Chapter 3
Neurons and Perception

Overview of Questions

• How do chemicals in the eye called pigments affect our perception?
• How does neural processing determine what we see?
• How does the neurons are “wired up” affect our perception?
• What does it mean to say that perception is indirect?

Light is the Stimulus for Vision

• Electromagnetic spectrum
  – Energy is described by wavelength
  – Spectrum ranges from short wavelength gamma rays to long wavelength radio waves
  – Visible spectrum for humans ranges from 400 to 700 nanometers
  – Most perceived light is reflected light
Light is the Stimulus for Vision

The electromagnetic spectrum, showing the wide range of energy in the environment and the small range within this spectrum, called visible light, that we can see.

Focusing Images on the Retina

- The cornea, which is fixed, accounts for about 80% of focusing
- The lens, which adjusts shape for object distance, accounts for the other 20%
  - Accommodation results when ciliary muscles are tightened which causes the lens to thicken
- Light rays pass through the lens more sharply and focus near objects on retina

Focusing of light rays by the eye. (a) Parallel rays from a light source further than 20 feet from the eye. Focus point: on retina; (b) nonparallel rays from a light source closer to the eye. Eye relaxed. Focus point: behind the retina; (c) non-parallel rays. Eye accommodated (indicated by fatter lens). Focus point: on retina.
Focusing Images on Retina …

• The near point occurs when the lens can no longer adjust for close objects
• Presbyopia - “old eye”
  – Distance of near point increases
  – Due to hardening of lens and weakening of ciliary muscles
  – Corrective lenses are needed for close activities, such as reading

Transduction of Light into Nerve Impulses

• Receptors have outer segments, which contain:
  – Visual pigment molecules, which have two components:
    • Opsin - a large protein
    • Retinal - a light sensitive molecule
• Visual transduction occurs when the retinal absorbs one photon
  – Retinal changes it shape, called isomerization
Physiological Reaction after Isomerization

- Isomerization triggers an enzyme cascade
  - Enzymes facilitate chemical reactions
  - A cascade means that a single reaction leads to increasing numbers of chemical reactions

Retinal Processing - Rods and Cones

- Differences between rods and cones
  - Shape
    - Rods - large and cylindrical
    - Cones - small and tapered
  - Distribution on retina
    - Fovea consists solely of cones
    - Peripheral retina has both rods and cones
    - More rods than cones in periphery
Retinal Processing - Rods and Cones …

- Number
  - 120 million rods
  - 5 million cones
- Blind spot - place where optic nerve leaves the eye
  - We don’t see it because:
    - One eye covers the blind spot of the other
    - It is located at edge of the visual field
    - The brain “fills in” the spot
Measuring Dark Adaptation

- Three separate experiments are used
- Method used in all three experiments:
  - Observer is light adapted
  - Light is turned off
  - Once the observer is dark adapted, she adjusts the intensity of a test light until she can just see it

![Figure 2.23 Viewing conditions for a dark adaptation experiment. The image of the fixation point falls on the fovea, and the image of the test light falls in the peripheral retina.](image)

Figure 2.23 Viewing conditions for a dark adaptation experiment. The image of the fixation point falls on the fovea, and the image of the test light falls in the peripheral retina.

![Figure 2.24 Three dark adaptation curves. The red line is the two-stage dark adaptation curve, with an initial cone branch and a later rod branch. The green line is the cone adaptation curve. The black line is the rod adaptation curve. Note that the downward movement of these curves represents an increase in sensitivity. The curves actually begin at the points indicating “light-adapted sensitivity,” but there is a slight delay between the time the lights are turned off and when measurement of the curves begins. (Partial data [pure rod curve] from “Rhodopsin Measurement and Dark Adaptation in a Subject Deficient in cone Vision,” by W. A. H. Ruston, 1961, Journal of Psychology, 55, 193-205. Copyright © 1961 by the Psychological Society, Cambridge University Press.)](image)

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Measuring Dark Adaptation …

- Experiment for rods and cones
  - Observer looks at fixation point but pays attention to a test light to the side
  - Results show a dark adaptation curve:
    - Sensitivity increases in two stages
    - Stage one takes place for 3 to 4 minutes
    - Then sensitivity levels off for 7 to 10 minutes - the rod-cone break
    - Stage two shows increased sensitivity for another 20 to 30 minutes
Measuring Dark Adaptation …

- Experiment for cone adaptation
  - Test light only stimulates cones
  - Results show that sensitivity increases for 3 to 4 minutes and then levels off

- Experiment for rod adaptation
  - Must use a rod monochromat
  - Results show that sensitivity increases for about 25 minutes and then levels off

Visual Pigment Regeneration

- Process needed for transduction:
  - Retinal molecule changes shape
  - Opsin molecule separates
  - The retina shows pigment bleaching
  - Retinal and opsin must recombine to respond to light
  - Cone pigment regenerates in 6 minutes
  - Rod pigment takes over 30 minutes to regenerate

Figure 2.25 A frog retina was dissected from the eye in the dark and then exposed to light. (a) This picture was taken just after the light was turned on. The dark red color is caused by the high concentration of visual pigment in the receptors. As the pigment bleaches, the retina becomes lighter, as shown in (b) and (c).

Figure 2.26 (a) The threshold for seeing a light versus wavelength. (b) Relative sensitivity versus wavelength -- the spectral sensitivity curve. (Adapted from “The Receptors of Human Color Vision,” by G. Wald, 1964, Science, 145, p. 1009 and 1011. Copyright © 1964 by the American Association for the Advancement of Science. Adapted with permission.)
Spectral Sensitivity of Rods and Cones

- Rod spectral sensitivity shows:
  - More sensitive to short-wavelength light
  - Most sensitivity at 500 nm
- Cone spectral sensitivity shows:
  - Most sensitivity at 560 nm
- Purkinje shift - enhanced sensitivity to short wavelengths during dark adaptation when the shift from cone to rod vision occurs

Spectral Sensitivity of Rods and Cones

- Difference in spectral sensitivity is due to absorption spectra of visual pigments
  - Rod pigment absorbs best at 500 nm
  - Cone pigments absorb best at 419nm, 532nm, & 558nm
  - Average of all 3 equals 560nm
- These match the spectral sensitivity curves
Convergence in the Retina

- Rods and cones send signals vertically through
  - Bipolar cells
  - Ganglion cells
  - Ganglion axons
- Signals are sent horizontally by
  - Horizontal cells
  - Amacrine cells

Convergence and Sensitivity

- Rods are more sensitive to light than cones
  - Rods take less light to respond
  - Rods have greater convergence which results in summation of the inputs of many rods into ganglion cells increasing the likelihood of response
  - Trade-off is that circuits that are driven by rods cannot distinguish detail

Convergence in the Retina ...

- 126 million rods and cones converge to 1 million ganglion cells
- Higher convergence of rods than cones
  - Average of 120 rods to one ganglion cell
  - Average of 6 cones to one ganglion cell
  - Cones in fovea have 1 to 1 relation to ganglion cells

Figure 3.2 The wiring of the rods (left) and the cones (right). The spot and arrow above each receptor represents light that stimulates the receptor. The numbers represent the number of response units generated by the rods and the cones in response to a spot of intensity of 2.0.
Convergence and Detail

- All-cone foveal vision results in high visual acuity
  - One-to-one wiring leads to ability to discriminate details
  - Trade-off is that circuits that are driven by cones need more light to respond than rods

Lateral Inhibition of Neurons

- Experiments with eye of Limulus
  - Ommatidia allow recordings from a single receptor
  - Light shown into a single receptor led to rapid firing rate of nerve fiber
  - Adding light into neighboring receptors led to reduced firing rate of initial nerve fiber
Lateral Inhibition and Lightness Perception

- Three lightness perception phenomena explained by lateral inhibition
  - The Hermann Grid: Seeing spots at an intersection
  - Mach Bands: Seeing borders more sharply
  - Simultaneous Contrast: Seeing areas of different brightness due to adjacent areas

Hermann Grid

- People see an illusion of gray images in intersections of white areas
- Signals from bipolar cells cause effect
  - Receptors stimulated by dark areas inhibit the response of neighboring cells receiving input from white area
  - The lateral inhibition causes a reduced response which leads to the perception of gray
Mach Bands

- People see an illusion of enhanced lightness and darkness at borders of light and dark areas
  - Actual physical intensities indicate that this is not in the stimulus itself
  - Receptors responding to low intensity (dark) area have smallest output
  - Receptors responding to high intensity (light) area have largest output
Simultaneous Contrast

- People see an illusion of changed brightness or colour due to effect of adjacent area
  - An area that is of the same physical intensity appears:
    - Lighter when surrounded by a dark area
    - Darker when surrounded by a light area