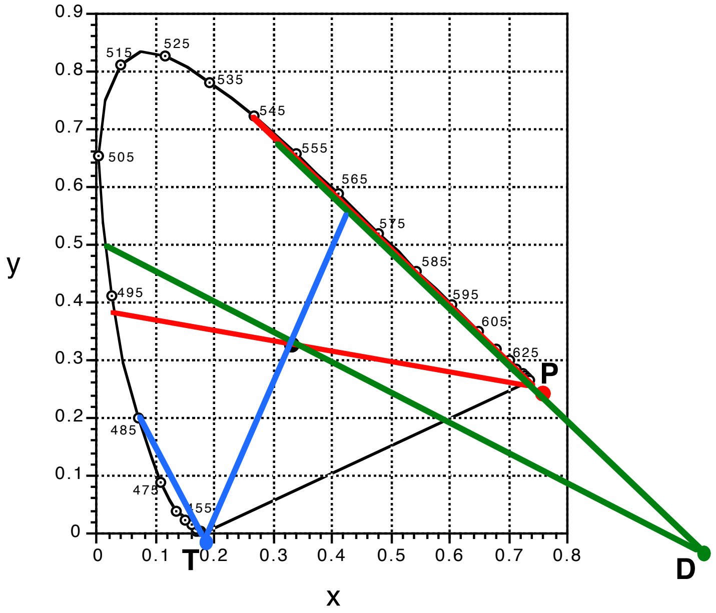

Figure 2. Copunctal points and a few of the color confusion lines. See Schwartz for details.

Relative spectral saturation

Schwartz **Fig. 6-7A** shows the relative saturation for different color anomalies. For a normal trichromat, yellow (~570 nm) appears to be the least saturated color. The relative spectral saturation function for protanopes and deuteranopes is shifted toward shorter wavelengths, and the minimum saturation value approaches zero. This means that those wavelengths are indistinguishable from white or gray.

- For the protanope, the saturation function falls to zero at ~492 nm
- For the deuteranope it falls to zero at ~498 nm.
- The tritanope neutral point is ~569 nm.

The wavelengths, where the colors appear to be white are called the **neutral points** (mentioned above).

Schwartz **Fig. 6-7B** shows that anomalous trichromats show a similar shift in their relative saturation functions, but they do not have neutral points.

COLOR LABELING

Dichromats and anomalous trichromats may have little difficulty identifying the colors of objects in real life since they base their color labeling on other factors learned from experience, such as context, shape, relative luminance, etc. For example, they can easily identify the color of different fruit.

When these cues are absent, and they are forced to rely on wavelength alone, they will probably make mistakes. Schwartz Fig. 6-8 shows how the spectrum might appear to persons with normal and anomalous color vision.

The 4th edition of Schwartz uses a color figure and shows that for the mid to long wavelengths, there is no wavelength discrimination for the protanope and deuteranope. Note that the longest wavelengths appear darker for the protanope. The older editions of Schwartz have no color figures and try to illustrate these spectrum using lines to delineate different color bands within the spectra. The width of the bands represents the span of wavelengths that appear to be the same color. Where the wavelength discrimination is best, the bands are narrow.

Normal trichromat: Full spectrum from violet to red. Two regions of very good wavelength discrimination - ~500 and 600 nm.

Protanope: Monochromatic above 545 nm. Poor color saturation (nearly white) around 492 nm. Short wavelength discrimination poor—all look blue. Also, spectrum is cut short at about 650 nm due to absence of erythrolabe.

Deuteranope: Also monochromatic above 545 nm and poor color saturation (nearly white) around 498 nm. Short wavelength discrimination poor—all look blue. Spectrum extends to 700 nm as in normals.

Protanomaly is between trichromacy and protanopia. Deuteranomaly is between trichromacy and deuteranopia.

HEREDITARY COLOR ANOMALIES

Read about the genetics of color vision anomalies on pages 145-148 of Schwartz. The important points:

- Protan and deutan (red-green) anomalies are passed on as a recessive trait on the X chromosome.
- The defect will only be expressed is when two affected X'X' chromosomes are present (female; rare) or if the affected X' chromosome is paired with a Y chromosome (X'Y; male; more common).
- Therefore, red-green color anomalies are predominantly seen in males (8% of males); incidence in females is about 0.4%.
- Although the anomaly will not be expressed in a female with an X'X pair, she can still pass it to her children.
- Any male who inherits a color anomaly, must inherit the anomalous gene from his mother.

Review the Punnett squares in Schwartz Fig. 6-9 and be able to predict the pattern of inheritance for each possible case.

Among the four red-green anomalies (protanopia, deuteranopia, protanomaly, deuteranomaly), the most common is deuteranomaly (5% incidence in males). The others have a male incidence of 1% each (see Schwartz Table 6-2).

Inherited tritanopia and tritanomaly are very rare (male incidence 0.005%) and are passed on as autosomal dominant traits.

Achromatopsia

In this condition the patient apparently has no color perception, and he usually has other severe visual anomalies including poor visual acuity, nystagmus and photophobia. There are several types:

- **Rod monochromat** (typical achromacy) - Very rare hereditary (autosomal recessive) condition in which the patient has only rods. He will have poor visual acuity, nystagmus, photophobia & abnormal color perception.
- **Blue cone monochromacy** (incomplete congenital cone dysfunction or cone monochromacy) - rare hereditary (X linked recessive) condition; has rods and S cones only.
- **Green cone monochromacy** - has rods and M cones only. Very rare.
- **Red cone monochromacy** - has rods and L cones only. Very rare.