**Chapter 3**

**VISUAL SYSTEM: The Eye**

Vision affects most of our experience by allowing us to perceive light. Visible light is a small slice of the electromagnetic spectrum. Light is made up of particles called photons that behave in a wavelike manner. Perceptually, wavelength correlates with color, and intensity correlates with brightness. In the basic process of vision, 1) light comes from a light source and falls on objects in the environment; 2) some wavelengths are reflected on those objects; 3) the reflected light enters the eye through the pupil and is focused on the retina by the cornea and lens through the process of accommodation; and 4) photoreceptors (rods and cones) in the retina transduce light energy into an electrochemical signal that is sent through the optic nerve to the brain. Rods prevail in the periphery. Cones are clustered in and near the fovea, the center of the retina. Both type of photoreceptors convert light into a neural signal using chemicals called photopigments. Rods and cones project to retinal ganglion cells, whose axons exit the eye through the optic nerve.

The duplex theory of vision suggests that there are two distinct systems in which our eyes work, the photopic system (associated with cones and daytime vision) and the scotopic system (associated with rods and nighttime vision). These two systems are different in terms of spectral sensitivity and acuity. Dark adaptation refers to adjusting to low light levels, whereas light adaptation refers to adjusting to high light levels. Retinal ganglion cells have receptive fields, which correspond to the region of space in the environment to which a certain a particular vision neuron responds. Edge detection is completed using center-surround receptive fields. Refractive errors of the eye include myopia (nearsightedness), hyperopia (farsightedness), presbyopia (old-sightedness), and astigmatism. Disease of the eye include macular degeneration and retinitis pigmentosa, which are partially treatable by vision prostheses.

Introduction

* Vision affects most of our experience.
* Our visual system provides us with useful information in order for us to navigate the world and to give us a sense of beauty and wonder.

Light

* Vision allows us to perceive light; therefore, the physics of light are important.
* According to modern physics, light is made up particles called photons that behave in wavelike manner.
* Waves have characteristics.
  + **Wavelength**—distance between peaks
  + **Intensity**—height of the wave
  + **Frequency**—number of waves per unit of time
* Perceptually, wavelength correlates with color, and intensity correlates with brightness.
* For humans, visible light represents wavelengths between 400 and 700nm on the **electromagnetic spectrum.**
  + Other animals can see light beyond this range, including ultraviolet light.
* Photons are useful when thinking about the amount of light.
  + Brighter light has more photons.
* Wavelength is associated with color; photons are associated with intensity and brightness.

The Eye and Its Role in the Visual System

* The eye is the primary organ of visual perception.
* The basic process of vision is as follows:
  + Light emanates from a light source and falls on objects in the environment.
  + In turn, some wavelengths are reflected on those objects.
  + The reflected light from objects is what we actually see.
  + The reflected light enters the eye through the pupil and is focused on the retina by the cornea and lens.
  + Rods and cones in the retina transduce light energy into an electrochemical signal that is transferred through the optic nerve to the brain for processing.

Field of View

* Human eyes are close to each other (~6cm) to allow for accurate depth perception.
  + Frontally placed eyes give humans and other primates two slightly different views of the world.
  + By computationally comparing the two images, the visual system can estimate distance.
* A person’s **field of view** is the part of the world that can be seen without eye movements.
  + In humans, it is approximately 190o horizontally and 140o vertically.

Anatomy of the Eye

* The **sclera** is the protective covering of the eye and provides the “white” of the eye.
* The **cornea** is the transparent part of the sclera that allows light in.
  + It is the major focusing element of the eye.
  + It is rigid, which means that changes in refraction must come from the adjustable lens.
* The **iris** is a muscle with an opening in the middle, called the **pupil**, which lets light through.
  + The iris gives color to eyes based on the amount of melanin in it.
  + **Heterochromia** describes the condition when a person has irises of two different colors.
* The **pupillary reflex** is an automatic process by which the iris contracts or relaxes in response to the amount of light entering the eye.
* Located just behind the iris, the **lens** is the adjustable focusing part of the eye.
  + **Accommodation** is the rapid process of adjusting the lens so that both near and far objects can be seen.
  + **Ciliary muscles** and **zonule fibers** control accommodation automatically by either making the lens more curved to focus on a close object or less curved to focus on a far object.
* Accommodation has limits.
  + The **near point** is the closest distance at which an eye can focus.
  + As we get older, the near point moves farther away from the eyes.
  + More common in older adults, **presbyopia** describes the condition in which focusing on close-up objects is difficult.

The Retina

* The goal of the processes of the iris, pupil, and lens is to focus an image on the **retina,** the eye’s photosensitive surface.

Anatomy of the Retina

* The retina is the location in the eye where transduction takes place.
* Two types of photoreceptors are in the retina, rods and cones.
  + Rods prevail in the periphery whereas cones are clustered in and near the **fovea,** the center of the retina.
  + There are about 120 million rods and 7 million cones in each eye.
* The fovea is unique anatomically.
  + It is the location on the retina with the highest density of cones.
  + Other retinal cells are not present at the retinal surface, allowing light to reach the surface of the fovea with minimal light scatter.
  + Both of these features evolved to enhance visual acuity, or clarity of vision.
* The **optic disc** is the part of the retina where the optic nerve leaves the eye and heads to the brain.
  + No receptors are at the optic disc, so this location is called the blind spot for that eye.

Retinal Physiology

* Rods and cones convert light into a neural signal by using chemicals called **photopigments**, the molecules that absorb light which releases an electric potential by altering the voltage in the cell.
* When a photopigment absorbs a photon of light, it changes shape, initiating a series of biochemical processes leading to a neural signal.
* Photopigments are composed of two bound molecules, an **opsin** in rods (chromopsin in cones) and **retinal** (a form of vitamin A).
  + In rods, the photopigment is called rhodopsin.
    - When a photon of light is absorbed by the photopigment, the rhodopsin straightens out and the photopigment breaks apart, causing the receptor to have a **hyperpolarization (**more negative charge inside relative to outside).
    - Hyperpolarization causes release of less of the neurotransmitter.
    - Thus, light is peculiarly inhibitory but only in the sense that the neurotransmitter (probably glutamate) is also inhibitory. This ultimately excites the visual system.
  + In cones, there are three classes of photopigments, each of which is maximally sensitive to a particular frequency of light.
    - The interaction of these three photopigments and subsequent perceptual processing give us complex color vision

The Duplex Theory of Vision

* The **duplex theory of vision** suggests that there are two distinct ways in which our eyes work.
  + The first system is called the **photopic system**, which is associated with cones and daytime vision.
  + The second system is called the **scotopic system**, which is associated with rods and nighttime vision.
* There is also a range of intermediate light intensity in which both systems work, which results in mesopic vision.

Spectral Sensitivity and the Purkinje Shift

* Spectral sensitivity refers to the relative sensitivity of a receptor type to all wavelengths.
* Rods are relatively more sensitive to shorter wavelengths and cones are relatively more sensitive to longer wavelengths.
* The difference in spectral sensitivity is called the **Purkinje shift**, which occurs as we transition from day vision to night vision and back again.

Spatial Summation and Acuity

* *Acuity* refers to the ability to see or resolve fine details.
* The relative acuity of photopic and scotopic vision is different because of how well each system carries out spatial summation.
* *Spatial summation* refers to the ability to pool light across different regions of space.
  + Rods are more sensitive to dim light than cones, partly because many rods connect to one retinal ganglion cell, allowing the scotopic system to pool responses across different rods in order to maximize sensitivity to light.
  + A drawback of pooling across rods, however, is that the scotopic systems loses some ability to converge light.
  + Each cone connects to only one retinal ganglion cell, providing phototopic vision with greater visual acuity.

Dark and Light Adaptation

* **Dark adaptation** is the process whereby the visual system’s sensitivity to low light levels is increased. It takes nearly 30 minutes to complete.
* **Light adaptation** the process whereby the visual system’s sensitivity to low light levels is decreased so that it can operate in higher light levels. It takes 5 minutes or less to complete.
* The difference in time to completion is due partly to light adaptation being driven actively by light entering the eye whereas dark adaptation is a passive response.
* Red light is not absorbed by the rods as well as other wavelengths, which is why car tail lights are red.

Retinal Ganglion Cells and Receptive Fields

* Each photoreceptor is connected to one or more retinal ganglion cells, which convey the signal into the optic nerve toward the brain.
* There are fewer ganglion cells than there are photoreceptors; therefore, most ganglion cells receive inputs from many different photoreceptors through a process called **convergence.**
* The **receptive field** is the area in the visual field that a particular vision neuron responds to.
  + Receptive fields of cones are quite small because one or a few cones maps onto each retinal ganglion cell.
  + Receptive fields of rods are much larger because many rods (sometimes hundreds) map onto a single ganglion cell.
* **Edge detection** involves determining the location at which one object ends and another begins.
  + The earliest stage of edge detection occurs in the retinal ganglion cells and is known as **center-surround receptive fields**.
    - In **on-center receptive fields**, the cell’s center produces activation, whereas the surround produces inhibition.
    - In **off-center receptive fields**, the cell’s center produces inhibition, whereas the surround produces activation.
    - In either case, if you present light that covers the entire receptive field of the cell, the response will be small, because the excitation and inhibition will cancel each other out.
  + The physiological mechanism that creates center-surround receptive fields is quite complex, involving horizontal cells, bipolar cells, rods, cones, and retinal ganglion cells.
  + **Lateral inhibition** facilitates edge detection by reducing a response of the eye to light stimulating one receptor by stimulation of nearby receptors, caused by inhibitory signals in horizontal cells.

Refractive Errors and Diseases of the Eye

Myopia (Nearsightedness)

* **Myopia** is a common form of mild visual impairment in which people can focus well on near objects but faraway objects appear blurry.
* The eye tends to be too long from front to back for the lens, projecting distant objects in front of the retina instead of onto it, making them appear blurry.
* To correct the problem, the lens must be weakened by using a diverging or negative artificial lens such as those in eyeglasses.

Hyperopia (Farsightedness) and Presbyopia (Old-Sightedness)

* **Hyperopia** is a common form of mild visual impairment in which people can focus well on far objects but near objects appear blurry.
* The eye tends to be too short for the lens, projecting near objects behind the retina instead of onto it, making them blurry.
* To correct the problem, the lens must be strengthened.
* **Presbyopia** is a condition associated with older eyes.
* As we age, the lens hardens, and the ciliary muscles lose power, making it difficult for older eyes to accommodate to nearby objects.
* As with hyperopia, the lens projects near objects behind the retina.

Astigmatism

* **Astigmatism** is a condition that develops from an irregular shape of the cornea or lens, making it impossible for the lens to accommodate a fully focused image.
* The cornea may be unsymmetrical, bending light more strongly in one direction.
* Thus, an object in a particular location and orientation will not be in focus.
* Some orientations are blurry but others are still relatively clear.

Cataracts

* **Cataracts** result from the clouding of the lens due to water buildup, eventually leading to blindness unless there is surgical intervention.
* Cataracts may result from complications of diabetes, exposure to ultraviolet light, or just natural aging.

Macular Degeneration

* **Macular degeneration** is a disease that destroys the fovea and the area around it, causing a blind spot in central vision.
* It occurs in two forms, wet and dry.
  + Wet macular degeneration has a very fast onset but is partially treatable.
    - It occurs because of abnormal growth of blood vessels, leading to the leaking of blood below the retina, causing scarring of the macula.
  + Dry macular degeneration may take years to develop but no treatment is available.
    - It results from degeneration of the cells that produce photopigments for the photoreceptors in the macula, resulting in impaired function of the photoreceptors.

Retinitis Pigmentosa

* **Retinitis pigmentosa** is an inherited progressive degenerative disease of the retina that may lead to blindness due to degeneration of the photoreceptors, particularly rods at the periphery.
* This results in tunnel vision at first but may result in total blindness as it spreads to the cones.
* Presently, no treatment is available.

***In Depth: Vision Prostheses***

* Vision prostheses are mechanical devices intended to restore visual function to blind individuals, particularly due to macular degeneration or retinitis pigmentosa.
* The goal of vision prostheses is to replace missing photoreceptors with essentially an “artificial retina”
* At present, the only visual prosthesis with FDA approval has limited visual acuity, with recognizing faces and reading still not options.