* Learning Objectives:
1. State which three color sensitive receptors are present in the human eye
2. Explain the differences between congenital & acquired color vision defects
3. List at least two primary color vision tests used in most eye clinics

* Color Vision – Anatomy & Physiology
1. Retinal layers
2. Photoreceptors
   1. Rods
   2. Cones
3. Chemical secretion translates to electrical conduction
   1. Rhodopsin
   2. Iodopsin

Photoreceptors: Rods & Cones

RODS:
- Don’t see color!
- Good for seeing MOVEMENT
- Good for NIGHT VISION

CONES:
- See COLORS!
- Work best w/LOTS OF LIGHT
- Provide us SHARP, CLEAR vision (20/20)

RETINAL LAYERS

- Color vision starts with the retina
- There are 10 layers to the retina, but the one we are most interested in is the...

PHOTORECEPTOR LAYER

RETINAL LAYERS (cont.)
Photoreceptors: Rods & Cones (cont.)

- The PHOTORECEPTOR LAYER has the Rods & Cones
- Rods are for ‘night-vision'; only see mono-chromatically (i.e., kind of like B&W television); 20/400 vision
- **Cones** are for **COLOR** VISION! Need lots of light to

The Electromagnetic spectrum & what the eye can see:
- The **visible spectrum** is the portion of the electromagnetic spectrum **visible** to the human eye.
- Electromagnetic **radiation** in this range of wavelengths is called **visible light**, or simply light.
- A typical human eye will respond to **wavelengths** from about 400 nm to 700 nm.

Photoreceptors: Rods & Cones (cont.)

- People w/normal color vision can differentiate **150** wavelengths of colors.
  - **Green-blind** - able to distinguish around **27** wavelengths.
  - **Red-blind** - can see around **17** different wavelengths.
  - **Blue-blind** - distinguish even **LESS** than red or green blind folks!

Chemical secretion translates to electrical conduction

1. **RODS** (90% of receptors) = secrete **Rhodopsin**
2. **Cones** (10% of receptors) = secrete **Iodopsin**
3. Light is **ENERGY**!
4. When light ‘strikes’ a ROD or CONE, that receptor secretes a chemical that triggers an electrical impulse that goes to the brain. (Remember: **Only Cones ‘detect’ color**!)
5. If the RED, GREEN, and BLUE ‘sensitive’ cones are stimulated **EQUALLY**, the brain sees **WHITE LIGHT**

To put it another way, **WHITE LIGHT** has all the **colors** of the “visible spectrum” in it!
Chemical secretion translates to electrical conduction (cont.)
• 62% of your CONES are ‘sensitive’ to the red wavelengths of light
• 31% of your CONES are ‘sensitive’ to the green wavelengths of light
• 7% of your CONES are ‘sensitive’ to the blue wavelengths of light

* Color Blind VS. Color “Deficient”
1. 1 in 100,000 are truly color “blind” (monochromatic; also called achromatopsia)
2. Most people are color “deficient”
   1. Anomalous = cone is defective but present & kind of works
   2. Anopia/Anopsia = cone is absent (doesn’t work @ all)
3. Men & Women = Different from birth (CONGENITAL)
   1. 8% of men are color deficient (1 in 12)
   2. 0.5% of women are color deficient (1 in 200)

1 in 100,000 truly Color “Blind”
When someone tells you they are “color blind” what they probably mean is they are...
   “Color deficient”
• What’s the difference?
  – Color BLIND means they can’t discriminate any difference in colors (they see in “one” color only, meaning they have ‘achromatopsia’; also called ‘monochromacy’)
  – Color DEFICIENT is much more common & means they have trouble with a PARTICULAR COLOR but can generally tell one color from another

Most people are Color “Deficient”
Achromatopsia (Monochromacy) - See no colors at all (visual world is just variations of black/white/gray) = 1 in 100,000!

Most people are Color “Deficient” (cont.)
There are three main types of color vision deficiency: protan-, deutan-, and tritan- defects.
– Anomalous = means person can see that color, but not in the ‘right’ way (i.e., they don’t see it the same as everyone else.)
– Anomalous Trichromats are not “normal” trichromats; one of their color receptors isn’t working quite right
– Anopia or Anopsia = person can’t see that color at all. They are “missing” the CONE that is sensitive to that particular color.
– These people are technically Dichromats (i.e., can only use TWO color receptors)
Most people are Color “Deficient” (cont.)

* Severity of color deficiency/blindness divided into four categories:
* The terms protan, deutan, and tritan are Greek & translate to first, second, & third. Think of it this way:
  – Pro = RED (also called “L” cone)
  – Deu = GREEN (also called “M” cone); Deuteranomaly = the most common form of color deficiency.
  – Tri = BLUE (also called “S” cone); Blue color deficiency is not a sex linked trait; this means both men & women are equally affected.

More appropriate terms for color issues would be:

• Protanopia = Red-blindness; affects 1% of males
• Protanomaly = Red-weakness (deficiency); affects 1% of males
• Deuteranopia = Green-blindness; affects 1% of males
• Deuteranomaly = Green-weakness (deficiency); affects 5% of males

* COLOR VISION TESTS

1. Pseudoisochromatic Plates (PIP) - HRR or Ishihara type
2. Farnsworth D-15 Dichotomous Color Blindness Test
3. The Oculus Heidelberg Multi-Color (HMC) Anomaloscope

---

Men & Women – We are different!

CONGENITAL COLOR VISION ISSUES
(Born that way):

• 8% of men (XY)
• 0.5% of women (XX)
  – If a woman is red-green color deficient, all her sons will also be color deficient
  – A father can’t pass his red-green color defect on to his sons.

Men & Women – We are different! (cont.)

• Color blindness is more prevalent among males than females, because the most common form of color vision deficiency is encoded on the “X” sex chromosome
• Boys only have one “X” chromosome, so if it’s defective…
• Girls have TWO “X” chromosomes, so BOTH would have to be defective for them to have color vision issues
• 99% of color deficiencies are of the “Red-Green” type
• 1% of color deficiencies are of the “Blue-yellow” type (tritanopia). Tritanopia is linked to the chromosome pair 7 and is therefore sex independent
  – That means BOYS and GIRLS have equal chances of having a TRITAN (blue, or “S” cone) color vision problem

Tritanopia (Blue-blindness & Tritanomaly (Blue-weakness, or deficiency) are extremely RARE!
• Affects males (XY) & females (XX) EQUALLY
Pseudoisochromatic Plates (PIP)

1. First introduced by Jakob Stilling, a Professor of Ophthalmology @ University of Strasbourg (Germany), around 1883.

2. As a general rule, the PIP tests only look for RED & GREEN color vision issues (which covers 99% of people!)

3. Newer (24 plate versions) claim to check for BLUE, too.

4. To a color-deficient person, all the dots in a plate will appear similar or the same—"isochromatic".

5. To a person w/normal color vision, some of the dots will appear different enough to form a distinct pattern (a number, a character, or a line) — "pseudoisochromatic".

6. 70cm = test distance (27.5” away).

7. Patient gets 5 seconds per plate to answer.

THINGS TO KEEP IN MIND:

- Test should be done by a window (no tint!) so “natural” sunlight is the illumination source. If you don’t have that option, you can use:
  - Macbeth Easel lamp (no longer made)
  - True Daylight illumination lamp (google it!)

- Wear Gloves! Have patient Wear Gloves!
  - Don’t touch the plates (or let the patient touch the plates) with “bare” hands
  - Oils in skin will change the ‘colors’ over time
  - Patient wears whatever corrective eyewear is needed (UNLESS GLASSES HAVE TINT or “blue blocking” features!) Needs to see 20/100 or better
  - Pt gets 5 SECONDS to respond (per plate)
  - Read the instructions for YOUR color vision test!

- Most common “older” version of PIP test was a booklet with 15 plates.
  1. First image in the booklet is the “DEMO” plate (#16 in orange on green background).
  2. Find malingerers! (That’s what the DEMO plate is about; EVERYONE can see it.)
  3. Then there are 14 actual “TEST” plates
    a. Get 10 (or more) correct? YOU PASSED!
    b. Miss 5 (or more)? YOU FAILED.

HRR Color Test = Hardy Rand & Rittler

- Composed of 24 pseudoisochromatic plates
  - First 4 plates show the patient how the test works
    • The fourth plate has no figure on purpose; is patient malingering?
  - Next 6 plates (screening series) present the most difficult protan, deutan and tritan) targets.
    • Success w/these plates means ‘normal color vision’ & completes the test.
  - Remaining 14 plates are “diagnostic”
    • Give you information on EXTENT of color defect (mild, medium or strong) & TYPE of defect (Protan, Deutan, Tritan).
**Pseudoisochromatic Plates (PIP) – cont.**

Ishihara Color Vision Test = Dr. Shinobu Ishihara of Japan

- Produced three different test ‘sets’ in the early 1900s (pseudoisochromatic plates)
- Full test consists of 38 plates; there are also ‘versions’ w/10, 14, or 24 test plates

**Modern 24 Plate versions:** Screens adults & kids for “all” color vision defects (Red, Green, & Blue);

- Adults (17 plates w/numbers on them)
  - 14 plates screen for red/green deficiencies
  - 1 plate estimates type & degree of red/green deficiency
  - 2 plates screen for blue/yellow (tritan) deficiencies
- Pediatric (7 plates w/symbols on them)
  - 6 plates screen for red/green deficiencies
  - 1 plate screens for blue/yellow (tritan) deficiencies

---

**Farnsworth D-15 Color Blindness Test**

- Test introduced about 1947; tests for RED (protan), GREEN (deutan), and BLUE (tritan)
- Has 15 “free to move” different colored discs & one “fixed in place” blue colored disc
  - Patient uses the “fixed blue disc” as a starting point...
  - Must put other discs in the correct order by finding which disc matches closest, then the next closest match, and so on until all the discs are in correct order
  - Score sheet: pattern formed tells you what color vision defect the patient has (if any)
Farnsworth D-15 Color Blindness Test (cont.)

Things to keep in mind:
- Actual sunlight or “True Daylight Illumination” lamp for testing
- Patient wears GLOVES! (oils = bad)
- If patient wears glasses, have them wear them for the test (unless they are tinted or 'blue blocking')

The Oculus Heidelberg Multi-Color (HMC) Anomaloscope (cont.)

The test is hard to describe, but this website will give you an idea of how it works:

Other color vision tests?

Farnsworth-Munsell 100 Hue Color Vision Test
- 88 colored discs (like the D-15)
- Four batches of 22 mixed colored discs
  - Arrange each “batch” of discs in the correct order
  - Overall “error score” rates severity of color vision defect
  - Possible to compute the ‘main confusion axis’; that tells you the color vision defect TYPE; pro-, deu-, or tri-
Other color vision tests? (cont.)

The Farnsworth Lantern (FALANT) Test; (like Optec 900)

- Looks like a “lantern”; shows two lights at a time (options are RED, GREEN, or WHITE); 9 different ‘tests’ shown; if no errors on first run of 9, patient passes. If a single error, pt repeats test twice more; can’t miss any on those runs
- Used by the U.S. military on fliers; only checks for RED & GREEN defects

Cambridge Color Test

- Similar to PIP plate concept, except displayed on a computer
- Goal is to identify “C” shape, which is a different color from background
- The “C” is presented randomly, in one of four orientations (opening is: up, down, backward, or forward)
- Pt presses a key that corresponds to the direction the opening of the “C” is pointing on the screen. (Color defective? Can’t tell!)

Sources of ACQUIRED color vision defects

ACQUIRED color vision problems can be caused by:
- Aging (hello cataracts!)
- Disease (diabetes, glaucoma, macular degeneration, Alzheimer’s, Parkinson’s, multiple sclerosis [MS], chronic alcoholism, leukemia, & sickle cell anemia)
- Injury to the eye or brain
- Optic nerve problems (optic neuritis)
- Side effects of some medications (especially those for: heart problems, high blood pressure, infections, nervous disorders, & psychological problems)
- Heavy metal overexposure (lead or mercury)
- Chemical Exposure (fertilizers & styrene, have been known to cause loss of color vision)

Test Binocularly or Monocularly?

- If checking for CONGENITAL color vision problems, you can check patient BINOCULARLY (i.e., pt uses both eyes @ the same time.)
- If checking for ACQUIRED color vision problems, check patient MONOCULARLY (i.e., patch an eye & only test one at a time.)
- If in doubt? – MONOCULARLY (each eye by itself)