Perceptual Factors and Their Application

Visual Perception

Proctor, R.W. & VanZandt, T. (2008). *Human Factors in Simple and Complex Systems*, 2nd edition. Boca Raton: CRC Press

Introduction to Visual Perception

- How people perceive environmental information is of great importance in ergonomic design.
- We are always concerned about how to display information in ways easily perceptible.
- We must understand the basic principles of sensory processing and characteristics of the different sensory systems when considering the design of displays, controls, signs and other.
- If someone looks at a light, the sensory effect of the *intensity* of the light is quite different from the perceived *brightness* of the light.
- If the light is turned on in a dark room, the person may perceive it as being very bright indeed. But if that same light is turned on outside on a sunny day, he may perceive it as being very dim.

Visual sensory system

- Considering the visual information received, all the patterns of light and movement that fall on your retinas organize themselves into a representation of the world.
- Our perceptions of the world are made up of only a very limited amount of all the information that we actually receive.
- *Ex while you drive*, the visual information received such as the location of the roadway, the yellow line down the center of the road, the locations of the other vehicles on the road.
- All of cases of visual sensation, information is conveyed by light energy projected or reflected into the eye.

Visual sensory system

- *The light* that reaches the eye can be characterized as *waves of photons* that are either emitted by or reflected from objects in environment.
- The *intensity* of a light is determined by the *number of photons* it produces. The color of a light is determined by *light's wavelength.*
- The range of wavelengths to which humans are sensitive runs from approximately *380-760 nanometers(nm).*
- Long wavelengths are perceived as red, whereas short wavelengths are perceived as violet.
- Most colors that we experience are not composed of a single wavelength, but are mixture of many different wavelengths.
- White light, is composed of approximately equal amounts of all the different wavelengths.

Visual sensory system

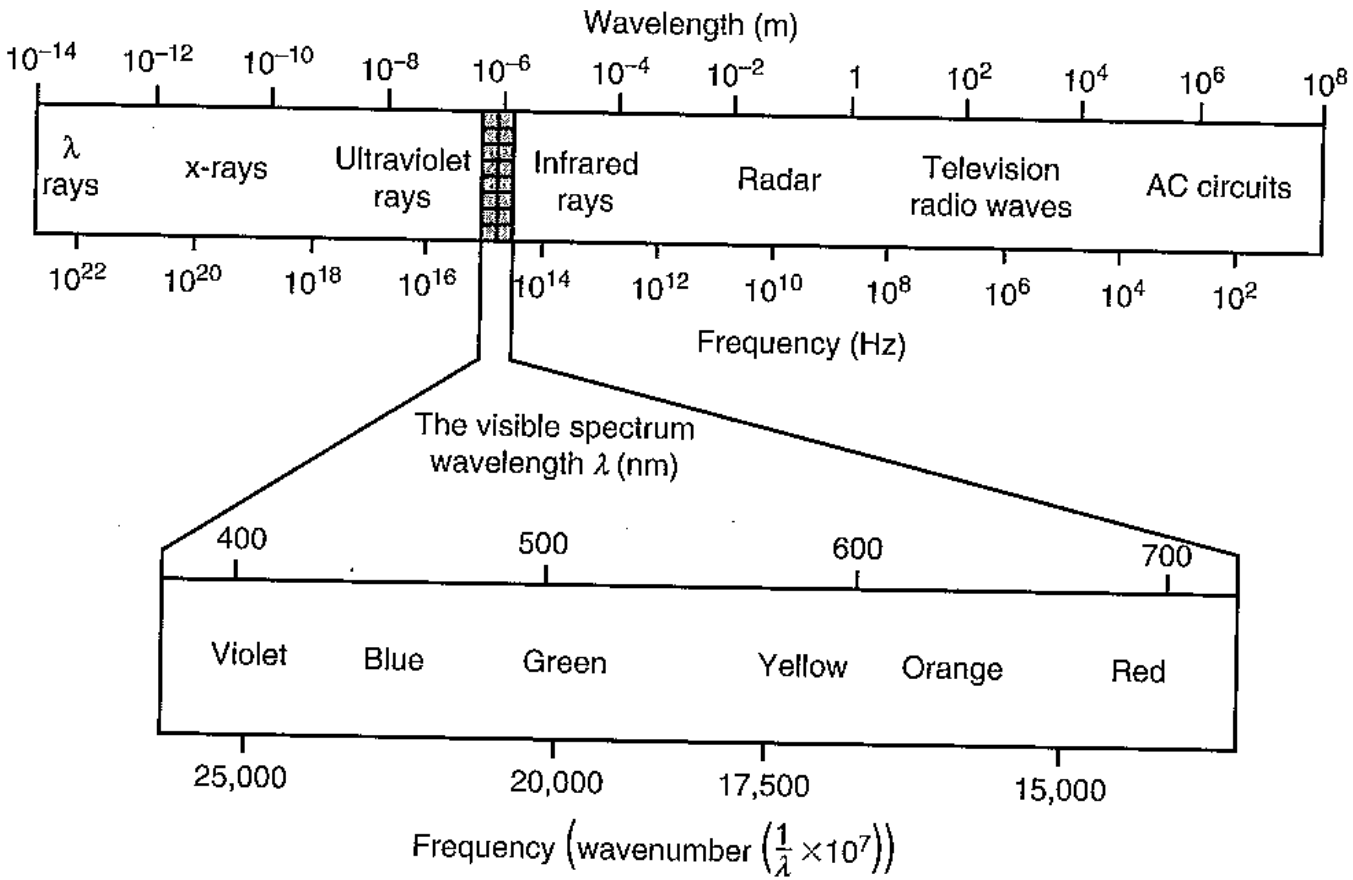


FIGURE 5.1 The visual spectrum, as located within the electromagnetic spectrum.

Anatomy of the Eye: Retina

- Visual images are focused on the retina, which is the organ that lines the back of the eye.
- The retina contains a layer of receptor cells, as well as layers of nerve cells that perform the transformations of the retinal image into a neural signal.
- *Photoreceptors.* The retina contains two types of receptors, *rods* and *cones*.
- Rods and cones respond to different things. While cones are responsive to different colors, rods are not.

Anatomy of the Eye: Retina

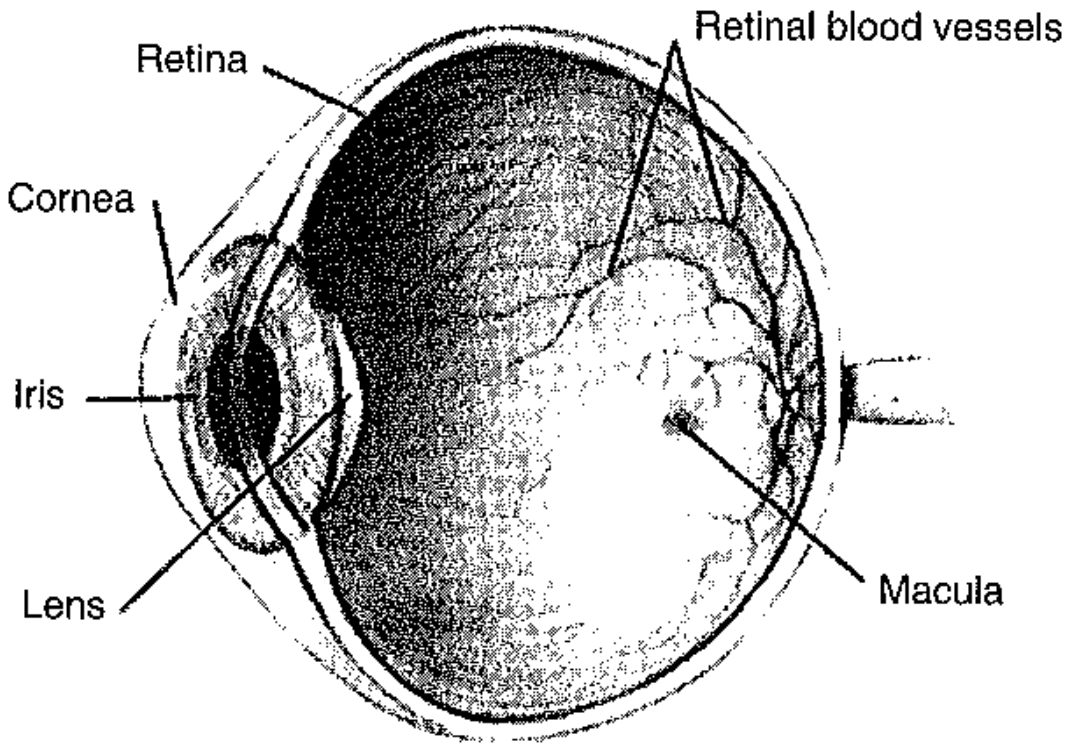


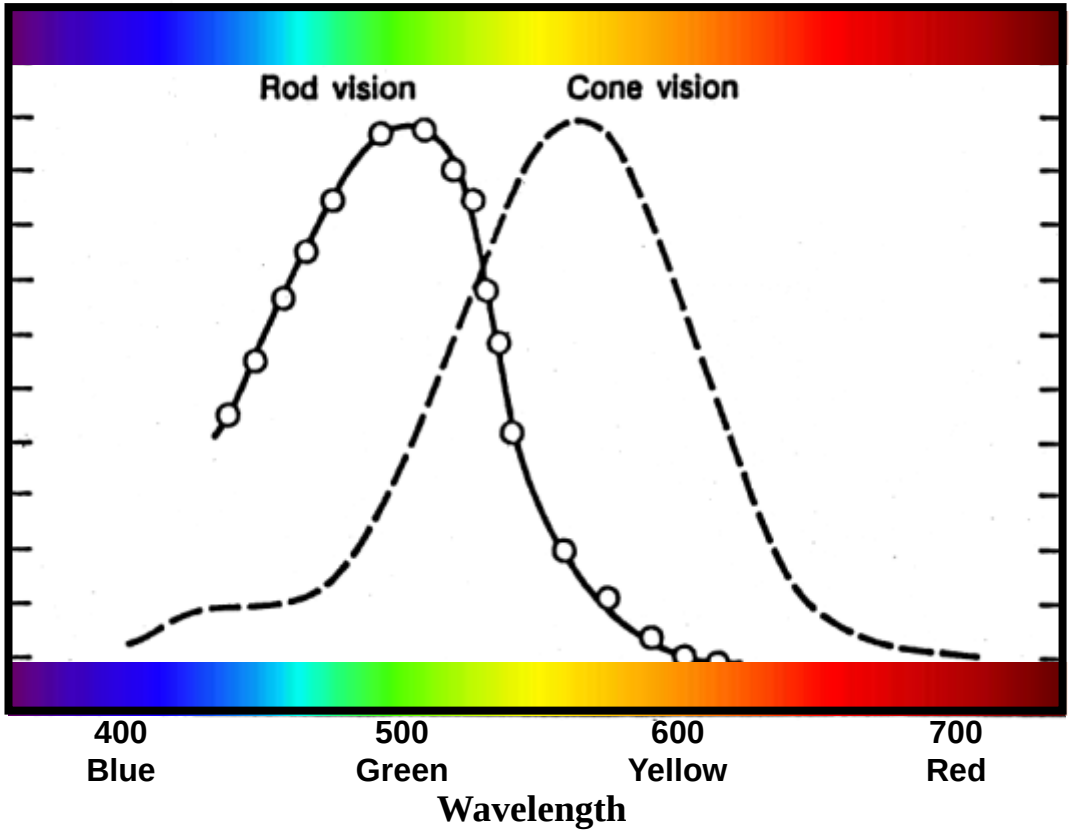
FIGURE 5.2 The human eye and optic nerve.

Anatomy of the Eye: Retina

- All rods have the same kind of *photopigment*, whereas there are three types of cones, each with different photopigment.
- Rods, 500 nm; short wavelength cones, 440 nm or bluish; middle wavelength cones, 540 nm or greenish; and long wavelength cones, 565 nm or reddish.
- There are many rods (approximately 90 million) than cones (approximately 4-5 million).

Spectral sensitivity

- The different photoreceptors have different spectral sensitivities.



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Anatomy of the Eye: Retina

- An important part of the retina is the *fovea*, which is a region about the *size of a pinhead* that falls directly in the line of sight.
- There are only cones in the center of the fovea. Both rods and cones are found outside of the fovea.
- The *rod system* is responsible for vision in *dim light* (scotopic vision), whereas the *cone system* is responsible for vision in *bright light* (photopic vision)
- The cone system is responsible for color vision and perception of detail.
- The rod system is unable to provide any information about color and fine detail.
- But it is much more sensitive that the cone system in that *rods can detect tiny amounts of light* that cones cannot.

Anatomy of the Eye

Duplicity Theory

- **Rods**
  - **Nighttime vision**
  - **Poor detail**
  - **Relatively insensitive to color (see shades of gray, purple, blue, green)**
  - **Poor motion detection**
  - **Peripheral vision**
- **Cones**
  - **Require high levels of illumination - Daylight vision**
  - **Detailed high resolution**
  - **Color vision**
  - **Motion detection**
  - **Concentrated in the fovea (center of the retina)**
  - **Central "Foveal" vision**

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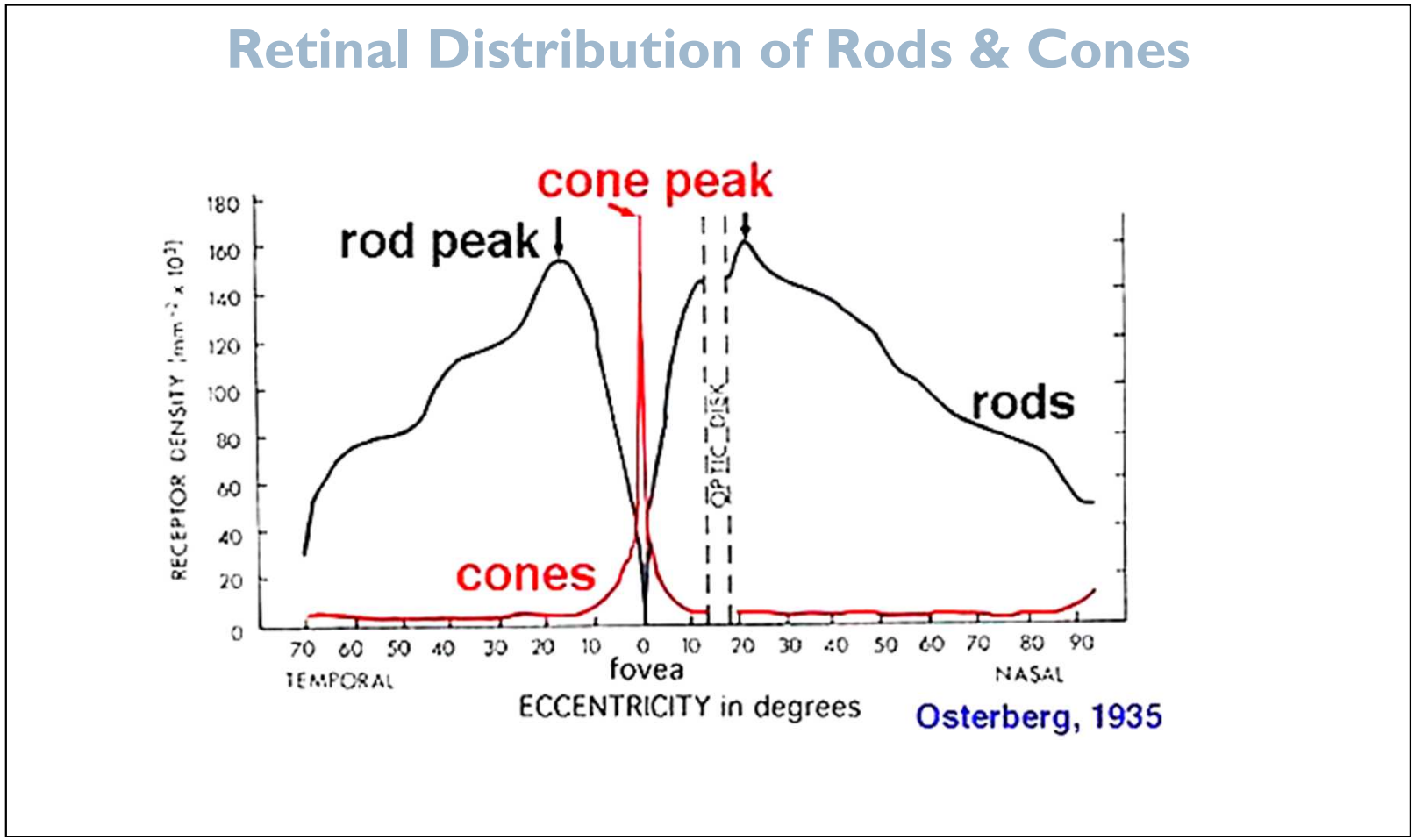
Anatomy of the Eye



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Anatomy of the Eye

Implications

- We naturally look directly at objects to perceive them.
- At night, our central vision becomes functionally blind.
- Therefore, under low illumination (e.g., at night) we must maximize vision by utilizing the rods in the periphery.
  - Since the maximum density of rods is found about 10° from the fovea, the visibility of dim objects is maximized by looking approximately one hand width (held at arm's length) away from them.
  - This technique will not improve the visibility of red objects or lights.

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Brightness

- Assuming that the problem with car-motorcycle accidents really is one of visibility.
- For the headlamp to increase visibility of the motorcycle, we might consider whether the headlamp increase the perceived *brightness* of the motorcycle
- The primary physical determinant of brightness is the intensity of the energy produced by a light source (luminance).
- We can determine perceived brightness by measuring the intensity of the light reflecting from its surface.

B is brightness

I is the intensity of the light

a is a constant

$$B = aI^{0.33}$$

Brightness

- *Brightness not depend on intensity.*, but it is influenced by many other factors.
- We might not perceive much if any change in brightness between a motorcycle with its headlamp turned off and one with its headlamp turned on if the sun is already making the motorcycle appear very bright.
- However, on a cloudy day, when the sun reflecting off the motorcycle is greatly reduced, turning on the headlamp may greatly increase perceived brightness, even though *the headlamp has exactly the same intensity on sunny and cloudy days.*

Dark and Light Adaptation

- If we look at a *bright light* for some time and *then look into total darkness*, our sensitivity to light is impaired for a *considerable time* and only gradually returns to its original sensitivity. This gradual process is referred to as *dark adaptation.*
- Adaptation depends on the time it takes for photochemicals (rhodopsin) in the light sensitive receptors to "bleach" and return to their normal unbleached condition.
  - **Dark to light adaptation** - 50% recovery in 90 seconds
  - **Light to dark adaptation** - May take up to 40 minutes

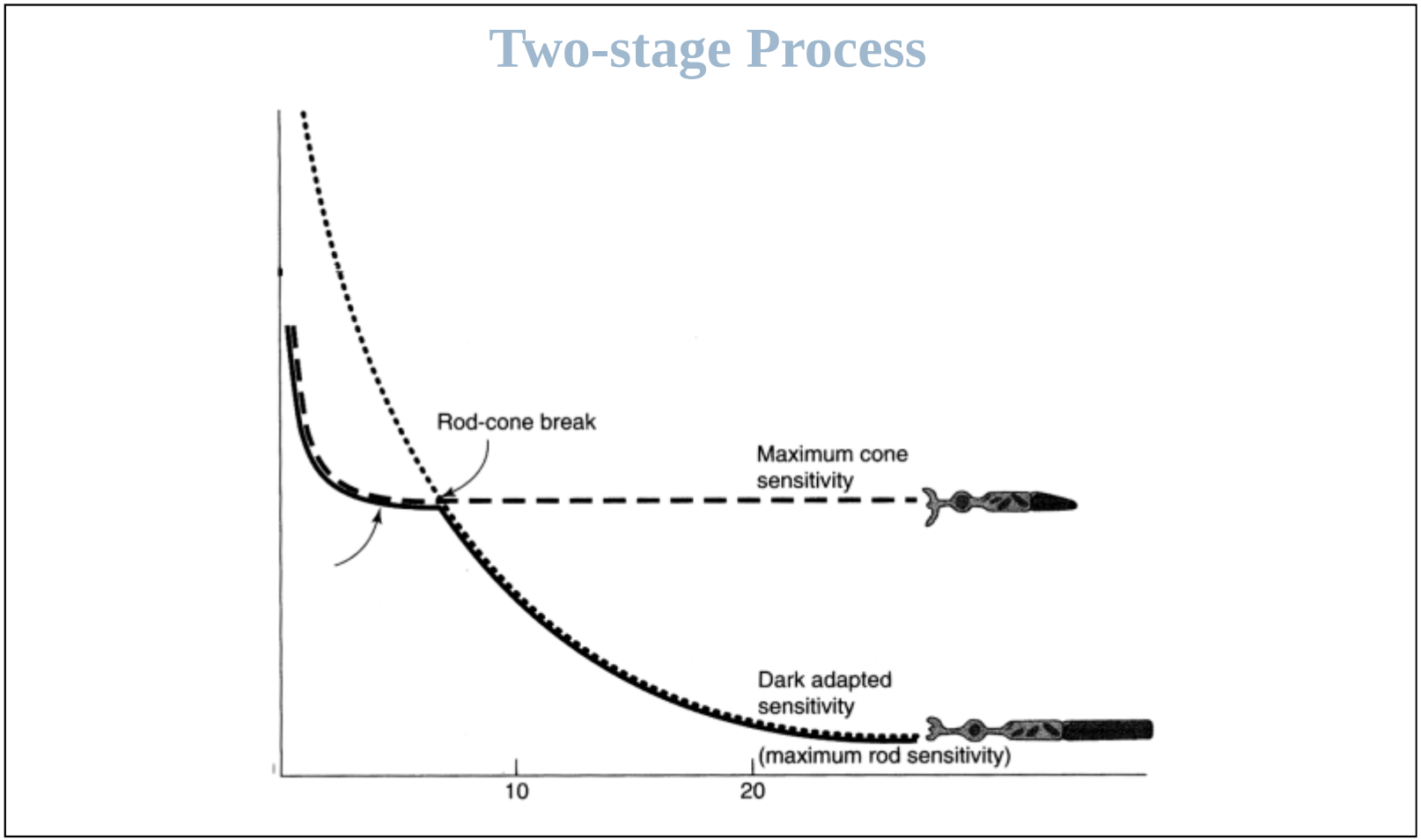
Dark- adaptation

- The differences between rods and cones are responsible for the phenomenon of dark-adaptation.
- When you first *enter a dark room* it is very difficult to see anything at all.
- However, during the first few minutes in the dark, your ability to see improves, and then level off.
- *After about 8 min, you will experience another improvement,* and your ability to see will again get better and continue to do so until approximately 45 min have passed since you entered the room.

Dark- adaptation

- Why does this happen? When you enter the dark, many of your photoreceptors, both rods and cones, are bleached.
- The cones regenerate their pigment the fastest, resulting in the first improvement in your ability to see.
- *At the end 3 min, the cones finish* regenerating their pigment, but remember that cones are not very good for seeing in the dark.
- *After about 8 min in the dark, the rods catch up* with the cones and your ability to see again state to improve.
- The remainder of the increase in sensitivity as time progress is entirely due to the rods continuing to regenerate photopigment.

Dark Adaptation



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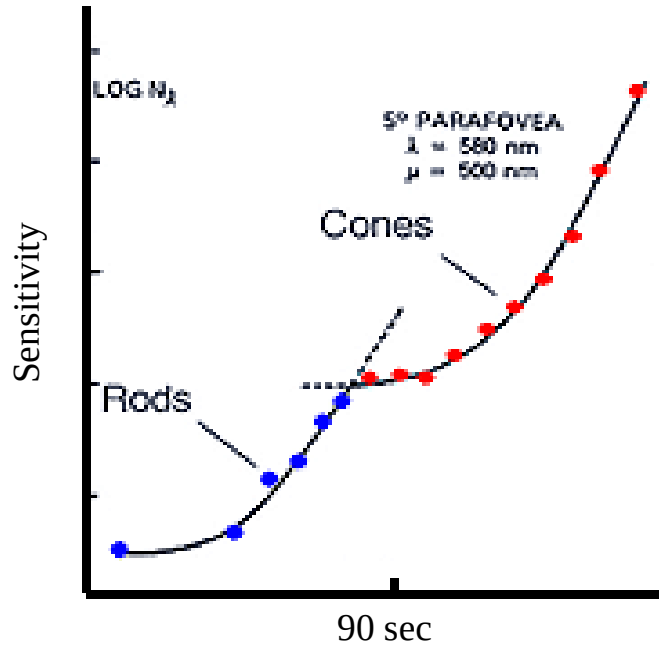
Light- adaptation

- The opposite of dark-adaptation is light-adaptation.
- Light-adaptation happens after you come out of the dark room.
- If you have dark-adapted, it is usually uncomfortable to return to a fully lighted environment.
- This discomfort arises because your eyes are far more sensitive to light.
- In fact, if we were to measure your ability to detect small amounts of light, your threshold would be very low if you were dark-adapted.
- After you return to lighted, your threshold begins to increase. *After 10 min, your threshold will have stabilized* to a relatively high level.

Light Adaptation

Two-stage Process



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Dark and Light Adaptation

- For any environment, light-adaptation is a concern in night driving, where a driver needs to maintain maximal sensitivity to light.
- If the *light intensity created* by a driver's own headlights close to his vehicle is too high, the driver's eyes will light-adapt, and he will *not be as able to see objects* farther in front of the car.
- However, *the brighter and wider the headlight beam pattern can be farther* from the vehicle, the better the driver will be able to see.
- However, this increased distance and intensity must be accomplished without creating to much glare for other drivers.

Dark and Light Adaptation

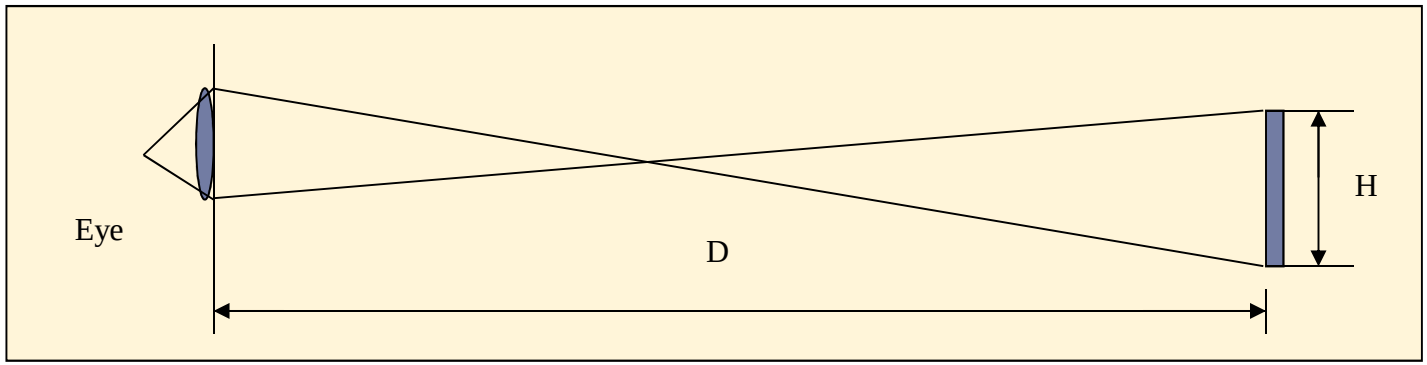
- In some problem situation, highway tunnels, force driver to change from one level of adaptation, that required by the environment outside of the tunnel, to another, that required by the tunnel lighting.
- Problems I light sensitivity are particularly severe just upon entering a tunnel and just after leaving a tunnel.
- During daytime driving, the roadway will appear very dark at the tunnel entrance and very bright at it exit.
- *Brighter lights placed at the beginning* and end of a tunnel provide *more gradual changes illumination* and less visual impairment.

Dark and Light Adaptation

- Rods are important for scotopic viewing conditions and cones are important for photopic viewing conditions.
- A *dark-adapted* person can enter a *room lit with red light* and remain dark-adapted.
- Astronomers might need to *read charts* without losing their ability to see dim objects through a telescope.
- Military personnel on night missions may need to *read maps* or perform other tasks while preserving dark-adaption.
- This need has led to the design of *low intensity red flashlights*, *red-lit cockpits* and control rooms, *red finger-lights* for map reading, and *red dial and gauges* in vehicle control system.

Visual Acuity

- **Refers to the ability to discriminate fine detail and depends on the accommodation of eyes.**
- The structure of the retina determines many characteristics of perception.
- One of the most important of these is the ability to perceive detail as function of retinal location.
- Visual Angle (minutes) = 3438 * Height / Distance



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Visual Acuity

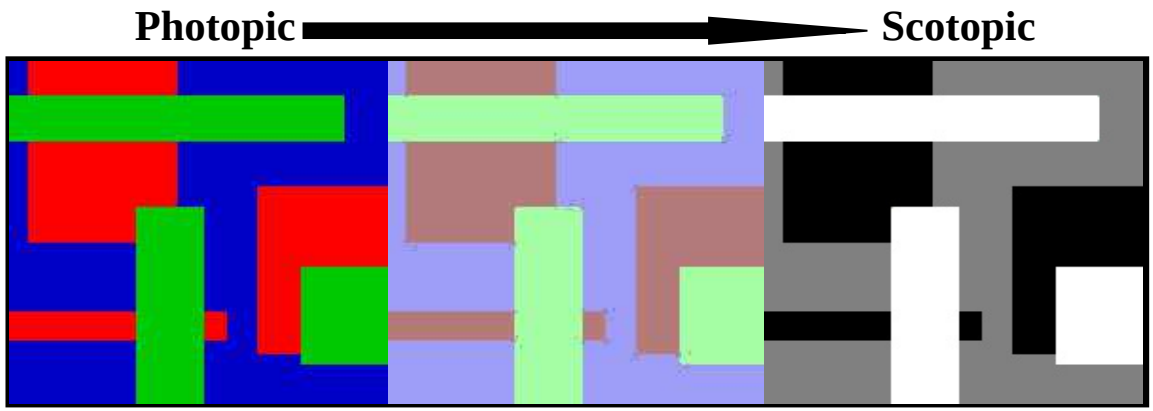
- More formally, acuity can be measure by finding the minimum *visual angle* for a detail that can be resolved.
- Visual angle is a measure of stimulus size that does not depend on distance: it is a measure of the size of the retinal image.
- The size of the retinal image is a function of the size of the object and its distance from the observer.
- An example of a task that required good visual acuity is detecting a small gap between two lines.
- If the gap is very small, the two lines may look like a single line, but when it is larger it is easier to see two lines.
- Acuity is highest at the fovea and decrease as the image is moved further.

Visual Acuity

- The acuity varies with ambient light levels.
- Under photopic viewing conditions, the cone system is doing a lot of the work and so acuity is great.
- Under scotopic viewing conditions only the rods are operating. Acuity is much worse.
- Fine detail cannot be discriminated in the dark, but can be only in full light.
- Ergonomic design, for example, in determining the design of *gauges and dials* should be located in *fovea region*.
- If it is so forth, will need to be larger.

Purkinge Shift

- As illumination goes from bright to dim, relative lightness of colors change.
  - Green goes from dark to lighter.
  - Red goes from lighter to darker
- This is the result of switching between using **photopic** vision under bright light, to using **scotopic** vision under dim light.
  - What do you think the implications are?



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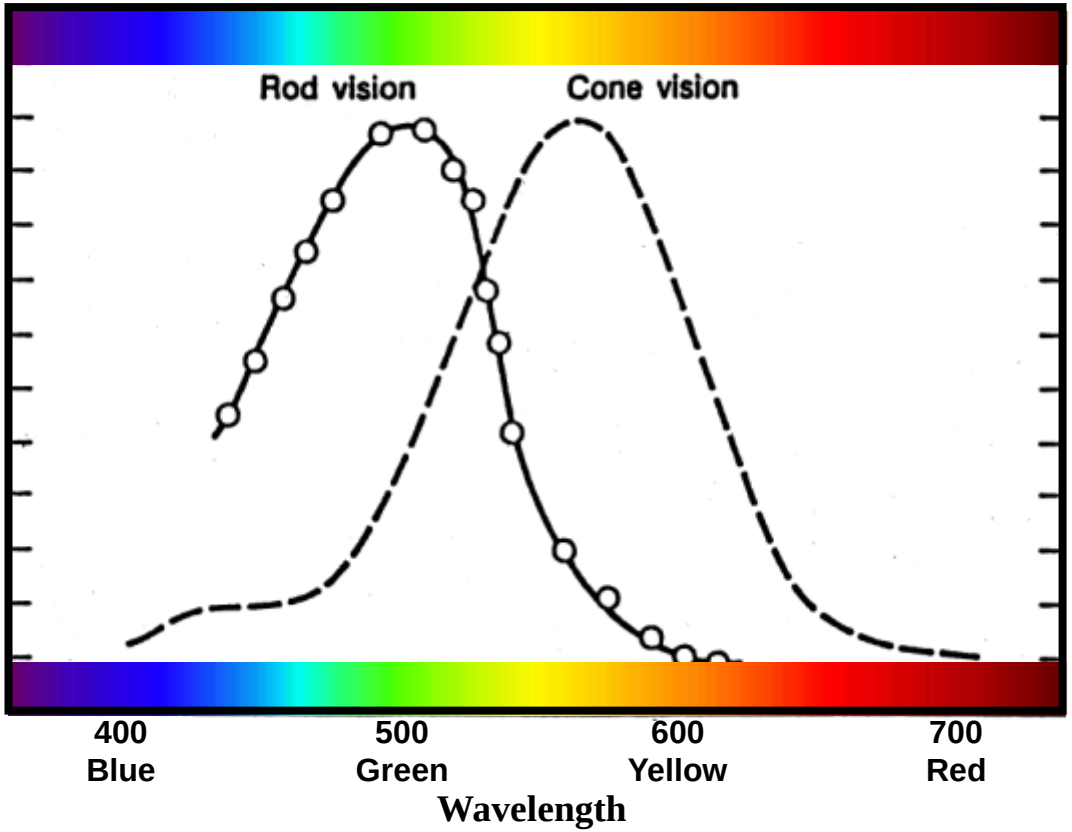
Spectral sensitivity

- The different photoreceptors have different spectral sensitivities.



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Lightness

- The amount of light reflected from an illuminated surface is a function of both level of illumination and the degree to which the surface reflects light.
- While *brightness* is the perceptual attribute associated with overall *light intensity*, the term *lightness* refers to the perceptual attribute associated with *reflectance*.
- Lightness describes *how dark or light an object* appears on a *scale from black to while.*
- Black surfaces have low reflectance and absorb most of the light that falls on them, whereas white surface have high reflectance and reflect most of the light that falls on them.

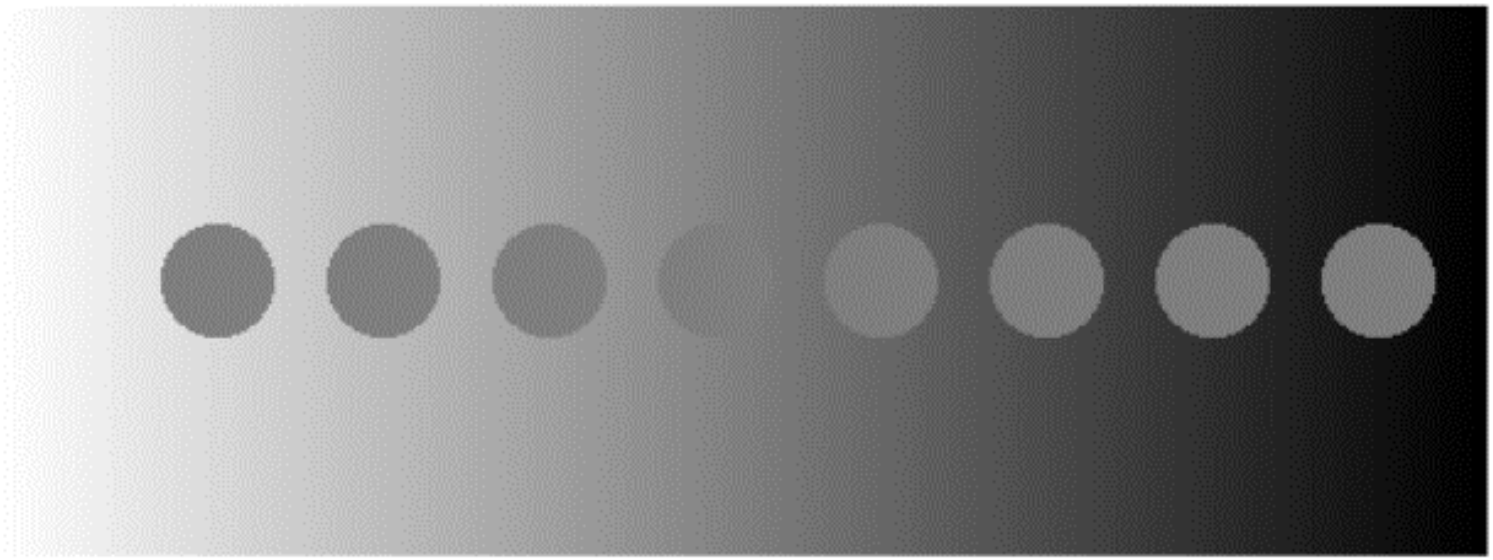
Lightness is different from brightness

- Brightness is a function of intensity; intensity increases, brightness increases.
- Consider, however, the reflectance of two surfaces under two levels of illumination. Under high levels of illumination both surface will reflect much more light energy than under low levels of illumination, yet their relative *lightness will tend to remain the same*.
- This phenomenon is called *lightness constancy.*

Lightness contrast

- Lightness contrast refer to the fact that the perceived lightness of an object is *affected by the intensity of surrounding areas.*
- The key different to note between *lightness contrast* and lightness constancy is that the former occurs when only *the intensity of surrounding regions is changed*, whereas the latter occurs when the intensity of illumination across the entire visual field is changed.

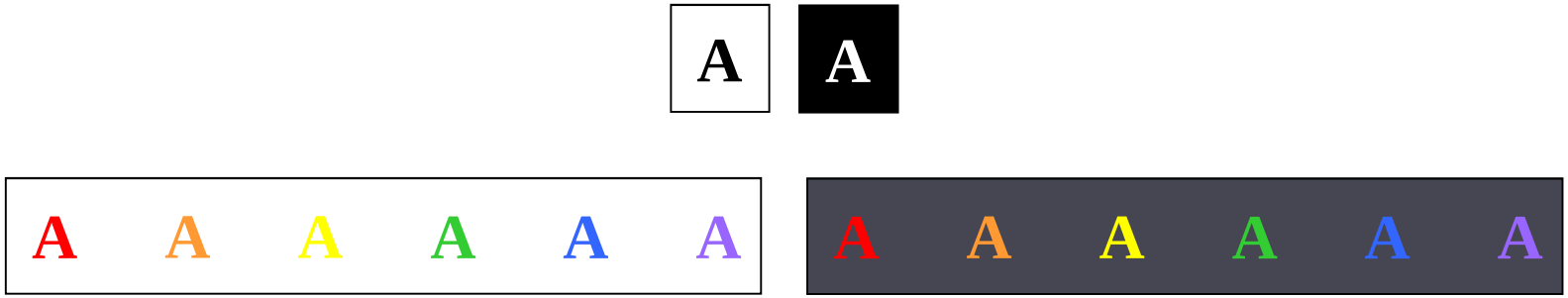
Lightness contrast



From http://usd-apps.usd.edu/coglab/contrastdemos.html

Contrast Sensitivity

- Contrast is an important parameter in assessing vision
- Contrast is a big factor in legibility
- Black letters on a white background provide the greatest legibility.
- The use of color can markedly reduce contrast and therefore legibility.



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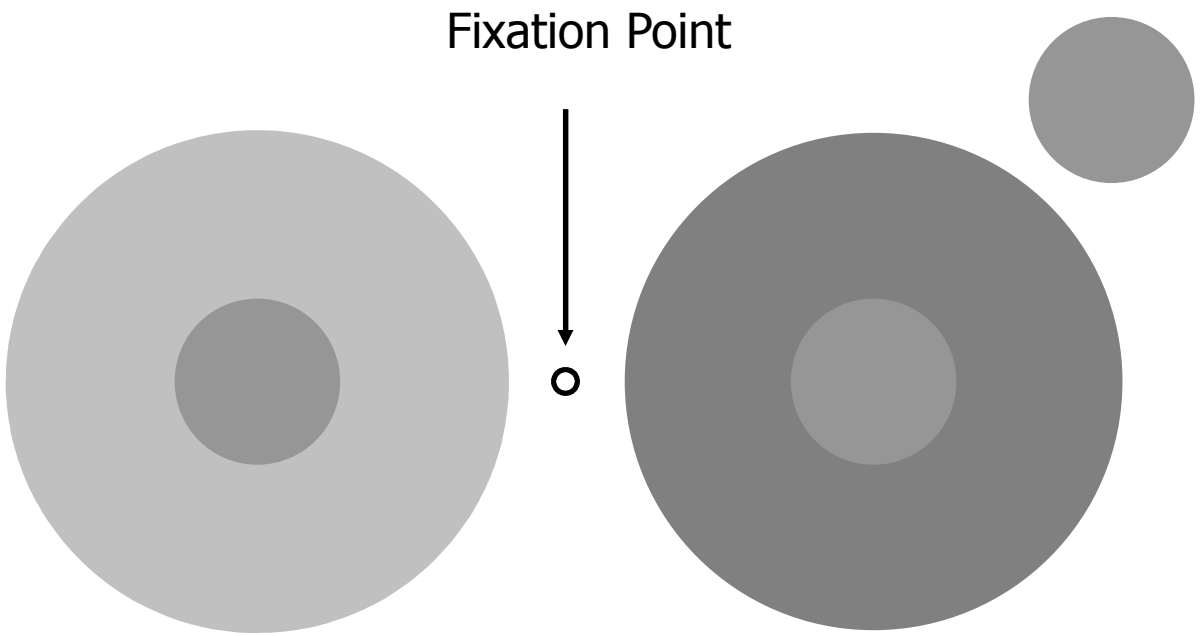
Contrast Sensitivity



Center disks have an apparent Lightness Contrast, but actually are of equal *brightness*

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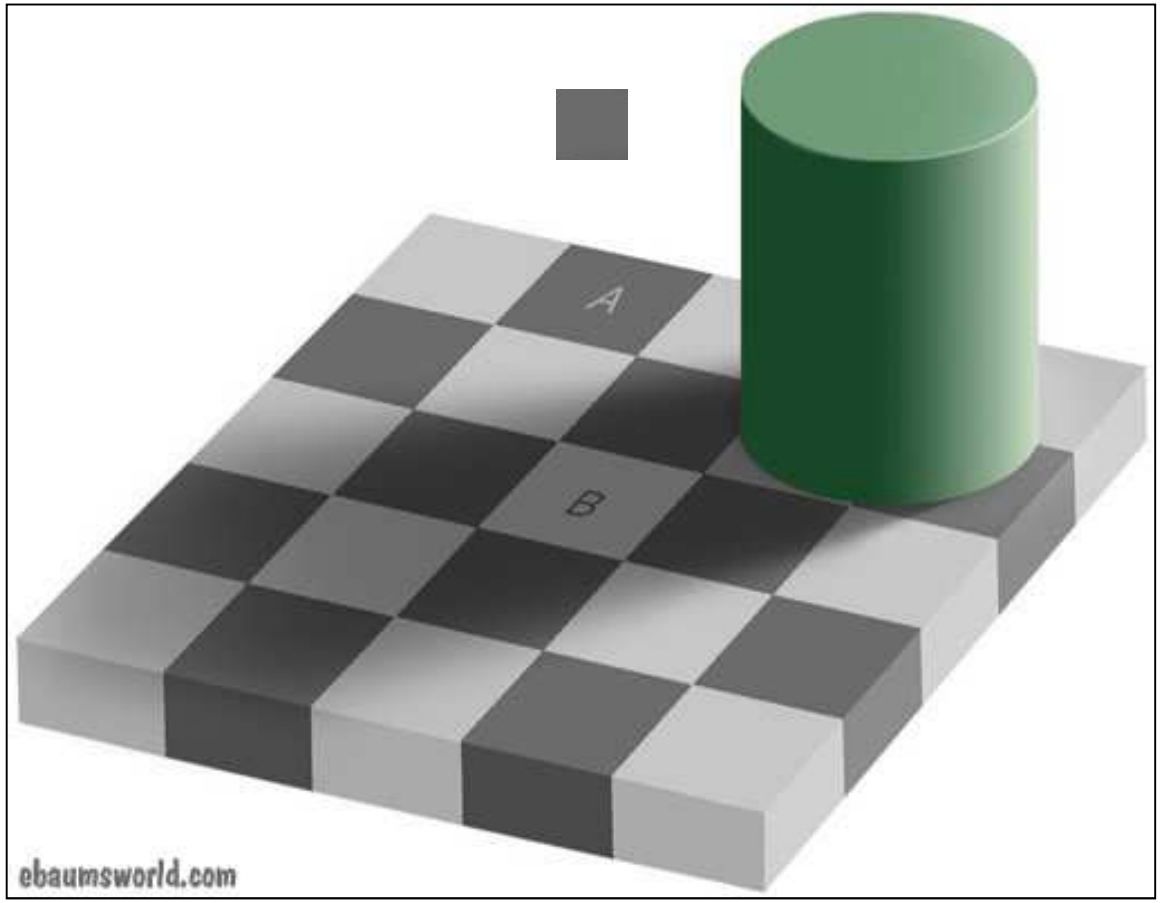
Contrast Sensitivity



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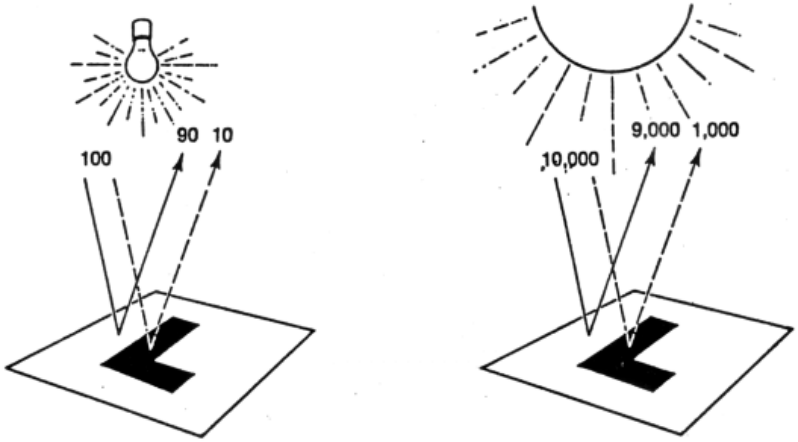
Visibility

- Refers to *how well something can be seen* by the human eye.
  - A key factor in visibility is contrast
  - **Note that visibility and contrast are not the same thing**
    - *Contrast is not affected by illumination* but visibility is!
    - Imagine a target (see below) with a contrast of illuminated by a lightbulb. Now imagine that same target illuminated by the sun outdoors with 100 times the intensity. *The contrast did not change but clearly the visibility did.*



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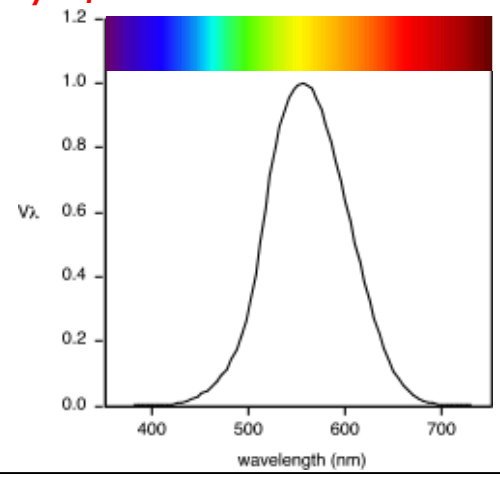
Luminance

- Luminance is simply a statistic designed to express the fact that ***lights of equal energy but*** *different wavelengths do not* ***all appear*** *equally bright.*
- This is because even though the lights of the various wavelengths are equal in power from a physical standpoint, the visual system is not equally sensitive to them.
  - Brightness is greatest for wavelengths in the *vicinity of 565 nm* and decreases toward both ends of the spectrum.
  - Somewhere between *green (500 nm) and yellow (600 nm)*



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