Lecture 8

Relative Luminous Efficiency

The sensitivity of the eye to different wavelengths in an equal energy spectrum is known as the 'Relative Luminous Efficiency (V_λ) function'.

At photopic levels of intensity, the RLE curve has a single peak, in the green-yellow region, of 555 nm. This means that when vision is denominated by cones, the eye is most sensitive to 555 nm wavelength in the visible spectrum.

In scotopic viewing conditions the peak sensitivity of the eye shifts to 500 nm corresponding to the peak sensitivity of the rod receptors. This change in peak sensitivity from photopic to scotopic viewing conditions is referred to as the ***Purkinje*** shift.

The RLE is measured by ***Flicker Photometry***.

Two circles of light are used, the larger circle subtending 10^0 at the nodal point of the eye. The larger circle is the ***background*** circle. A smaller circle, at the center of the larger one, subtends an angle of 1^0.

The smaller light circle is flickered (flashed) at about 1 Hz. At first it is very faint. Subsequently, its intensity is increased until the subject first notices it. Both the test (small circle) and backgrounds lights can be colored. The background light is referred to as the ***adapting field***.

The peak sensitivity for protanopia occurs at 535 nm instead of 555 nm and there is a marked reduction insensitivity to wavelengths above 600 nm and an absence of sensitivity for wavelengths above 630 nm. The absence of sensitivity, in protanopes, for wavelengths above 630 nm is usually referred to as a ***shortening of the red end of the spectrum***.

For Deuteranopia, the peak sensitivity occurs at 565 nm, but here, there is a much smaller red-end shortening.

No red-end shortening occurs in tritanopia and the peak sensitivity in the tritanopic eye is normal (555 nm), but there is a blue-end-of-the-spectrum shortening.

Congenital Color Deficiency

The first recorded case of congenital color deficiency was the case of Harris the shoemaker in 1777. From that time onward, different hypotheses have been postulated to explain the classes of color vision defects and their mechanism of inheritance. What we know today, about color vision defects, can be summarized as follows:

- Congenital color deficiency is caused by inherited photopigment abnormalities. One, two, or all three photopigments may be present or absent. When they are all present, they may exist in normal proportions (resulting in normal color vision), or they may exist in abnormal proportions (resulting in ***anomalous trichromatic color vision***). This information is summarized in the table below.

Table 8.1 Classification of Congenital Color Deficiency

No. of Photopigs.	Type	Denomination	Hue Discrimination
None	Monochromat	Typical (Rod) Monochromat	Absent
One	Monochromat	Typical (cone) Monochromat	Absent
Two	Dichromat	Protanope Deuteranope **or** Tritanope	Severely impaired
Three	Anomalous Trichromat	Protanomalous Deuteranomalous **or** Tritanomalous	Continuous range of severity from mildly to severely impaired
Three	Normal trichromat	Normal Trichromat	Optimum

The anomalous trichromat also uses three colors to match all spectral hues, but the ratio of mixing of these colors is different from that of a normal.

The classification of protan (red-defective), deutan (green defective), and tritan (blue defective) - meaning first, second, and third) in Greek, also hold for ***dichromatism***.
Except that while in anomalous trichromatism, the protan defective is ***Protanomalous***, in dichromatism, the protan defective is a ***Protanope***.
In dichromatism, all spectral hues are matched using only two color variables.
Very severe dichromats confuse even colors which are very bright. For example, severe red-green dichromats confuse bright reds with bright greens, whereas mild red-green dichromats only confuse dark (desaturated) colors.

Monochromats are able to match all spectral hues with just one color. Differentiation of different hues is by shades of brightness only. There are two types of monochromatism:

Rod Monochromatism

Rod monochromats have no functioning cone receptors and typically have very poor visual acuity, in the range between 6/36 and 6/60. Photophobia and nystagmus are usually present.

Cone Monochromatism

This type of monochromatism is very rare. Cone monochromats have only one type of cone receptor, usually the blue-sensitive cones. Visual acuity is in the range between 6/9 and 6/24, but only in those cases where the V.A. is less than 6/18 would one find photophobia and nystagmus.

Incidence and Inheritance of Congenital Color Vision Defects

Large-scale surveys using modern screening techniques have shown that the incidence of red-green color deficiency is about 8% in men and 0.4% to 0.5% in women. Therefore, one in 12 males, and 1 in 200 females, has one form or another of defective color vision.

Actually, the reported prevalence of congenital color defects is 8% for Caucasian men, 5%for Asian and African men (Nathans J., Neuron 1999;24:299-312)

The consensus is that the incidence of congenital color vision defects does not vary significantly between different ethnic groups, and between people resident in different geographical locations.

Red-Green Defects

X-linked diseases are transmitted from mother to son, because a defective gene from mum is all the male child has to work with. A defective gene from mum (or dad) inherited by the female, can be 'switched off' if the gene on the other X chromosome is normal. The female thus, does not have the defect/disease but is a ***carrier*** (of the disease). **This sort of inheritance is referred to as an X-linked recessive inheritance.**

There are cases though, where, with one normal and one defective gene in the female offspring, it is the normal gene which is 'switched off'. This sort of inheritance is referred to as an **X-linked dominant inheritance**, and in this case, the female actually has the defect/disease.

Congenital defective red-green color vision is a typical example of an X-linked recessive inherited defect.

Tritan Defects

The inheritance of tritan defects is autosomal dominant. In autosomal dominant traits (as in X-linked dominant traits) males and females are affected equally. However, in autosomal traits, there is a variable genotype expression so that some family members may display, for example, a tritanopic trait, while others may be tritanomalous trichromats.

Congenital tritan incidence is not greater than 1 in 10,000 or 0.0001.

Typical rod monochromatism is an autosomal recessive condition, the prevalence of which is estimated at about 0.003 for both men and women.

Lecture 9

Tests for Defective Color Vision

Test Designs

Color vision tests are used clinically to identify and differentiate congenital and acquired color deficiencies, and to select personnel for occupations which require good color vision.

Clinical color vision tests exploit color confusions and abnormal wavelength discrimination.

Different tests are used for different functions. The two basic functions are ***Screening*** and ***Grading***. Screening tests diagnose the type of color deficiency and Grading tests assess the severity of the deficiency.

There are four test designs in use today:

Pseudoisochromatic (PIC) Plates These exploit colors that lie on or close to pseudoisochromatic lines of particular color defects. Colors on these lines a regularly confused by an observer who has a particular color defect.

The tests plates use a random arrangement of dots as a background, and within this background, and using a pseudoisochromatic color (i.e. pseudoisochromatic with the background color) a figure is presented. Such a figure is seen by a normal but not by a color defective. There are other designs based on the same principle

Hue Discrimination Tests Basically, after showing the patient an example, he is expected to arrange the colors provided for him in the appropriate sequence. These tests requires more complex color discrimination than with the PIC plates.

Color Matching Tests These require matching of test colors with 'standard' colors provided.

Lantern Tests These involve naming of colors presented to the subject.

Note 1. The sensitivity of a test refers to the proportion of color deficient people correctly identified.

2. The specificity of a test refers to the number of color normals correctly identified.

High values for both these parameters indicate an efficient test.

Congenital tritan defects are rare, therefore most color vision tests are designed to detect red-green color deficiencies only.

PSEUDOISOCHROMATIC PLATES

Design

These plates use the principle of color camouflage. As was mentioned earlier, the background is made up of random dots, and then the figure – printed in an isochromatic color – is printed within the background. The fact that the figure is made up of dots breaks up its outline and thus conceals its shape. Another important point is that the colors of the figure have to be isoluminant (have the same brightness) with the background. This is necessary so that the observer does not differentiate the figure based on brightness cues alone.

Vanishing designs are the easiest to construct, and in this design, a figure is concealed within the background and is unseen to a particular type of color deficient, while it is easily seen by a normal trichromat. A negative response to such plates should arouse a suspicion of a color defect.

In ***transformation*** designs, the first design principle is that the situation above is reversed and the figure is visible to only a person with a particular type of color defect. To actual call a design a transformation design, the figure visible to only the color-defective is superimposed on a vanishing design. When this is done, the color-defective sees one number (e.g. 78), while the normal trichromat sees another number (e.g. 73).

Such a positive response (in addition to the negative Vanishing design response) is confirmation that the subject does have a particular type of color defect.

There is no doubt that in selecting the colors for PIC plates, extreme care must be taken. First, the colors must be chosen so that they lie along the color-confusion lines of one type of dichromatism. Next, the distance between the colors on these lines must be far enough so that normal trichromats are not confused, but close enough so that mild dichromats in that category, are detected.

PIC tests used to grade the severity of color vision defects work by using colors that are separated by different distances along the color-confusion lines, to grade the severity of the color vision defect. The closer the colors of correctly identified figures (with their background colors), the milder the color vision defect of the observer.

Classification designs to distinguish between protan and deutan defects make use of neutral colors (colors confused with grey). For tritan defects, the color-fusion line intersects with greys and yellows. However, because it is difficult to get the correct luminance contrast relationships between greys and yellows, neutral colors in the violet part of the spectrum are used against greys.

Finally PIC tests require minimum levels of visual acuity to be reliable. Some of these acuities are as follows:

Bostrum-Kugelberg ---------- ***6/9***
Tokyo Medical College ---------- ***6/12***
Ishihara ---------- ***6/18***
Hardy, Rand, Rittler ---------- ***6/60***

Administration of Ishihara Plates

- ✓ Tests plates are held by the examiner at two-thirds of a meter (arm's length) away from the subject.
- ✓ An introductory plate is usually included with PIC tests. A correct response to this plate indicates that the subject possesses sufficient acuity for the test, and is not malingering (pretending).
- ✓ Maximum allowed viewing time is 4 seconds. The examiner should change the figure after that period.
- ✓ Some PIC tests do not use figures or numbers, but ***pathways*** which can be traced by children or none verbal patients
- ✓ PIC patterns have been used in computer displays to test for color deficiency. These tests are good at isolating isochromatic zones but they cannot distinguish between dichromats, and anomalous trichromats.

HUE DISCRIMINATION TESTS

Design

These are grading tests which identify moderate and severe color deficiency and classify protan, deutan, and tritan defects.

These tests are unsuitable for young children and educationally disadvantaged groups.

These tests are particularly useful for acquired defects which can easily be monitored.

The most widely used tests in this category are the dichotomous (D15) test, and the Farnsworth-Munsell 100 hue test. Both these tests contain colors selected from the complete hue circle.

Individual colors in both tests, are contained in a circular cap subtending 1.5^0 at a test distance of 50 cm.

The Farnsworth-Munsell test is the more detailed test having 85 colors to be arranged in order instead of 15 in the D15 tests.

The FM-100 hue test is presented in four separate boxes. The second box colors (for example) are arranged only after the first box has been completed. Whereas with the D15 test it is easy to identify color defects because opposite hues on the isochromatic lines are arranged side by side, the same is not possible for the FM-100 hue test, because opposite hues are not presented at the same time in this test.

Two shortened tests have been developed from the FM-100 hue test – the 28 hue test and the 40 hue test). Each of these tests like the D15 can identify particular color defects because all the test caps are presented together and isochromatic lines can be delineated. However the reliability of both these tests is unknown because neither has gained widespread use.

Administration of Hue Discrimination Tests

To start, all the colors are brought out of the box and arranged randomly on the table. For the 100-Hue test, one box is emptied at a time, in rank order, starting from box 1, or from box 4.

The patient is then asked to replace the caps in what he perceives to be the natural other using the fixed cap/s in the box, as start (and end, in the case where there are two fixed caps) points.

In the F-M 100 Hue test, the ***error score*** for each cap is calculated and plot on a polar diagram such as that depicted in figure 8.1. Some color vision clinics use computer programs to assist this process.

In scoring this test, we have the ***plotted value*** (which is the sum of the numerical difference between the preceding cap and the test cap, and between the subsequent cap and the test cap), and the ***Error Score*** (basically it is the plotted value minus 2. Why 2? Because 2 is the baseline value on the polar diagram).

The plotted value is actually what is plot against a number on the polar diagram. As we see in the illustration below, you write out the correct sequence of caps from 1 to 85, and then you strike out numbers in this sequence and place the actual numbers that the patient placed.

Example

Correct sequence of numbers ***7 8 9 10 11 12 13 14***

Actual (patient) sequence ***7 11 8 9 13 10 12 14***

Let us take the test cap no. 9 in the correct sequence. Here, 8 comes before 9 (the preceding cap), and 10 comes after 9 (the subsequent cap). The difference between 8 and 9 is 1, and the difference between 9 and 10 is also one.

So in this situation, the plotted value for cap no. 9 is 2, and the error score is 2 – 2 = 0.
We should then understand that if all the caps are arranged in the correct sequence, the plotted value for each test cap will always be two, and the error score for each test cap will always be zero.

Let us take cap no. 13 in the actual (patient) sequence. Nine comes before 13, and 10 comes after. The plotted score for cap no. 13 is therefore (13 – 9 =) 4 + (13 – 10 =) 3 =7
The error score for cap no. 13 is thus, 7 – 2 = 5.

The individual error scores are added to get the total error score.

Recording for the D-15 test is much simpler. As depicted in figure 9.1, 15 dots representing the 15 test caps are arranged (sequentially) in a circular pattern. These dots are then connected by lines (drawn by the examiner's hand) in the other in which they were placed by the patient.

Usually on the same recording sheet are dotted lines which depict the common confusion lines of protans, deutans, and tritans.

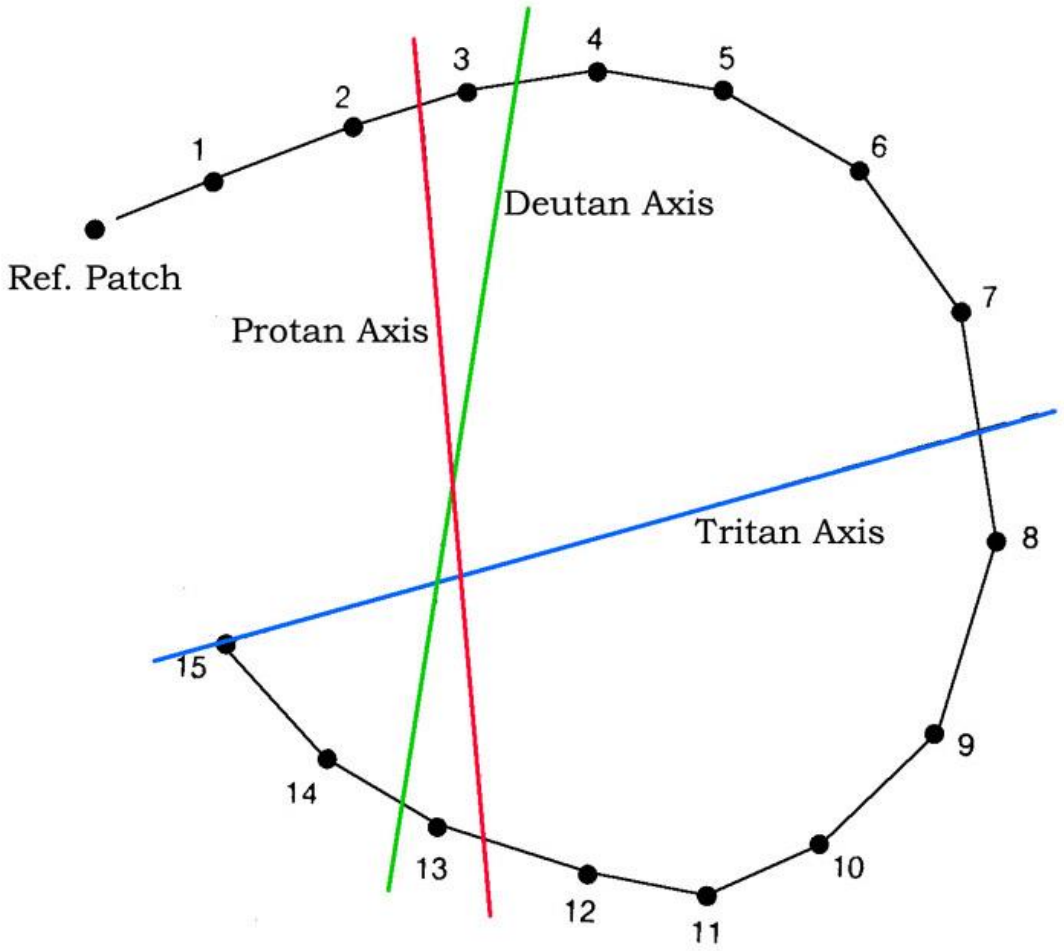

Figure 9.1 D15 Recording Sheet. A Tritan subject (for example) will have a line approximately parallel to the blue line in the figure
http://www.google.com.sa/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&docid=F06tI5WBaPxGEM&tbnid=E-v4QvvmEMgBhM:&ved=0CAUQjRw&url=http%3A%2F%2Fpsych.ucalgary.ca%2FPACE%2FVA-Lab%2Fcolourperceptionweb%2Fcongenital.htm&ei=Xmt6Uq63GIqx0AXds4CQDw&psig=AFQjCNF7xPn_m-fxYiIPYYvo0ZhwL78Ijg&ust=1383840983307096

ANOMALOSCOPES

Design

Spectral anomaloscopes have been designed for the diagnoses of different types of congenital color deficiency. They are psychophysical tests which present one or two diagnostic color matches.

The two color matches presented are: ***The Rayleigh match*** where red is mixed with green to produce yellow; and more rarely.

In most anomaloscopes, the two-sides matching field subtends an angle in the eye of about 2^0 (fovea angular subtense is 5^0) to ensure that only the foveal cones are stimulated, and, at a region where the macular pigment is uniform.

The characteristics of a Rayleigh match determine whether a person has normal or defective color vision; whether the patient is a dichromat or anomalous trichromat; and whether the patient is a protan or a deutan.

Several different wavelengths can be can be used to get a successful Rayleigh match, but the best results are usually obtained when the matching wavelengths are widely separated on the straight line locus of the CIE (Committee Internationale de L'Eclairage) chromaticity diagram.

The wavelengths for a blue-green match have to be chosen more carefully selected so to eliminate the effect of the normal variation of macula pigment density. It is also important to note that there is no straight line in the blue-green section of the spectral locus, therefore a desaturation wavelength needs to be added to the blue-green test field to get a perfect match. Therefore the matching procedure is much less complicated for the Rayleigh match than for the Engelking-Trendelenberg match.