DH2323 DGI18

# COMPUTER GRAPHICS AND INTERACTION

# COLOR PERCEPTION

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# Literature

- **Goldstein, E. (2009). Sensation and Perception.**
- Chapter 9 (Edns. 8 and 9): *Perceiving Color*

- **Weinschenk, S.M. (2011). 100 Things Every Designer Needs to Know About People.**
- Chapter 10: *Red and blue together are hard on the eyes*
- Chapter 12: *The meanings of colors vary by culture*

# Overview

- Introduction to color
  - Functions of color and how we perceive it
- Theories of color vision
  - Trichromatic and opponent-process theories of color vision
- Color in the cortex
  - Color-related processes that occur in the visual areas of the brain
- Color and Light Constancy
  - Perceptual stability during environmental changes

# Hungry? Find the berries...

Bruce Goldstein

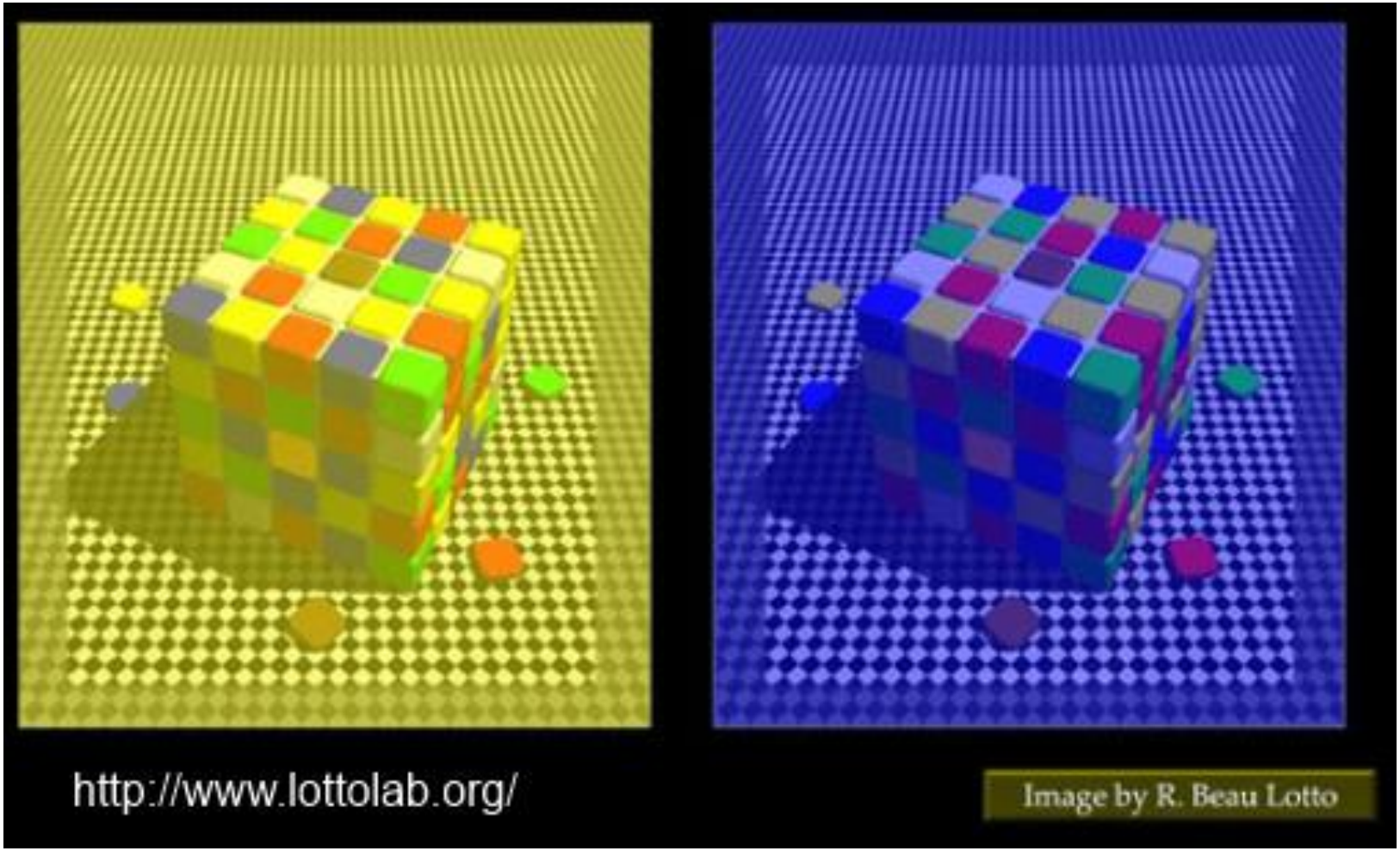
# Hungry? Find the berries...

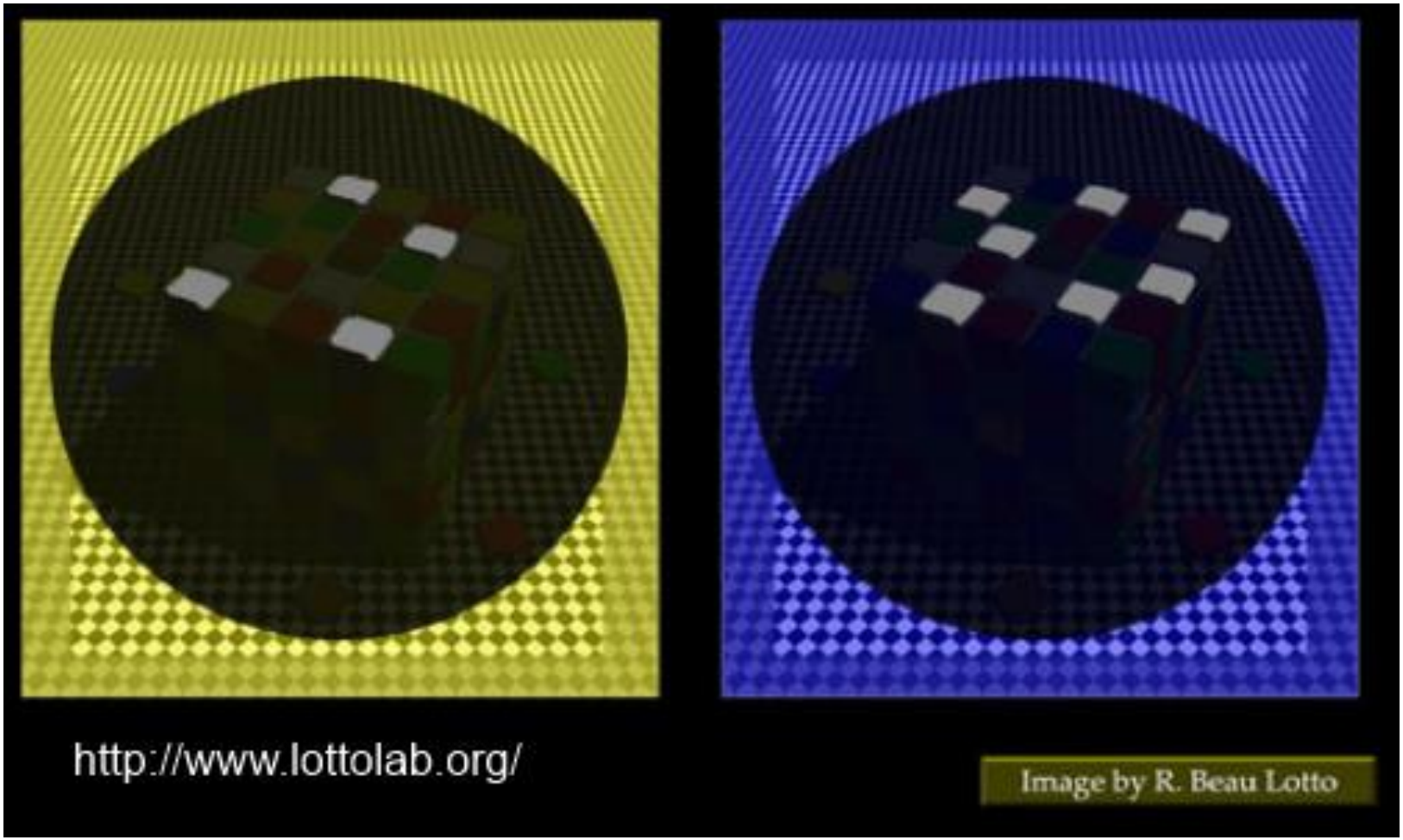
Bruce Goldstein

# Hungry? Find the berries...

# From berries to Van Eyck

•*Arnolfini Portrait*,
•Jan Van Eyck, 1434


http://www.lottolab.org/
Image by R. Beau Lotto


http://www.lottolab.org/
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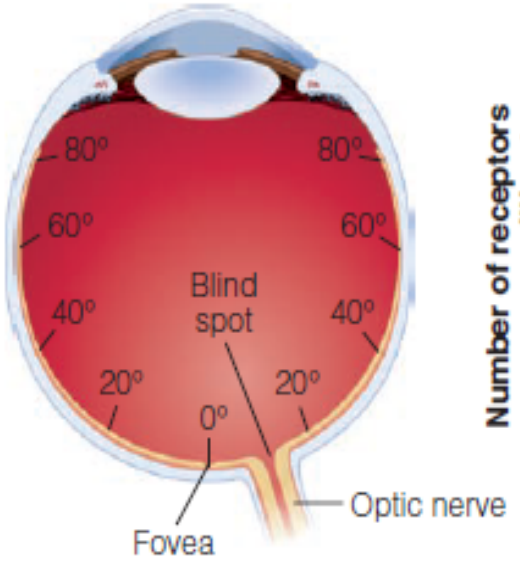
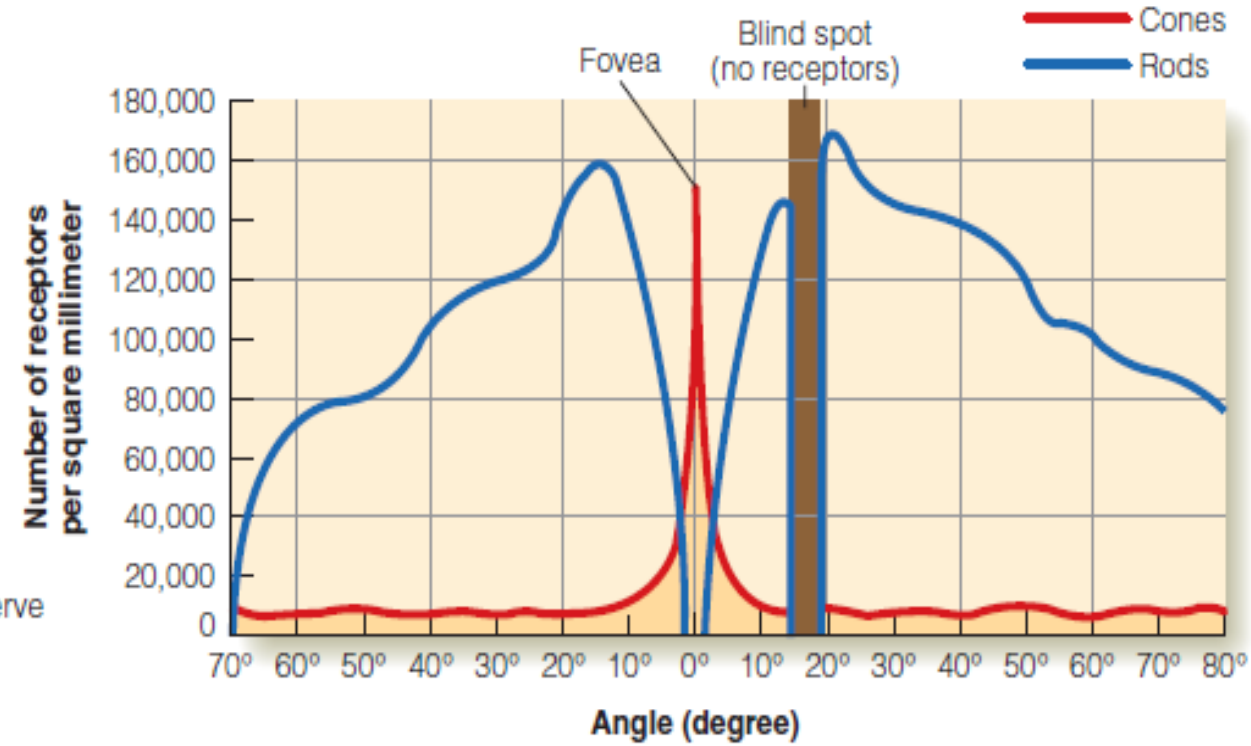
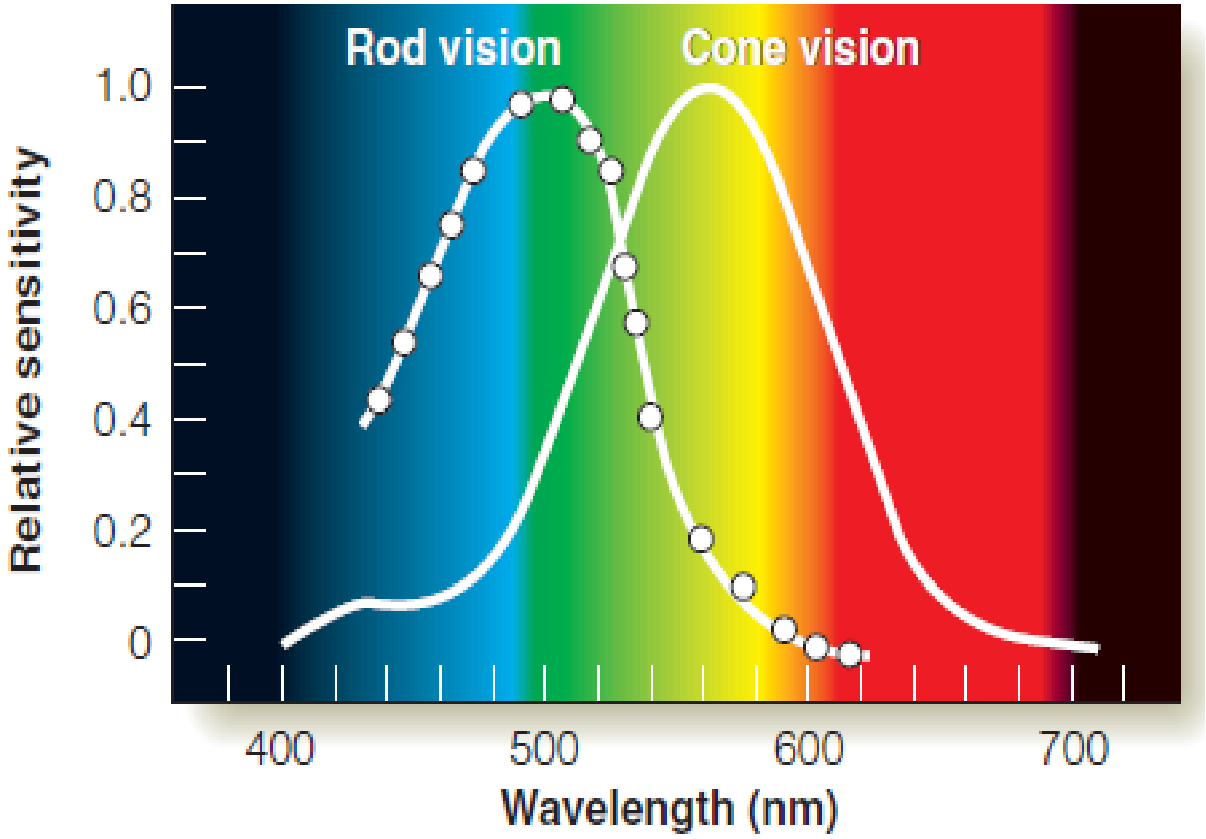
# Pigments


80°
80°
60°
60°
40°
40°
20°
20°
0°
Blind spot
Optic nerve
Fovea


Cones
Rods
Fovea
Blind spot (no receptors)
Number of receptors per square millimeter
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
70° 60° 50° 40° 30° 20° 10° 0° 10° 20° 30° 40° 50° 60° 70° 80°
Angle (degree)

# Wavelengths



# Wavelengths

- Reflectance curves
- for surfaces

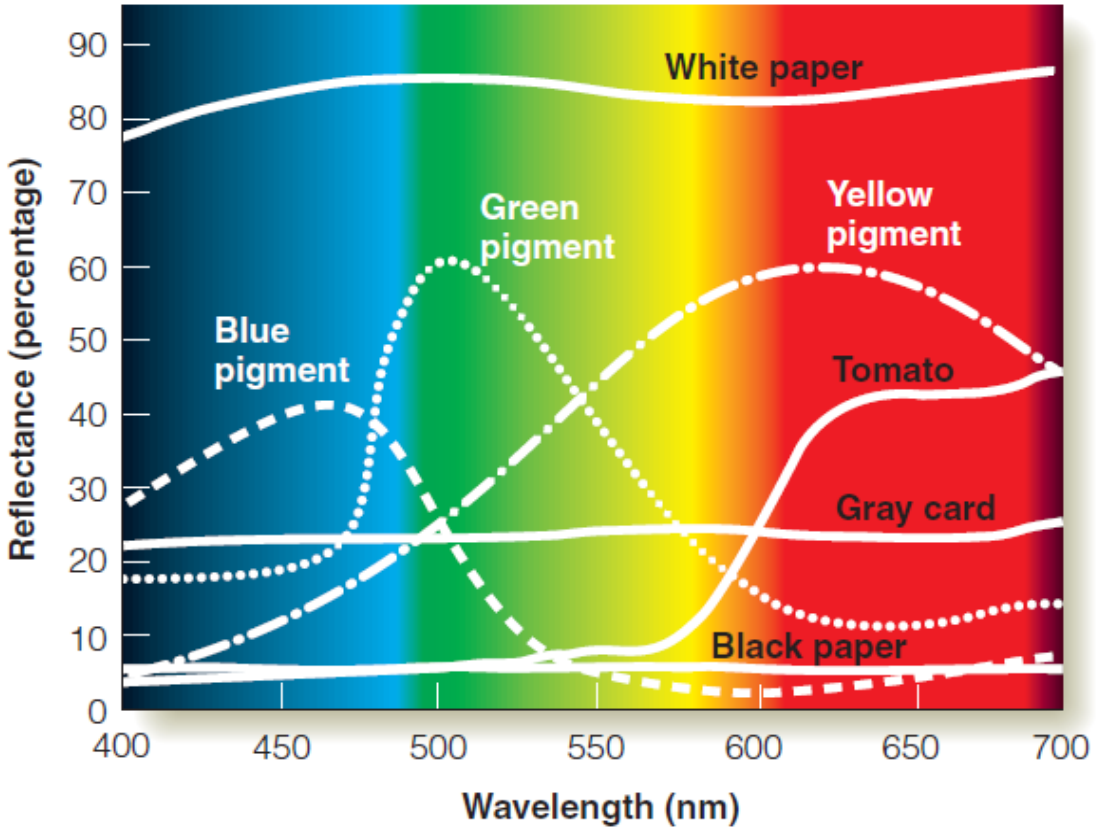
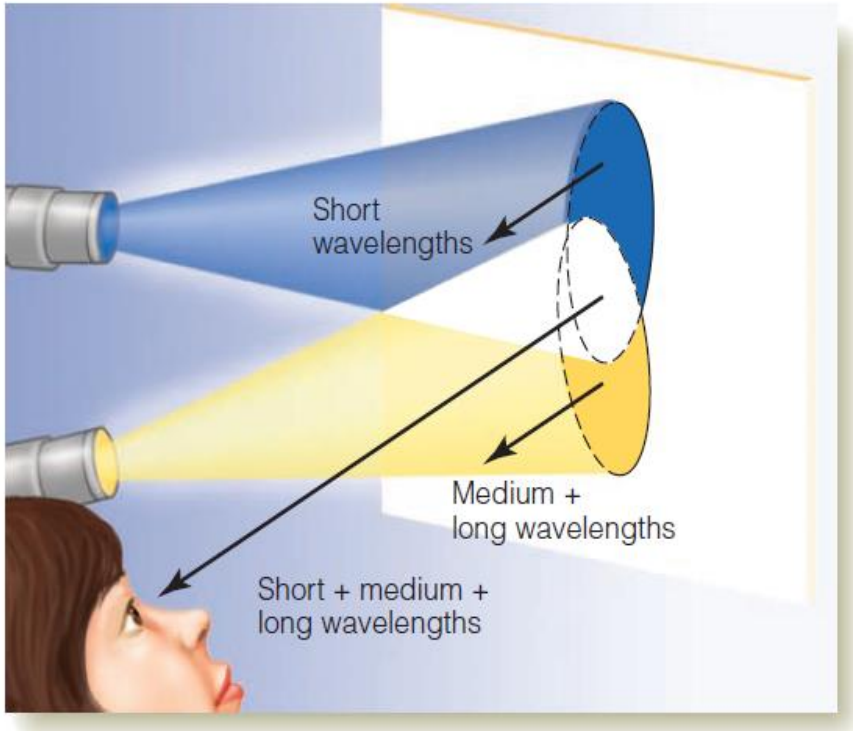



**TABLE 9.1** Relationship Between Predominant Wavelengths Reflected and Color Perceived

| WAVELENGTHS REFLECTED | PERCEIVED COLOR |
|---|---|
| Short | Blue |
| Medium | Green |
| Long | Red |
| Long and medium | Yellow |
| Long, medium, and short | White |

# Color Mixing: Lights (additive)

•More colors => lighter => towards white



# Color Mixing: Lights (additive)

•More colors => lighter => towards white

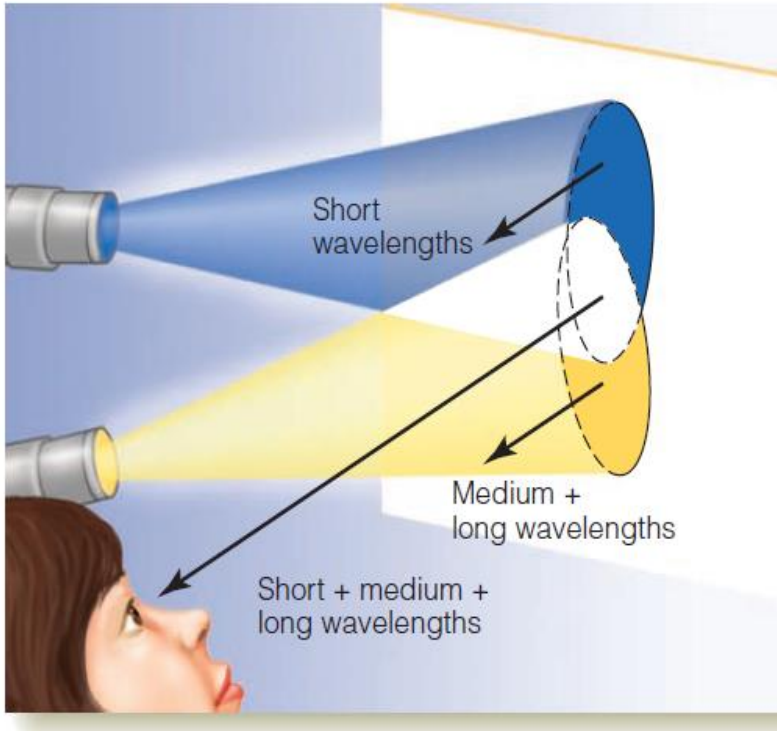


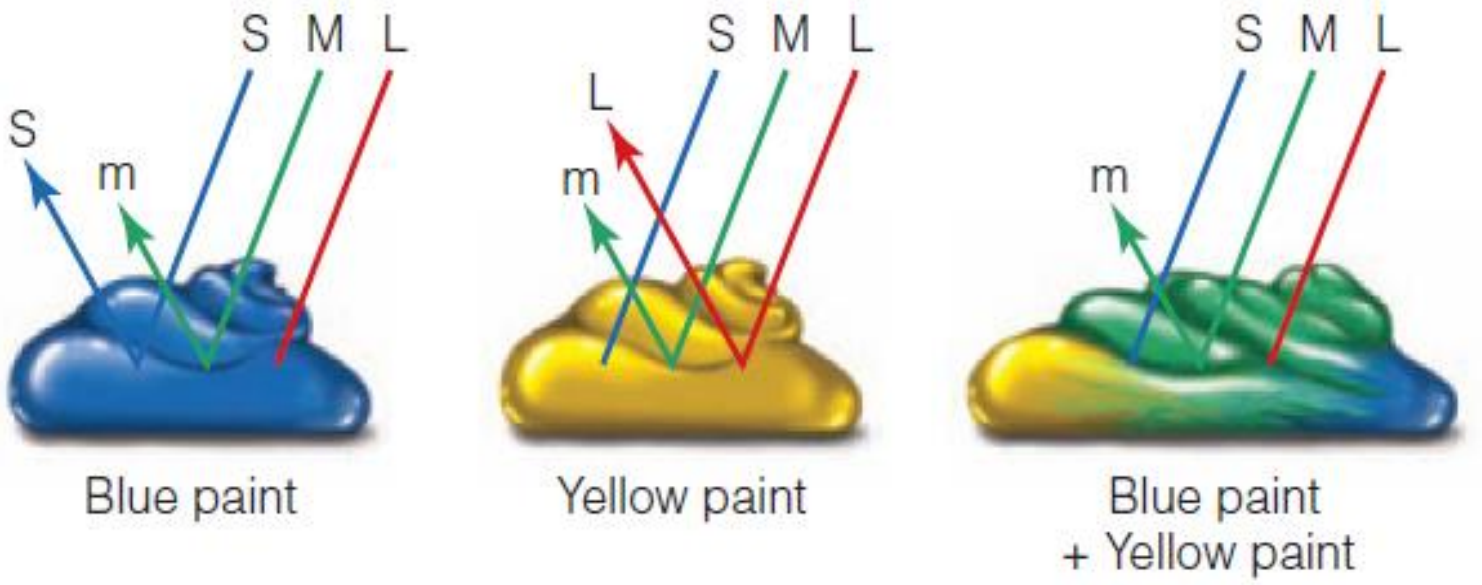

**TABLE 9.2** **Mixing Blue and Yellow Lights (Additive Color Mixture)**

Parts of the spectrum that are reflected from a white surface for blue and yellow spots of light projected onto the surface. Wavelengths that are reflected are highlighted.

| | WAVELENGTHS | | |
|---|---|---|---|
| | SHORT | MEDIUM | LONG |
| Spot of blue light | Reflected | No Reflection | No Reflection |
| Spot of yellow light | No Reflection | Reflected | Reflected |
| Overlapping blue and yellow spots | Reflected | Reflected | Reflected |

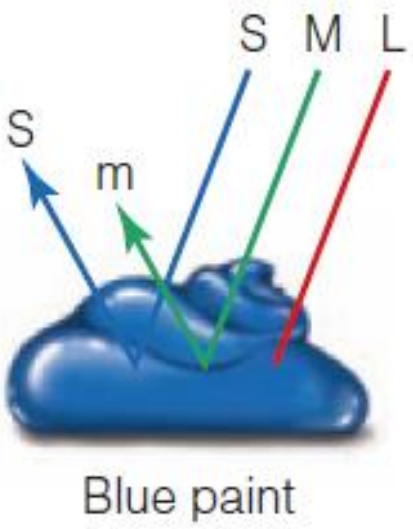
# Color Mixing: Paints (subtractive)

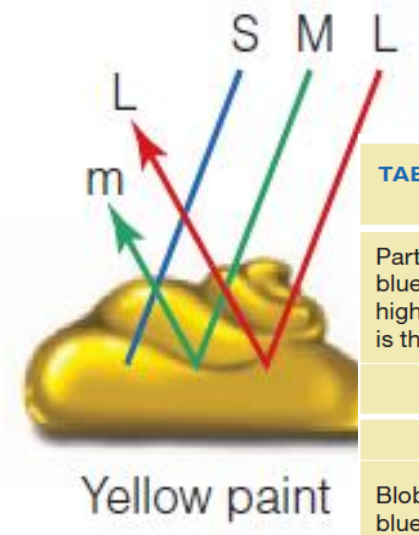
•More colors => darker => towards black



# Color Mixing: Paints (subtractive)

•More colors => darker => towards black




S M L

**TABLE 9.3** **Mixing Blue and Yellow Paints (Subtractive Color Mixture)**

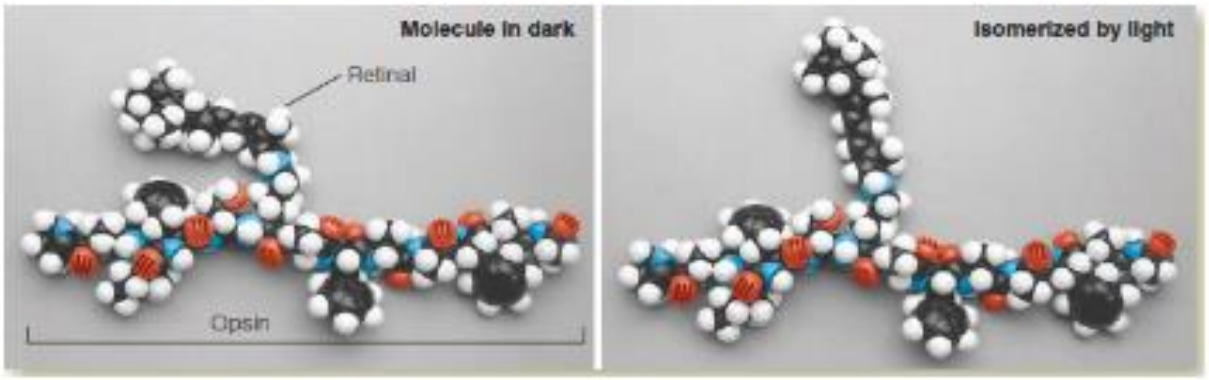
Parts of the spectrum that are absorbed and reflected by blue and yellow paint. Wavelengths that are reflected are highlighted for each paint. Light that is usually seen as green is the only light that is reflected in common by both paints.

| | WAVELENGTHS | | |
|---|---|---|---|
| | SHORT | MEDIUM | LONG |
| Blob of blue paint | Reflects all | Reflects some | Absorbs all |
| Blob of yellow paint | Absorbs all | Reflects some | Reflects some |
| Mixture of blue and yellow blobs | Absorbs all | Reflects some | Absorbs all |

# Remember: Wavelengths don't have color!

## Introduction to vision - Transforming light onto electricity

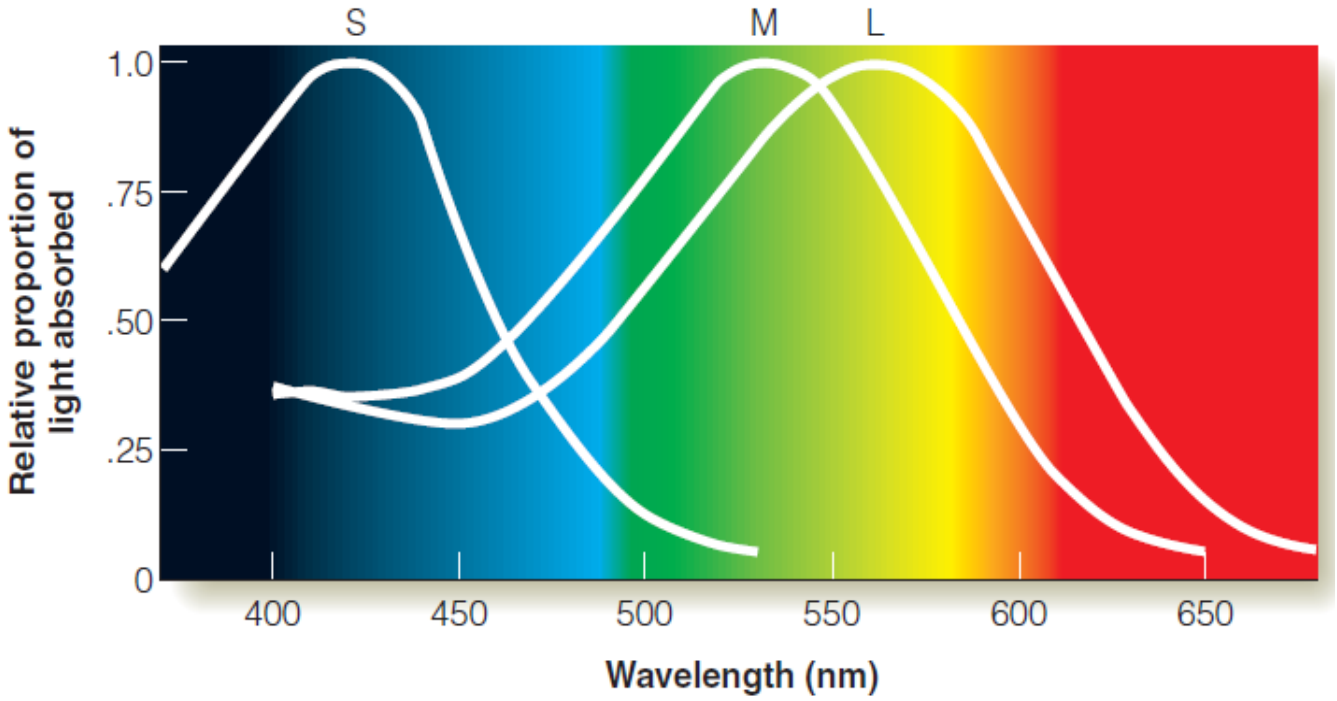
- Retinal is the part of the visual pigment that is sensitive to light
- Isomerization -> activation of the entire receptor



# Trichromatic theory of color vision

- Thomas Young (1773-1829) and Hermann Von Helmholtz (1821-1894)
  - Psychophysical color-matching experiments
- Light's wavelength signalled by activity of *three* receptor mechanisms
  - Physiological evidence (1960's)
  - Cone pigments: (S)hort-, (M)iddle- and (L)ong-wavelengths

# Trichromatic theory of color vision




(S)max @ 419nm; (M)max @ 531nm; (L)max @ 558 nm

# Color Deficiency

- Monchromatism
  - Hereditary **color blindness**
  - 10 per million people [LeGrand, 1957]
  - Shades of lightness
  - Rod vision in both dim and bright conditions
- Anomalous trichromats
  - Not as good as trichromat at distinguishing wavelengths that are close together

# Color Deficiency

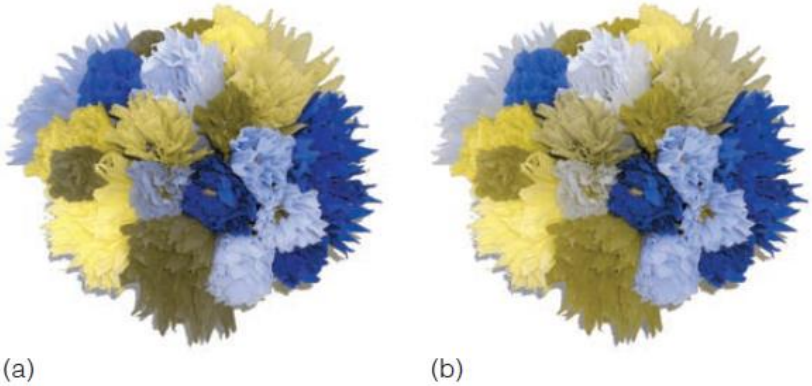
- Dichromatism
  - Protanopia
    - 1% males;
    - 0.02% females

(a)


(a)

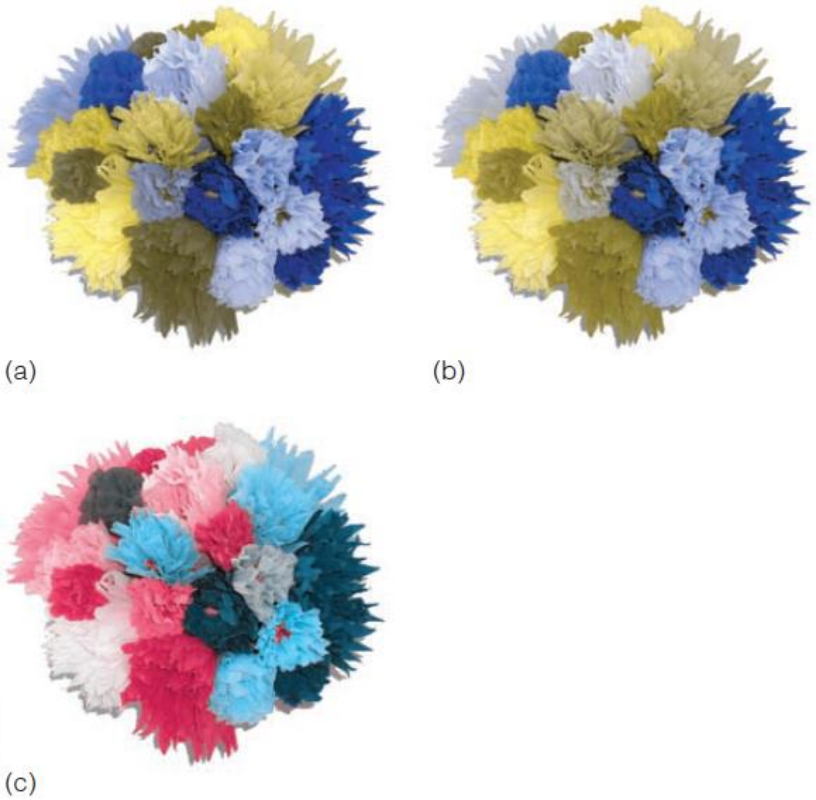
# Color Deficiency

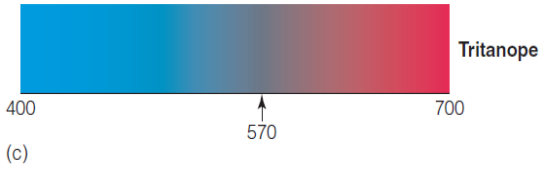
- Dichromatism
  - Protanopia
  - Deuteranopia
    - 1% males;
    - 0.01% females




# Color Deficiency

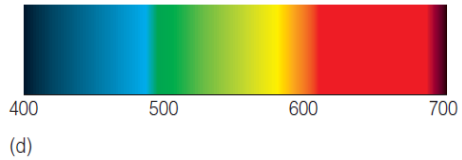
- Dichromatism
  - Protanopia
  - Deuteranopia
  - Tritanope
    - 0.002% males;
    - 0.001% females

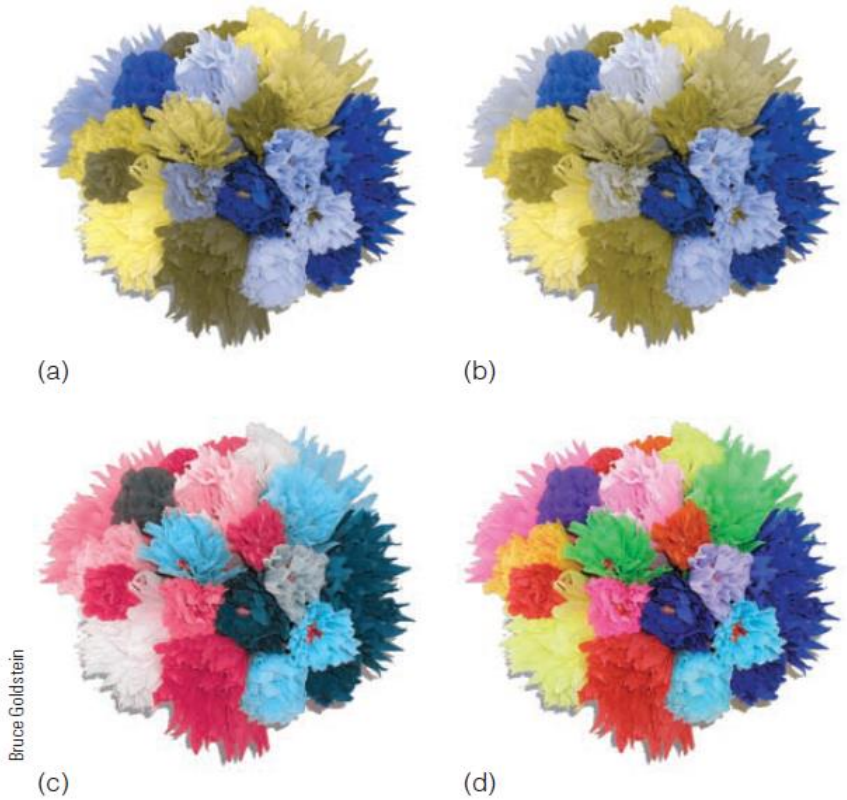


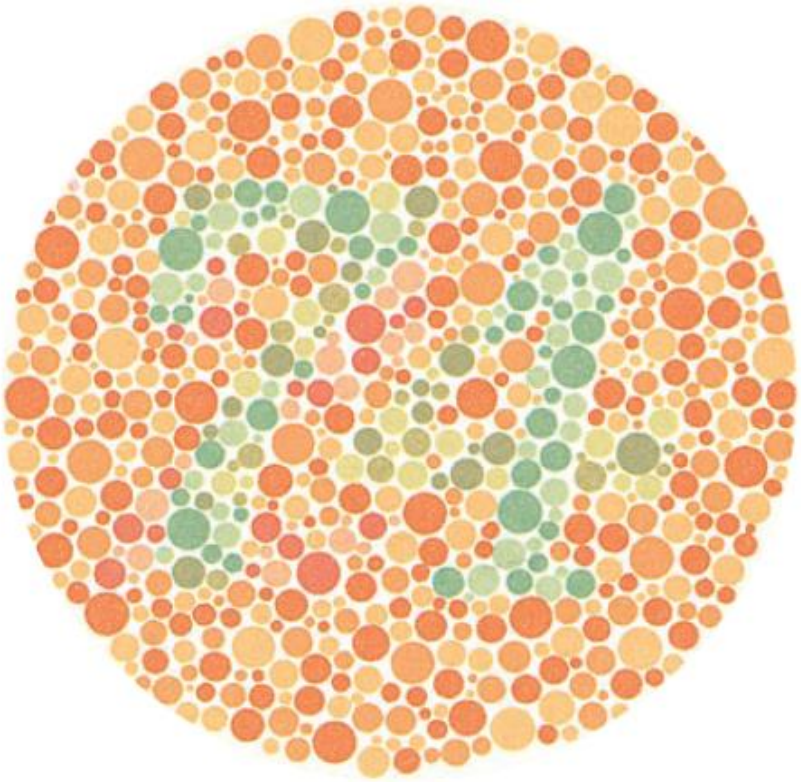
# Color Deficiency

- Dichromatism
  - Protanopia
  - Deuteranopia
  - Tritanope
  - Trichromats

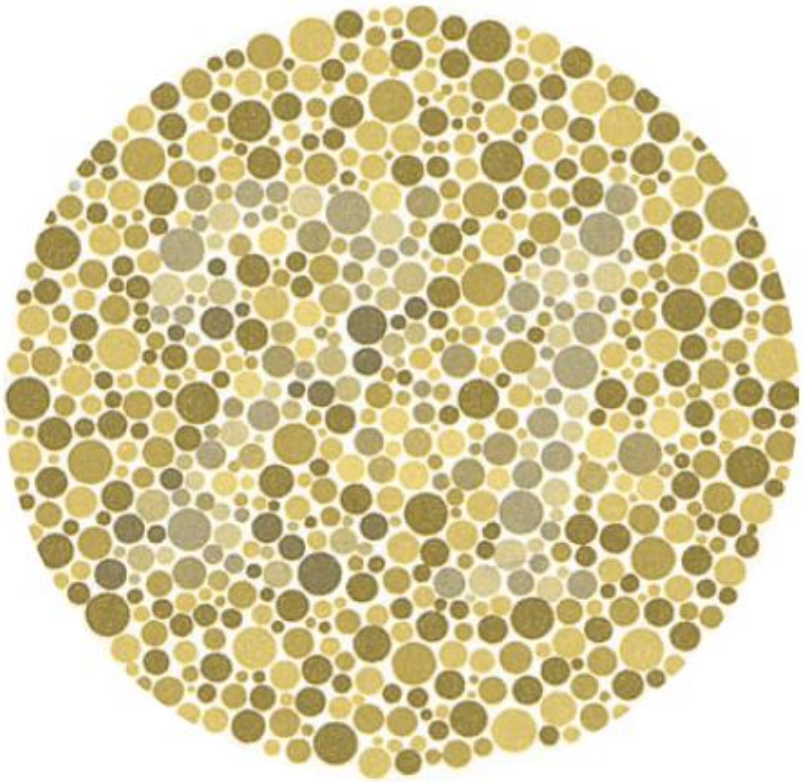


# Ishihara Plates



(a)

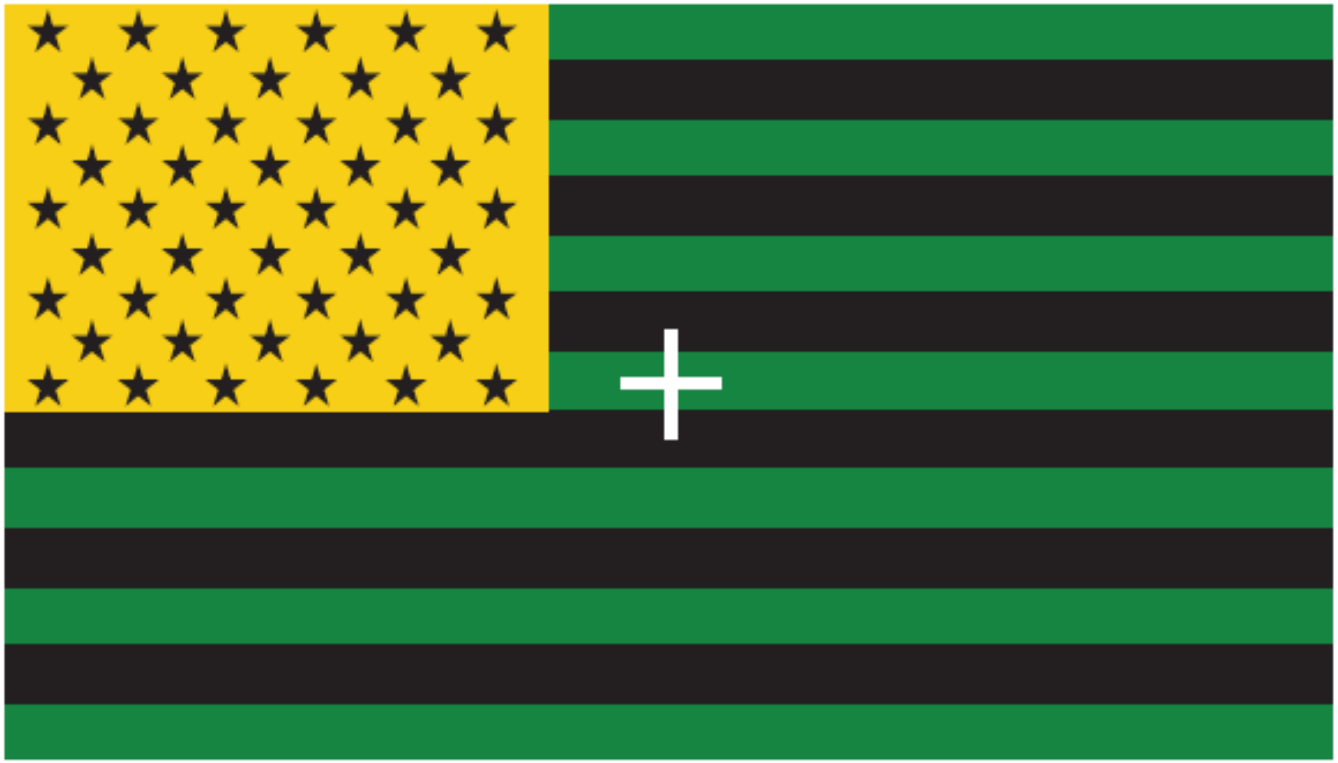


(b)


PC GAMER
WHY Games need color blind modes
You're hearing
Tyler Wilde, Senior Associate Editor

# Opponent-process theory of color vision

- Ewald Hering
- Based on behavioral observations
  - Observers describe perceived stimuli
- Color vision caused by opposing responses
  - Red / green; Blue / yellow
  - Simultaneous color contrast
- Physiological evidence
  - Opponent neurons (1950's and 1960's)
  - *Single*- and *double*-opponent neurons

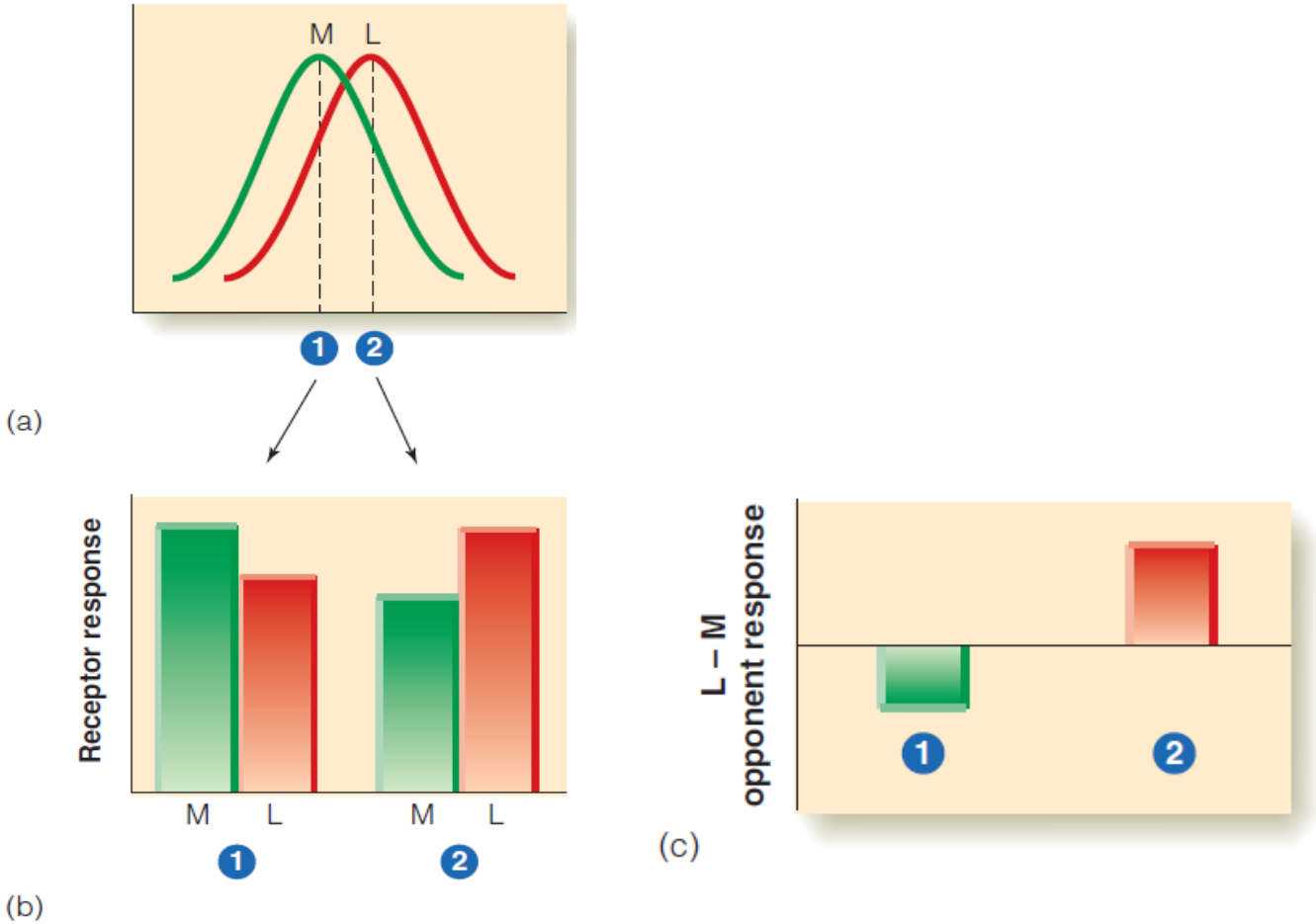


•(c) Cengage Learning

# Contrasting Theories of Color Vision?

- No...
  - Opponent responding can be created by three receptors
  - Physiological evidence from different parts of the visual system
- Signals for color sent to brain are based on the *difference* in responding pairs of cones
  - Trichromatic: *ratio* information (earlier)
  - Opponent-process: *difference* information (later)
  - Why two different methods necessary?

# Contrasting Theories of Color Vision?

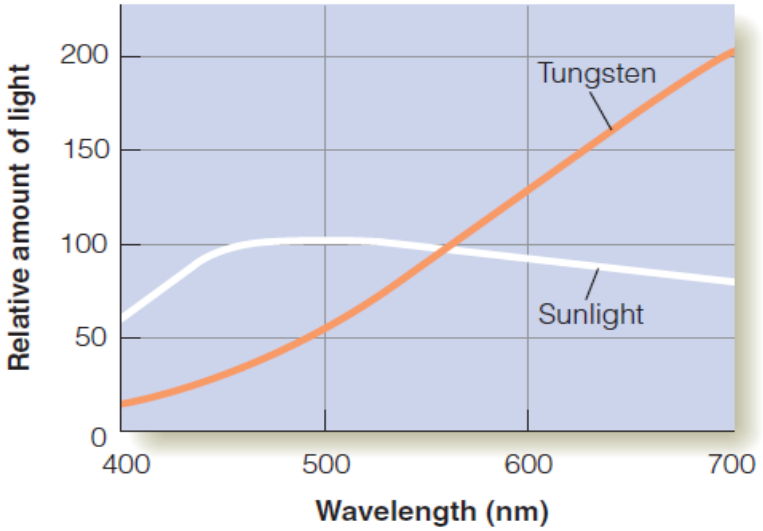


# Color in the Cortex

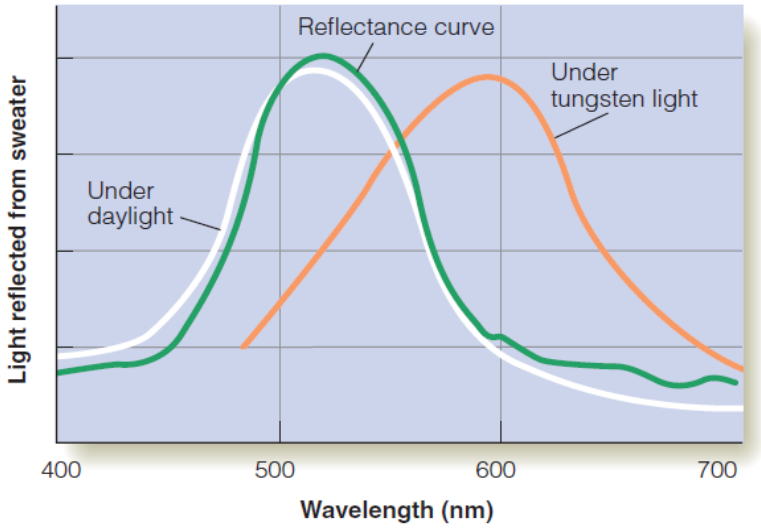
- Faces (FFA), bodies (ESB) and places (PPA)
- Is there a single color area?
- Semir Zeki
  - V4: cerebral achronmatopsia
- Distributed?
  - Opponent neurons in V1, IT and V4
  - Activity in many different visual areas that respond also to other qualities such as form

# Color Constancy

- Keep color perception stable as illumination changes
  - Impressive achievement



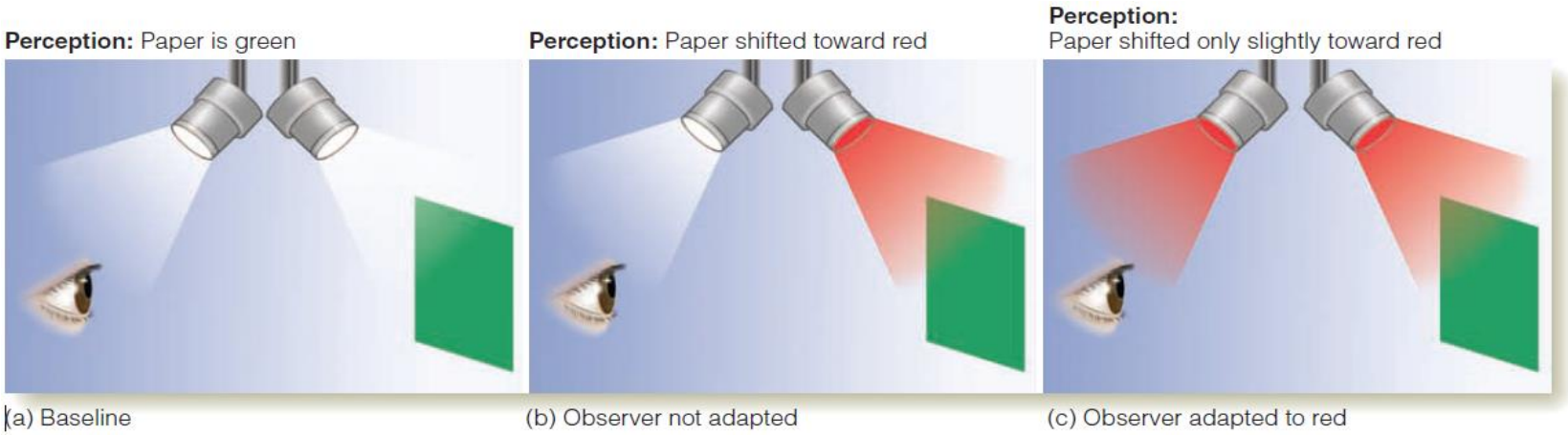

•Wavelength distribution: sunlight and tungsten lightbulb




•Reflectance curve and reflected light from sweater

# Chromatic Adaptation

- Eye adjust sensitivity to affected by the color of the illumination of the overall scene
- Keiji Uchikawa et al. (1989)

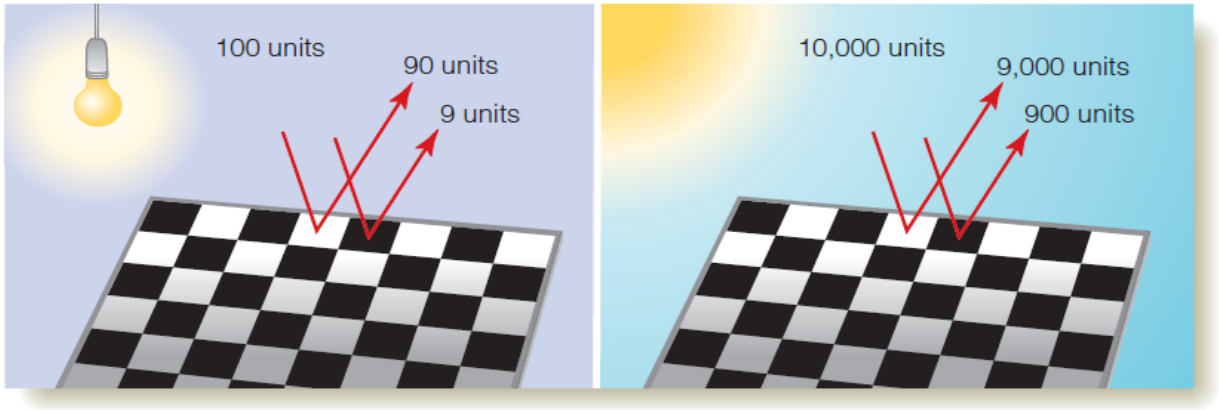


# Some other factors

- Effect of surroundings
  - Object's perceived color also affected by its surroundings
- Memory and Color
  - Our knowledge of the usual colors of objects in the environment has small effect
  - *Memory color*

# Lightness Constancy

- Achromatic colors (white, gray, black) perceived to stay same shade when illumination changes
  - Lightness determined by the object's *reflectance*
  - Not by *intensity* of illumination hitting on object
  - *Percentage* of reflected light, not *amount*



# Ratio Principle

- Ratio of reflectance of object to reflectance of surrounding objects
- As long as ratio remains the same, perceived lightness will remain the same
  - Works for flat, evenly illuminated objects
  - 3D scenes are usually illuminated unevenly

# Uneven Illumination

- Reflectance edges
  - (a)-(c)
- Vs.
- Illumination edges
  - (a)-(b)

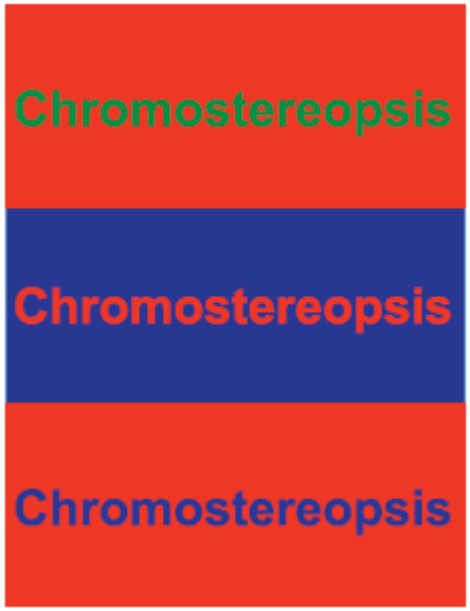
# Shadows

- Shadowed and unshadowed areas are bricks with same lightness
  - Less light falls on some areas because of shadow cast by tree

# Take-home messages

- Connection between wavelength and color
- Wavelengths are colorless
- Isaac Newton (*Optiks*, 1704): “The Rays...are not coloured” but “stir up a Sensation of this or that Colour...”
- Color is a construction of the nervous system
- Nervous system affects what we experience
- Experience *is created* by the nervous system

# Red and blue together are hard on the eyes



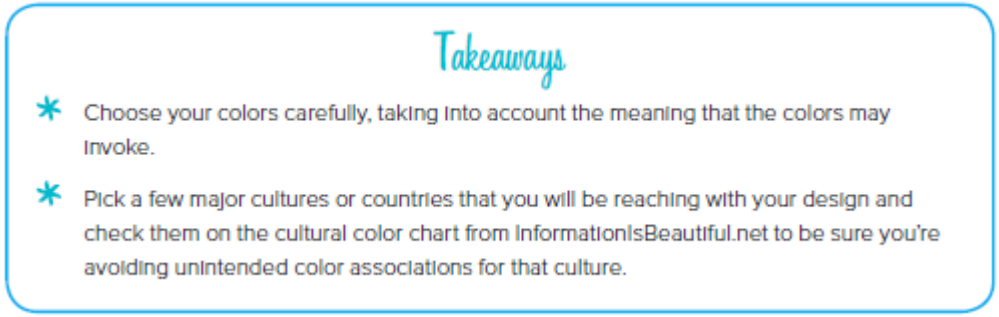

**Takeaways**

* Avoid putting blue and red or green and red near each other on a page or screen.
* Avoid blue or green text on a red background, and red or green text on a blue background.

Weinschenk, S.M. (2011). 100 Things Every Designer Needs to Know About People.

# The meanings of color vary by culture

- Use of red: financial trouble
- Colors of surroundings may affect mood
- Orange in US makes people agitated
- Browns and blues more soothing
- Some invariant: e.g. gold

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