Slide #2: Principles of Sensory System organization
In the last few sections, we have discussed the way in which the body responds to nervous system signaling via the release of neurotransmitter. This lecture relates to the system in our bodies that is responsible for detecting and reporting change—the sensory system. The first slide describes some of the major principles underlying the way in which the sensory system functions. Principle #1 states that sensory receptors are specific and produce a specific type of sensation when stimulated. The term “modalities” means types of sensation. Principle #2 states that the pathway that is traveled by a signal bringing incoming information is also specific to a reporting a certain type of stimulus. Principle #3 refers to the decussation of pyramids. This means that the sensory fibers cross from one side of the spinal cord to the other as the sensory information travels from the sensory receptor to the brain. Principle #4 states that the thalamus is the relay station for all sensory information, with the exception of smell. The sense of smell is transmitted by sensory neurons to the olfactory bulb and then to the olfactory cortex, which sits behind the temporal lobes. Principle #5 refers to cerebral lateralization. Certain parts of the brain specifically interpret initial sensory information. Principle #6 says that the descending pathways have an influence over those that bring information in (sensory or ascending pathways).

Slide #3: Transduction: We have mentioned the term “transduction” a few times before, when we discussed signal transduction mechanisms and the transduction of steroids from the cytoplasm to the nucleus of a cell. In this case, transduction refers to the ability to transform information detected by the sensory receptors into a signal that can be sent.

Slide #4: Category of sensory receptors Sensory receptors can be categorized in several ways. This slide represents two of these; categorizing sensory receptors by the type of stimulus that is detected and sent, and by type of sensory information being sent. In the first category, we see that the chemoreceptors, photoreceptors, thermoreceptors, and nociceptors (these detect pain); The later includes proprioceptors, which help determine the position of the body in space, cutaneous skin receptors which actively report stimulus received from the outside environment.

Slide #5: Tonic and phasic receptors: Tonic receptors are receptors that continue to signal, no matter how long they are stimulated. They do not adapt. A good example of this type of receptor are nociceptors (pain receptors). Pain signals a serious problem, with possible tissue damage. Therefore, pain signals will be sent no matter how long a particular event takes place. Phasic receptors are quick responding receptors that tell you that something his happening, but then reduce the rate of firing (signaling) if the stimulus is maintained. Think about putting on your watch in the morning. You know it is on your arm, but you aren’t reminded of it after awhile.

Slide #6: Image shows the response to stimulus in tonic vs phasic receptors.

Slide #7: Law of specific nerve energies: Have you ever wondered someone sees “stars” when they are punched in the eye? This occurs because the photoreceptors in the eye are stimulated by the punch! Photoreceptors are sensitive to light, but if they are strongly stimulated, you will see light (stars) even though the stimulus wasn’t appropriate. That’s because a sensory neuron always gives rise to the same sensation, no matter how it is stimulated.

Slide #8: Generator potential: When a sensory neuron is stimulated, a graded potential called a generator potential is initiated over the nerve cell bodies and dendrites as a consequence of the stimulation of the sensory receptor. Remember that this signal has to be transduced, or converted, into something that can be sent. That conversion results in a generator potential. So, the generator potential becomes the bridge between the actual stimulus and the signal that is transmitted to the CNS.

Slide #9: Cutaneous sensations: Your skin has receptors for touch, pressure, temperature, and pain. Some of these receptors are specialized, like Meissner’s or Pacinian corpuscle, and
others are just naked dendrites. There are two major neural pathways that take the signals received at these receptors to the CNS. One is for pressure receptors and proprioceptors, the other for hot/cold/pain receptors.

**Slide #10: Neural pathway for pressure receptors:** Follow the pathway from the stimulus to the postcentral gyrus of the sensory cortex in the brain. Note that the afferent neurons for pressure are myelinated, and that the fibers decussate in the medulla oblongata. They also synapse first on the medial lemniscus and finally in the thalamus, the brain’s relay station, before going to the sensory cortex. The medial lemniscus begins in the medulla oblongata and moves into the pons. See the picture below.

![Diagram of neural pathway for pressure receptors](image)

**Slide #11: Neural pathway for pain receptors:** Follow the pathway from stimulus to postcentral gyrus. Note that the afferent fibers are unmyelinated and that they synapse early in the pathway on 2\(^{nd}\) order interneurons in the spinal cord. Like the touch/pressure receptors, they also synapse on 3\(^{rd}\) order neurons in the thalamus before arriving in the postcentral gyrus.

**Slide #12: Receptive fields:** A receptive field is the area of the skin located just above sensory receptors. If you stimulate that area, it will change the firing rate of the neuron below it. In some parts of your skin, there are fewer sensory receptors and the receptive fields are large and not overlapping. In these areas, it is hard to localize accurately the point of the stimulus because if any part of that receptive field is stimulated, it will map the stimulus to the center of that receptive field. These areas have low sensory acuity. In other areas of your body, such as your fingertips, there is a greater ability to precisely determine the location of stimulus. This is because the sensory receptors are small and overlapping. Overlapping sensory receptors exhibit lateral inhibition of the other sensory receptors they overlay. So, it is easier to determine exactly where the stimulus was received. This ability is tested by measuring how close two points can be to each other and still be detected as being two points (two point discrimination). In order to detect two points, you have to stimulate two different receptor fields. Therefore, if the receptors are larger and farther apart, you can’t get two points close together and detect them as two distinct points. If the receptor fields are small, overlapping, and heavily distributed, it is easier to detect two separate points close to each other because you can easily stimulate two receptor fields. Therefore, this area is said to exhibit greater sensory acuity. You did this in lab with the calipers.

**Slide #13:** Image showing overlapping receptive fields.

**Slide #14:** Image showing lateral inhibition and how it makes the detection of stimulus more precise.
**Slide #15: Somatosensory cortex:** Some parts of the body have more sensory neurons than others. The homunculus of the somatosensory cortex in this image shows the approximate percentage of the brain that is dedicated to sensory perception in that region of the body. As you can see, the lips, face, fingertips and hands have significantly more inervation than the rest of the body and the viscera.

**Slide #16: Vestibular apparatus and equilibrium:** Balance and equilibrium are largely governed by two regions of the inner ear, the utricle and saccule (otolith organs), and the semicircular canals, which are arranged at 90° angles to each other.

**Slide #17: Otolith organs.** The otolith organs are composed of two structures, the utricle and the saccule. Note that the cells emanating from the bottom of the structure contain small hairs that protrude into the otolithic membrane. This membrane is more like a thickened, gelatinous substance that overlies the cells. On top of the otolithic membrane are the otoliths, or ear stones (yes, we all have “rocks in our heads”!) The otoliths weigh down the membrane and make it more sensitive. When your position changes or you accelerate, the membrane shifts, bending the hair cells. The bending of the hair cells creates an increase in firing that generates an action potential in the sensory nerve fibers. The otolith organs detect linear acceleration and tell you which way is up.

**Slide #18: Sensory hair cells:** Image shows the effect of hair bending. Note that one of the "hairs" is longer. This is called a kinocilium. The shorter hairs are the stereocilia. When the stereocilia bend toward the kinocilium, firing increases. When the stereocilia move in the opposite direction, away from the kinocilium, firing decreases.

**Slide #19: Semicircular canals:** This part of the vestibular apparatus detects rotational acceleration, and consists of 3 canals at 90° angles to each other. Each canal is composed of two parts, the ampula, which contains the hair cells, and the cupula, the gelatinous membrane overlying the hair cells. As previously described, when the hair cells bend toward the kinocilium, a depolarization occurs in the membrane that sets up an action potential in cranial nerve #8, the vestibulocochlear nerve.

**Slide #20: Sensory hair cells:** shows the image described in slide #19.

**Slide #21: Hearing:** In addition to the vestibular apparatus, the ear also contains the specialized sensory receptors associated with hearing. These receptors respond to sound waves. Frequency in a sound wave is associated with pitch and is measured in hertz. The higher the frequency, the higher the pitch. Increased pitch is reflected as a shorter distance between peaks in the sound wave, and lower pitch is reflected by increased distance. Intensity of sound is measured in decibels. The louder the sounded, the greater the amplitude of the sound waves.

**Slide #22: Pathway of sound through the ear.** Sound enters the ear at the auricle or pinna, moves through the ear canal to the tympanic membrane, where it sets up vibrations. Those vibrations are transferred to the auditory ossicles beginning with the malleus, then the incus, and finally the stapes, all located in the middle ear. The stapes is attached to the oval window of the inner ear. When it moves, it sets up vibrations in the fluid filled membranes within the inner ear that cause the hair cells in the organ of Corti to bend. This results in a depolarization that generates an action potential in CN VIII, the vestibulocochlear nerve, culminating in the detection of sound in the auditory cortex of the temporal lobe of the brain.

**Slide #23: Hearing:** Simplified graphic showing the three fluid filled regions of the inner ear, scala vestibuli, scala tympani, cochlear duct.

**Slide #24: Another graphic (read)**

**Slide #25: Another graphic (read) Shows movement of fluid**
**Slide #26:** Another graphic. Shows relationship of the organ of Corti to the anatomy of the inner ear. Graphic includes image of bending hair cells in organ of Corti.

**Slide #27:** **Organ of Corti:** Note the scanning electron micrograph showing the arrangement of hair cells.

**Slide #28:** **Neural pathway of hearing.** From the organ of Corti, the signal is sent through CN VIII (vestibulocochlear nerve) to the Cochlear nucleus in the medulla. From there it moves through the midbrain to the medial geniculate nucleus of the thalamus, and finally to the auditory cortex in the temporal lobe.

**Slide #29:** **Conduction deafness vs. sensory deafness:** There are two classifications of deafness based on whether there is something preventing sound waves from reaching the ear (conduction deafness) or damage to the sensory portion of the ear so that sound waves don't register properly (sensory deafness). In conduction deafness, it is sometimes not possible to hear all frequencies. Typical causes of conduction deafness are otitis media (middle ear infection), accumulation of ear wax, and occasionally, foreign bodies, such as cockroaches, or something else equally gross blocking the ear canal. Sensory deafness can be genetic, but it can also be the result of exposure to loud sounds that damage the hair cells of the inner ear.

**Slide #30:** **Tests for deafness:** Weber’s test and Rinne’s test (you did these in lab).

**Slide #31:** **Damaged organ of Corti:** This image is from JAMA and shows the results of exposure to loud sounds. Note the damaged region through the basilar membrane and organ of Corti depicted in image on right (left is normal). Moral: Always carry earplugs if you know you are going to be exposed to loud sound for any period of time. Damage can be permanent.

**Slide #32:** **Vision: parts of the eye:** Drawing of sagittal section of eye showing the visual axis (ie, the path that light takes when entering the eye).

**Slide #33:** **Pathway of light through eye:** Self-explanatory...make sure you know this pathway!

**Slide #34:** **Refraction:** Refraction refers to the way in which light bends as it goes through media of differing densities. You can demonstrate this for yourself by filling a glass half full with water, holding a pencil behind the glass and looking through the glass from the front at the pencil. What happens to the image of the pencil? The same type of thing happens as light enters the eye. It bends at the cornea, where the greatest refractive index is found. This is because the air and the cornea are very different in density. Refractive index is measured in diopters, and the refractory index between the air and the cornea is 43 diopters. The next point in which light is bent is at the lens. Notice that the refractory index can vary between 13-26 diopters. That is because the lens is elastic and the shape of the lens is changed, depending on whether you are trying to see something close up or far away. For images close up, the lens is relaxed and lemon shaped. To see images far away, the lens is flattened. This is a normal process called accommodation. The next part of the eye where the light is bent is at the retina itself.

**Slide #35:** **Accommodation:** This is a normal process that allows the eye to focus images on the retina that are a varying distance from the eye. This is accomplished by changing the shape of the lens. When the lens is relaxed, it is shaped like a lemon drop. To understand this process, you need to remember the structure of the eye from anatomy. In near vision (seeing things that are near), the ciliary muscle surrounding the eye (this is a circular muscle) contracts. When circular muscle contracts, it becomes smaller, and moves closer to the lens. This allows the zonular fibers that attach the lens to the ciliary muscle to relax. The lens remains lemon shaped and you are able to clearly see the object that is near. When something you are trying to see is farther away, the ciliary muscle relaxes, which makes it larger. The zonular fibers tighten, and the lens flattens out. Now you are able to clearly see the image that is farther away.
Slide #36: Image of eye with ciliary muscle and explanation

Slide #37: Visual acuity: Terms associated with vision. Normal vision is called emmetropia. This means that you can see at 20 feet (20/) what normal people can see at 20 feet (/20). Ametropia means that the light is not bending properly in your eye so that the image does not focus clearly on the retina. Three examples of this are myopia, hyperopia, and astigmatism. In myopia, the eyeball itself is too long and the image converges before the retina. This condition is referred to as “nearsighted” and is corrected by placing a concave lens in front of the eye. Hyperopia, or “farsightedness”, is the condition in which the eyeball is too short. The image converges behind the eye and a convex lens is placed in front of the eye to shorten the distance and cause the image to converge on the retina. In astigmatism, the surface of the eye has an irregularity that effects the final image. Presbyopia is a condition that occurs as we age. The lens continues to grow and occupies a larger space in the eye. This makes it difficult for the lens to completely relax for close vision, and older people “suddenly” have to wear glasses in order to see things close up. A convex lens is used to correct this condition. Many individuals are now having their vision corrected with laser eye surgery. Although this is an effective treatment for myopia and hyperopia, there is currently no way to correct presbyopia by this method.

Slide #38: Astigmatism: When the cornea, lens, or retina exhibit asymmetry, the image is blurred.

Slide #39: Images summarize the abnormalities discussed in the previous slides.

Slide #40: Structure of the retina: The retina is composed of a series of specialized cells. Notice that the pigmented epithelium is all the way in the back of the eye. Immediately in front of the epithelium are the rods and cones. Rods are associated with black/white or night vision, cones are associated with color vision. There are many more rods than cones. The rods and cones are the photoreceptors of the eye. As you move up toward the lumen, the next cells are horizontal cells, then bipolar cells, followed by ganglion and amacrine cells. It is in the ganglion and amacrine cells that the action potentials are generated. This is then sent to the optical nerve and from there, to the visual cortex of the brain.

Slide #41: Scanning electron micrograph and drawing showing the structure of the retina and its component cells.

Slide #42: Retinal cells: Action potentials occur only in the ganglion and amacrine cells in this series of cells found in the retina. All of the other cells in the series, photoreceptors, bipolar cells, horizontal cells, produce graded potentials. Photoreceptors are more positive than most neurons because of a constant flux of Na+. This is called a “dark current” and makes them extremely sensitive to change, so that the process of resolving an image is very fast.
Slide #43: Rods: These photoreceptors contain the protein rhodopsin, which transmits the colors blue and red, and absorbs light wave lengths in the range of green. The maximum absorption of the rods is 500nm. Rhodopsin is made up of two substances; the protein opsin (scotopsin), and retinal, a light absorbing pigment that comes from the fat soluble vitamin A. In the dark, these receptors gradually increase in sensitivity. That is why it is a little difficult to see initially in the dark, but your dark vision gradually improves. It takes about 30 minutes to optimize your vision in the dark.

Slide #44: Rhodopsin: The only light sensitive reaction in vision involves rhodopsin. When light strikes the rods, it causes opsin to change shape so that it can no longer associate with the retinal. This is called bleaching. Ultimately, this results in hyperpolarization that results in an action potential in the optic nerve.

Slide #45: Photoisomerization leads to phototransduction: Pathway shows that the events leading to an action potential in the optic nerve. Remember that isomers are chemicals that compositionally the same, but structurally oriented in a different way. Therefore, it is a change in the shape of the rhodopsin that initiates a split in the next chemical in the sequence, transducin. The transducin is in fact a G-protein, which subsequently dissociates activating cGMP. This causes Na+ channels to close, resulting in a hyperpolarization. Because both rods and cones continually release inhibitory neurotransmitter when they are not stimulated, the hyperpolarization decreases the amount of inhibitory NT produced, leading to a graded potential in the horizontal and ganglion cells, which ultimately results in the action potential in the optic nerve.

Slide #46: Cones. The greatest visual acuity is found in the cones. Although the cones exhibit greater visual acuity, they are less sensitive to light than the rods. The trichromatic theory of color vision states that there are three types of cones; blue, green and red. Cones are composed of a substance similar to rhodopsin, often referred to as “cone pigments” or “color pigments”. These are also composed of retinal (retinene) and associated protein. In the fovea centralis, the cones exist in a 1:1 ratio with the ganglion cells, and therefore, the fovea is the area of greatest visual acuity in the eye.

Slide #47: Image shows range of absorption of photopigments in cone.

Slide #48: Photoreceptor activation and action potential: Shows the pathway beginning with the release of inhibitory neurotransmitter, glutamate, from rods and cones at a constant rate, to the action potential in the optic nerve. This image shows what follows after the hyperpolarization in the rods and cones.

Slide #49: Image shows membrane hyperpolarization and depolarization by cell population.

Slide #50: Neural pathways from retina: From the optic nerve, two tracts move toward the brain. The outside tract from each side goes directly to the lateral geniculate body of the thalamus. The inner tract decussates in the optic chiasma. From there, 70-80% of the axons go to the strate cortex of the occipital lobe (geniculostriate system), where the image will form and be identified. 20-30% of the axons go to the superior colliculus of the corpora quadragemina (tectal system), and are responsible for the eye and body movements.

Slide #51: Image of tectal system.

Slide #52: Taste: Image of taste pores in the papilla of tongue and description of gustatory transduction.

Slide #53: Smell: Shows image of olfactory epithelium and describes olfactory neurons.