**(Slide 1) Lecture 15**

**Physiology of sensory systems.**

**Physiology of the visual sensory system**

**(Slide 2)** Lecture plan:

1. Physiology of Sensory Receptors.
2. Structural Receptor Types.
3. Functional Receptor Types.
4. Sensory Modalities.
5. General structure of the visual analyzer.
6. Features of the extraocular muscle functioning.
7. Functional structure of the retina.
8. Modification of photopigments upon perception of light.
9. Central Pathway of Visual Information.
10. Cortical Processing of Visual Information.

**(Slide 3)** A major role of sensory receptors is to help us learn about the environment around us, or about the state of our internal environment. Different types of stimuli from varying sources are received and changed into the electrochemical signals of the nervous system. This process is called sensory transduction. This occurs when a stimulus is detected by a receptor which generates a graded potential in a sensory neuron.

**(Slide 4)** If strong enough, the graded potential causes the sensory neuron to produce an action potential that is relayed into the central nervous system (CNS), where it is integrated with other sensory information − and sometimes higher cognitive functions − to become a conscious perception of that stimulus. The central integration may then lead to a motor response.

**(Slide 5)** Describing sensory function with the term sensation or perception is a deliberate distinction. Sensation is the activation of sensory receptors at the level of the stimulus. Perception is the central processing of sensory stimuli into a meaningful pattern involving awareness. Perception is dependent on sensation, but not all sensations are perceived. Receptors are the structures (and sometimes whole cells) that detect sensations. A receptor or receptor cell is changed directly by a stimulus. A transmembrane protein receptor is a protein in the cell membrane that mediates a physiological change in a neuron, most often through the opening of ion channels or changes in the cell signaling processes. Some transmembrane receptors are activated by chemicals called ligands. For example, a molecule in food can serve as a ligand for taste receptors. Other transmembrane proteins, which are not accurately called receptors, are sensitive to mechanical or thermal changes. Physical changes in these proteins increase ion flow across the membrane, and can generate a graded potential in the sensory neurons.

**(Slide 6)** Stimuli in the environment activate specialized receptors or receptor cells in the peripheral nervous system. Different types of stimuli are sensed by different types of receptors. Receptor cells can be classified into types on the basis of three different criteria: cell type, position, and function. Receptors can be classified structurally on the basis of cell type and their position in relation to stimuli they sense. They can also be classified functionally on the basis of the transduction of stimuli, or how the mechanical stimulus, light, or chemical changed the cell membrane potential.

**(Slide 7)** The cells that interpret information about the environment can be either (1) a neuron that has a free nerve ending (dendrites) embedded in tissue that would receive a sensation; (2) a neuron that has an encapsulated ending in which the dendrites are encapsulated in connective tissue that enhances their sensitivity; or (3) a specialized receptor cell, which has distinct structural components that interpret a specific type of stimulus. The pain and temperature receptors in the dermis of the skin are examples of neurons that have free nerve endings. Also located in the dermis of the skin are lamellated and tactile corpuscles, neurons with encapsulated nerve endings that respond to pressure and touch. The cells in the retina that respond to light stimuli are an example of a specialized receptor cell, a photoreceptor.

**(Slide 8)** Graded potentials in free and encapsulated nerve endings are called generator potentials. When strong enough to reach threshold they can directly trigger an action potential along the axon of the sensory neuron. Action potentials triggered by receptor cells, however, are indirect. Graded potentials in receptor cells are called receptor potentials. These graded potentials cause neurotransmitter to be released onto a sensory neuron causing a graded post-synaptic potential. If this graded post-synaptic potential is strong enough to reach threshold it will trigger an action potential along the axon of the sensory neuron.

**(Slide 9) Video. Generator potentials vs Action potentials in sensory receptor and Node of ranvier**

**(Slide 10)** Another way that receptors can be classified is based on their location relative to the stimuli. An **exteroceptor** is a receptor that is located near a stimulus in the external environment, such as the somatosensory receptors that are located in the skin. An **interoceptor** is one that interprets stimuli from internal organs and tissues, such as the receptors that sense the increase in blood pressure in the aorta or carotid sinus. Finally, a proprioceptor is a receptor located near a moving part of the body, such as a muscle or joint capsule, that interprets the positions of the tissues as they move.

**(Slide 11)** A third classification of receptors is by how the receptor transduces stimuli into membrane potential changes. Stimuli are of three general types. Some stimuli are ions and macromolecules that affect transmembrane receptor proteins by binding or by directly diffusing across the cell membrane. Some stimuli are physical variations in the environment that affect receptor cell membrane potentials. Other stimuli include the electromagnetic radiation from visible light. For humans, the only electromagnetic energy that is perceived by our eyes is visible light. Some other organisms have receptors that humans lack, such as the heat sensors of snakes, the ultraviolet light sensors of bees, or magnetic receptors in migratory birds.

**(Slide 12)** Receptor cells can be further categorized on the basis of the type of stimuli they transduce. Chemical stimuli can be detected by a **chemoreceptors** that detect chemical stimuli, such as a chemicals that lead to the sense of smell. **Osmoreceptors** respond to solute concentrations of body fluids. **Pain** is primarily a chemical and sometimes mechanical sense that interprets the presence of chemicals from tissue damage, or intense mechanical stimuli, through a nociceptor. Physical stimuli, such as pressure and vibration, as well as the sensation of sound and body position (balance), are interpreted through a **mechanoreceptor**. Another physical stimulus that has its own type of receptor is temperature, which is sensed through a **thermoreceptor** that is either sensitive to temperatures above (heat) or below (cold) normal body temperature.

**(Slide 13)** Ask anyone what the senses are, and they are likely to list the five major senses − taste, smell, touch, hearing, and sight. However, these are not all of the senses. The most obvious omission from this list is balance. Also, what is referred to simply as touch can be further subdivided into pressure, vibration, stretch, and hair-follicle position, on the basis of the type of mechanoreceptors that perceive these touch sensations. Other overlooked senses include temperature perception by thermoreceptors and pain perception by nociceptors.

**(Slide 14)** Within the realm of physiology, senses can be classified as either general or special. A general sense is one that is distributed throughout the body and has receptor cells within the structures of other organs. Mechanoreceptors in the skin, muscles, or the walls of blood vessels are examples of this type. General senses often contribute to the sense of touch, as described above, or to proprioception (body position) and kinesthesia (body movement), or to a visceral sense, which is most important to autonomic functions. A special sense is one that has a specific organ devoted to it, namely the eye, inner ear, tongue, or nose.

**(Slide 15)** Each of the senses is referred to as a sensory modality. Modality refers to the way that information is encoded into a perception. The main sensory modalities can be described on the basis of how each stimulus is transduced and perceived. The chemical senses include taste and smell. The general sense that is usually referred to as touch includes chemical sensation in the form of nociception, or pain. Pressure, vibration, muscle stretch, and the movement of hair by an external stimulus, are all sensed by mechanoreceptors and perceived as touch or proprioception. Hearing and balance are also sensed by mechanoreceptors. Finally, vision involves the activation of photoreceptors.

**(Slide 16)** Listing all the different sensory modalities, which can number as many as 17, involves separating the five major senses into more specific categories, or submodalities, of the larger sense. An individual sensory modality represents the sensation of a specific type of stimulus. For example, the general sense of touch, which is known as somatosensation, can be separated into light pressure, deep pressure, vibration, itch, pain, temperature, or hair movement.

**(Slide 17)** Vision is the special sense of sight that is based on the transduction of light stimuli received through the eyes. The eyes are located within either orbit in the skull. The bony orbits surround the eyeballs, protecting them and anchoring the soft tissues of the eye. The eyelids, with lashes at their leading edges, help to protect the eye from abrasions by blocking particles that may land on the surface of the eye. The inner surface of each lid is a thin membrane known as the palpebral conjunctiva. The conjunctiva extends over the white areas of the eye (the sclera), connecting the eyelids to the eyeball. Tears are produced by the lacrimal gland, located beneath the lateral edges of the nose. Tears produced by this gland flow through the lacrimal duct to the medial corner of the eye, where the tears flow over the conjunctiva, washing away foreign particles.

**(Slide 18)** Movement of the eye within the orbit is accomplished by the contraction of six extraocular muscles that originate from the bones of the orbit and insert into the surface of the eyeball. Four of the muscles are arranged at the cardinal points around the eye and are named for those locations. They are the superior rectus, medial rectus, inferior rectus, and lateral rectus. When each of these muscles contract, the eye to moves toward the contracting muscle. For example, when the superior rectus contracts, the eye rotates to look up. The superior oblique originates at the posterior orbit, near the origin of the four rectus muscles. However, the tendon of the oblique muscles threads through a pulley-like piece of cartilage known as the trochlea. The tendon inserts obliquely into the superior surface of the eye. The angle of the tendon through the trochlea means that contraction of the superior oblique rotates the eye medially. The inferior oblique muscle originates from the floor of the orbit and inserts into the inferolateral surface of the eye. When it contracts, it laterally rotates the eye, in opposition to the superior oblique. Rotation of the eye by the two oblique muscles is necessary because the eye is not perfectly aligned on the sagittal plane. When the eye looks up or down, the eye must also rotate slightly to compensate for the superior rectus pulling at approximately a 20-degree angle, rather than straight up. The same is true for the inferior rectus, which is compensated by contraction of the inferior oblique. A seventh muscle in the orbit is the levator palpebrae superioris, which is responsible for elevating and retracting the upper eyelid, a movement that usually occurs in concert with elevation of the eye by the superior rectus.

**(Slide 19) Video**\_**Eye Movements and Eye Muscles**

**(Slide 20)** The extraocular muscles are innervated by three cranial nerves. The lateral rectus, which causes abduction of the eye, is innervated by the abducens nerve. The superior oblique is innervated by the trochlear nerve. All of the other muscles are innervated by the oculomotor nerve, as is the levator palpebrae superioris. The motor nuclei of these cranial nerves connect to the brain stem, which coordinates eye movements.

**(Slide 21)** The eye itself is a hollow sphere composed of three layers of tissue. The outermost layer is the fibrous tunic, which includes the white sclera and clear cornea. The sclera accounts for five sixths of the surface of the eye, most of which is not visible, though humans are unique compared with many other species in having so much of the «white of the eye» visible. The transparent cornea covers the anterior tip of the eye and allows light to enter the eye. The middle layer of the eye is the vascular tunic, which is mostly composed of the choroid, ciliary body, and iris. The choroid is a layer of highly vascularized connective tissue that provides a blood supply to the eyeball. The choroid is posterior to the ciliary body, a muscular structure that is attached to the lens by zonule fibers. These two structures bend the lens, allowing it to focus light on the back of the eye. Overlaying the ciliary body, and visible in the anterior eye, is the iris—the colored part of the eye. The iris is a smooth muscle that opens or closes the pupil, which is the hole at the center of the eye that allows light to enter. The iris constricts the pupil in response to bright light and dilates the pupil in response to dim light. The innermost layer of the eye is the neural tunic, or retina, which contains the nervous tissue responsible for photoreception.

**(Slide 22)** The eye is also divided into two cavities: the anterior cavity and the posterior cavity. The anterior cavity is the space between the cornea and lens, including the iris and ciliary body. It is filled with a watery fluid called the aqueous humor. The posterior cavity is the space behind the lens that extends to the posterior side of the interior eyeball, where the retina is located. The posterior cavity is filled with a more viscous fluid called the vitreous humor.

**(Slide 23)** The retina is composed of several layers and contains specialized cells for the initial processing of visual stimuli. The photoreceptors (rods and cones) change their membrane potential when stimulated by light energy. The change in membrane potential alters the amount of neurotransmitter that the photoreceptor cells release onto bipolar cells in the outer synaptic layer. It is the bipolar cell in the retina that connects a photoreceptor to a retinal ganglion cell (RGC) in the inner synaptic layer. There, amacrine cells additionally contribute to retinal processing before an action potential is produced by the retinal ganglion cell. The axons of retinal ganglion cells, which lie at the innermost layer of the retina, collect at the optic disc and leave the eye as the optic nerve. Because these axons pass through the retina, there are no photoreceptors at the very back of the eye, where the optic nerve begins. This creates a “blind spot” in the retina, and a corresponding blind spot in our visual field.

**(Slide 24) Video\_The Retina**

**(Slide 25)** Note that the photoreceptors in the retina (rods and cones) are located behind the axons, retinal ganglion cells, bipolar cells, and retinal blood vessels. A significant amount of light is absorbed by these structures before the light reaches the photoreceptor cells. However, at the exact center of the retina is a small area known as the fovea. At the fovea, the retina lacks the supporting cells and blood vessels, and only contains photoreceptors. Therefore, visual acuity, or the sharpness of vision, is greatest at the fovea. This is because the fovea is where the least amount of incoming light is absorbed by other retinal structures. As one moves in either direction from this central point of the retina, visual acuity drops significantly. In addition, each photoreceptor cell of the fovea is connected to a single retinal ganglion cell. Therefore, this retinal ganglion cell does not have to integrate inputs from multiple photoreceptors, which reduces the accuracy of visual transduction. Toward the edges of the retina, several photoreceptors converge on retinal ganglion cells (through the bipolar cells) up to a ratio of 50 to 1. The difference in visual acuity between the fovea and peripheral retina is easily evidenced by looking directly at a word in the middle of this paragraph.

**(Slide 26)** The visual stimulus in the middle of the field of view falls on the fovea and is in the sharpest focus. Without moving your eyes off that word, notice that words at the beginning or end of the paragraph are not in focus. The images in your peripheral vision are focused by the peripheral retina, and have vague, blurry edges and words that are not as clearly identified. As a result, a large part of the neural function of the eyes is concerned with moving the eyes and head so that important visual stimuli are centered on the fovea.

**(Slide 27)** Light falling on the retina causes chemical changes to pigment molecules in the photoreceptors, ultimately leading to a change in the activity of the retinal ganglion cells. Photoreceptor cells have two parts, the inner segment and the outer segment. The inner segment contains the nucleus and other common organelles of a cell, whereas the outer segment is a specialized region in which photoreception takes place. There are two types of photoreceptors—rods and cones—which differ in the shape of their outer segment. The rod-shaped outer segments of the rod photoreceptor contain a stack of membrane-bound discs that contain the photosensitive pigment rhodopsin. The cone-shaped outer segments of the cone photoreceptor contain their photosensitive pigments in infoldings of the cell membrane. There are three cone photopigments, called opsins, which are each sensitive to a particular wavelength of light. The wavelength of visible light determines its color. The pigments in human eyes are specialized in perceiving three different primary colors: red, green, and blue.

**(Slide 28)** At the molecular level, visual stimuli cause changes in the photopigment molecule that lead to changes in membrane potential of the photoreceptor cell. A single unit of light is called a photon, which is described in physics as a packet of energy with properties of both a particle and a wave. The energy of a photon is represented by its wavelength, with each wavelength of visible light corresponding to a particular color. Visible light is electromagnetic radiation with a wavelength between 380 and 720 nm. Wavelengths of electromagnetic radiation longer than 720 nm fall into the infrared range, whereas wavelengths shorter than 380 nm fall into the ultraviolet range. Light with a wavelength of 380 nm is blue whereas light with a wavelength of 720 nm is dark red. All other colors fall between red and blue at various points along the wavelength scale.

**(Slide 29)** Opsin pigments are actually transmembrane proteins that contain a cofactor known as retinal. Retinal is a hydrocarbon molecule related to vitamin A. When a photon hits retinal, the long hydrocarbon chain of the molecule is biochemically altered. Specifically, photons cause some of the double-bonded carbons within the chain to switch from a cis to a trans conformation. This process is called photoisomerization. Before interacting with a photon, retinal’s flexible double-bonded carbons are in the cis conformation. This molecule is referred to as 11-cis-retinal. A photon interacting with the molecule causes the flexible double-bonded carbons to change to the trans–conformation, forming all-trans-retinal, which has a straight hydrocarbon chain.

**(Slide 30)** The shape change of retinal in the photoreceptors initiates visual transduction in the retina. Activation of retinal and the opsin proteins result in activation of a G protein. The G protein changes the membrane potential of the photoreceptor cell, which then releases less neurotransmitter into the outer synaptic layer of the retina. Until the retinal molecule is changed back to the 11-cis-retinal shape, the opsin cannot respond to light energy, which is called bleaching. When a large group of photopigments is bleached, the retina will send information as if opposing visual information is being perceived. After a bright flash of light, afterimages are usually seen in negative. The photoisomerization is reversed by a series of enzymatic changes so that the retinal responds to more light energy.

**(Slide 31)** The opsins are sensitive to limited wavelengths of light. Rhodopsin, the photopigment in rods, is most sensitive to light at a wavelength of 498 nm. The three color opsins have peak sensitivities of 564 nm, 534 nm, and 420 nm corresponding roughly to the primary colors of red, green, and blue. The absorbance of rhodopsin in the rods is much more sensitive than in the cone opsins; specifically, rods are sensitive to vision in low light conditions, and cones are sensitive to brighter conditions. In normal sunlight, rhodopsin will be constantly bleached while the cones are active. In a darkened room, there is not enough light to activate cone opsins, and vision is entirely dependent on rods. Rods are so sensitive to light that a single photon can result in an action potential from a rod’s corresponding retinal ganglion cell.

**(Slide 32)** The three types of cone opsins, being sensitive to different wavelengths of light, provide us with color vision. By comparing the activity of the three different cones, the brain can extract color information from visual stimuli. For example, a bright blue light that has a wavelength of approximately 450 nm would activate the “red” cones minimally, the “green” cones marginally, and the “blue” cones predominantly. The relative activation of the three different cones is calculated by the brain, which perceives the color as blue. However, cones cannot react to low-intensity light, and rods do not sense the color of light. Therefore, our low-light vision is—in essence—in grayscale. In other words, in a dark room, everything appears as a shade of gray. If you think that you can see colors in the dark, it is most likely because your brain knows what color something is and is relying on that memory.

**(Slide 33) Video\_Color vision**

**(Slide 34) Central Pathway of Visual Information.** The connections of the optic nerve are more complicated than those of other cranial nerves. Instead of the connections being between each eye and the brain, visual information is segregated between the left and right sides of the visual field. In addition, some of the information from one side of the visual field projects to the opposite side of the brain. Within each eye, the axons projecting from the medial side of the retina decussate at the optic chiasm. For example, the axons from the medial retina of the left eye cross over to the right side of the brain at the optic chiasm. However, within each eye, the axons projecting from the lateral side of the retina do not decussate. For example, the axons from the lateral retina of the right eye project back to the right side of the brain. Therefore the left field of view of each eye is processed on the right side of the brain, whereas the right field of view of each eye is processed on the left side of the brain.

**(Slide 35)** A unique clinical presentation that relates to this anatomic arrangement is the loss of lateral peripheral vision, known as bilateral hemianopia. This is different from “tunnel vision” because the superior and inferior peripheral fields are not lost. Visual field deficits can be disturbing for a patient, but in this case, the cause is not within the visual system itself. A growth of the pituitary gland presses against the optic chiasm and interferes with signal transmission. However, the axons projecting to the same side of the brain are unaffected. Therefore, the patient loses the outermost areas of their field of vision and cannot see objects to their right and left.

**(Slide 36)** Extending from the optic chiasm, the axons of the visual system are referred to as the optic tract instead of the optic nerve. The optic tract has three major targets, two in the diencephalon and one in the midbrain. The connection between the eyes and diencephalon is demonstrated during development, in which the neural tissue of the retina differentiates from that of the diencephalon by the growth of the secondary vesicles. The connections of the retina into the CNS are a holdover from this developmental association. The majority of the connections of the optic tract are to the thalamus—specifically, the lateral geniculate nucleus. Axons from this nucleus then project to the visual cortex of the cerebrum, located in the occipital lobe. Another target of the optic tract is the superior colliculus.

**(Slide 37)** In addition, a very small number of retinal ganglion cell axons project from the optic chiasm to the suprachiasmatic nucleus of the hypothalamus. These retinal ganglion cells are photosensitive, in that they respond to the presence or absence of light. Unlike the photoreceptors, however, these photosensitive retinal ganglion cells cannot be used to perceive images. By simply responding to the absence or presence of light, these retinal ganglion cells can send information about day length. The perceived proportion of sunlight to darkness establishes the circadian rhythm of our bodies, allowing certain physiological events to occur at approximately the same time every day.

**(Slide 38) Cortical Processing of Visual Information.** Likewise, the topographic relationship between the retina and the visual cortex is maintained throughout the visual pathway. The visual field is projected onto the two retinae, as described above, with sorting at the optic chiasm. The right peripheral visual field falls on the medial portion of the right retina and the lateral portion of the left retina. The right medial retina then projects across the midline through the optic chiasm. This results in the right visual field being processed in the left visual cortex. Likewise, the left visual field is processed in the right visual cortex. Though the chiasm is helping to sort right and left visual information, superior and inferior visual information is maintained topographically in the visual pathway. Light from the superior visual field falls on the inferior retina, and light from the inferior visual field falls on the superior retina. This topography is maintained such that the superior region of the visual cortex processes the inferior visual field and vice versa. Therefore, the visual field information is inverted and reversed as it enters the visual cortex—up is down, and left is right. However, the cortex processes the visual information such that the final conscious perception of the visual field is correct. The topographic relationship is evident in that information from the foveal region of the retina is processed in the center of the primary visual cortex. Information from the peripheral regions of the retina are correspondingly processed toward the edges of the visual cortex. Similar to the exaggerations in the sensory homunculus of the somatosensory cortex, the foveal-processing area of the visual cortex is disproportionately larger than the areas processing peripheral vision.

**(Slide 39)** In an experiment performed in the 1960s, subjects wore prism glasses so that the visual field was inverted before reaching the eye. On the first day of the experiment, subjects would duck when walking up to a table, thinking it was suspended from the ceiling. However, after a few days of acclimation, the subjects behaved as if everything were represented correctly. Therefore, the visual cortex is somewhat flexible in adapting to the information it receives from our eyes.

**(Slide 40)** The cortex has been described as having specific regions that are responsible for processing specific information; there is the visual cortex, somatosensory cortex, gustatory cortex, etc. However, our experience of these senses is not divided. Instead, we experience what can be referred to as a seamless percept. Our perceptions of the various sensory modalities − though distinct in their content − are integrated by the brain so that we experience the world as a continuous whole.

**(Slide 41)** In the cerebral cortex, sensory processing begins at the primary sensory cortex, then proceeds to an association area, and finally, into a multimodal integration area. For example, the visual pathway projects from the retinae through the thalamus to the primary visual cortex in the occipital lobe. This area is primarily in the medial wall within the longitudinal fissure. Here, visual stimuli begin to be recognized as basic shapes. Edges of objects are recognized and built into more complex shapes. Also, inputs from both eyes are compared to extract depth information. Because of the overlapping field of view between the two eyes, the brain can begin to estimate the distance of stimuli based on binocular depth cues.

**(Slide 41)** Lesson assignment:

John E. Hall and Michael E. Hall. Textbook of Medical Physiology. 14th Edition. Elsever.

Pages: 675 – 682.

Questions that we will analyze for a lesson on this topic:

1. Physiology of Sensory Receptors.
2. Structural Receptor Types.
3. Functional Receptor Types.
4. Sensory Modalities.
5. General structure of the visual analyzer.
6. Features of the extraocular muscle functioning.
7. Functional structure of the retina.
8. Modification of photopigments upon perception of light.
9. Central Pathway of Visual Information.
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Finish for today

The full lecture is at the indicated website.

**Thank you for attention**