Senses

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I. Vision

A. Vision and light
1. Vision is the perception of light; light is electromagnetic radiation, measured in wavelengths.
2. Most solar radiation reaching earth falls within 400 to 750 nm, the same range the eye is adapted to see.
B. Structure of the eyeball
Eyeball is composed of three layers or tunics:
1. The outermost layer is called tunica fibrosa and it consists of the sclera and transparent cornea
2. The middle layer – tunica vasculosa is formed by choroid, ciliary body and iris. Choroid supplies the deeper structures of the eye. Ciliary body produces the aqueous humor and regulates the curvature of the lenses. Iris changes the diameter of the pupil.
3. The innermost layer is called retina. Retina include the proper photoreceptors of vision rodes and cones.
C. Accessory structures of the eye
Eyebrows, eyelids, conjunctiva, lacrimal apparatus, and extrinsic eye muscles belong to accessory structures of the eyeball.
Eyelids close to protect the eye and remove debris. They are bordered with tarsal glands that secrete oil to coat the eye and reduce tear evaporation. The conjunctiva is the pink inner lining of the eyelid. It is highly sensitive to pain and keeps the eyeball moist. Six extrinsic eye muscles are responsible for movements of the eyeball. These are the superior, inferior, medial, and lateral rectus muscles and a superior and inferior oblique pair of muscles. They are inervated by three cranial nerves.
D. Tears and lacrimal apparatus of the eye
The lacrimal apparatus consists of a lacrimal gland, ducts, and short lacrimal canals that lead to a lacrimal sac. Tears wash foreign debris from the eye, moisten it, and contain lysozyme to keep the eye surface free from bacteria.
E. Structure of the retina
1. Retina contains rodes and cones which are the visual receptors and the four types of neuraons: bipolar cells, ganglion cells, horizontal cells and amacrine cells. All this cells form ten layers of retina. Nerve impulses are conducted by pigmented layer, layer of rodes and cones, outer limiting membrane, outer nuclear layer, outer plexiform layer, inner nuclear layer, inner plexiform layer, ganglionic layer, layer of stratum opticum and inner limiting membrane. But light rays pass through the retina in completely oposite direction.
2. The optic nerve leaves the eye at a point at the posterior pole of the eyeball which is called optic disk. There are no receptors and this spot is named the blind spot. Directly posterior to the lens lies macula lutea containing the fovea centralis that produces the most detailed image in vision. This is rod-free portion of the retina where visual acuity is greates.
F. Visual receptors. Comparison of rodes and cones.
Rodes and cones are composed of outer segment, inner segment and synaptic endings. The visual pigment of rodes, called rhodopsin or visual purple, is composed of the protein opsin and vitamin A derivative called retinal. In cones, the pigment is photopsin, or iodopsin. Three kinds of cones allow peak absorption of light of different wavelengths, making color vision possible. In the photochemical reaction, retinal exists as *cis*-retinal in the dark. When it

absorbs light, it is converted to *trans*-retinal. This isomer then separates from the opsin, a process called bleaching. The pigments in cones behave in a similar manner. Rodes are more numerous than cones. They are located away from fovea centralis. They are responsible for scotopic vision. Rodes are extremally sensitive for light. Cones are responsible for photopic vision, are less sensitive for light than rodes and are located mainly in fovea centalis.

G. Types of vision

1. Scotopic vision- black and white vision, without details, vision in dim light
2. Photopic vision- colour vision, with details, vision in bright light

H. Sensory transduction in the retina

1. The conversion of light energy into action potentials occurs in the retina. The most posterior layer of the retina is the pigment epithelium whose purpose is to absorb light that is not absorbed first by the receptor cells and to prevent it from degrading the visual image.
2. Rodes and cones synapse with bipolar cells.
3. Ganglion cells, which form the fibers of the optic nerve, receive input from bipolar cells.
4. Horizontal and amacrine cells form horizontal connections among rods, cones, and bipolar cells.

5.Generating the Optic Signal

a. In the dark, rods are very active, producing a steady ion flow called the dark current, which is maintained by cyclic guanosine monophosphate (cGMP).

b. When a rod absorbs light, the dark current drops or ceases. The rhodopsin molecule becomes enzymatically active and triggers a cascade of reactions that break down molecules of cGMP. The effect is amplifying, which explains why rods are sensitive to low light.

c. As cGMP is degraded, the sodium channels close, the dark current declines, and glutamate secretion is halted.

d. When bipolar cells detect fluctuations in light intensity, they communicate this to ganglion cells. Ganglion cells produce all-or-none action potentials, while all other retinal neurons produce graded local potentials.

e. When *trans*-retinal dissociates from rhodopsin, it is transported back to the pigmented epithelium, converted back to *cis*-retinal, carried back to the rod, and reunited with opsin.

I. Light and Dark Adaptation

1. Light adaptation occurs when we go from the dark into bright light. At first, pain is experienced from overstimulated retinas. The pupils quickly constrict. Rodes bleach quickly in bright light; the cones take over.
2. Dark adaptation occurs when we are in bright light and suddenly go into a very dark room. The rate at which rhodopsin regenerates begins to exceed the rate of bleaching. Dilation of pupils also helps get more light into the eyes.
3. The duplicity theory suggests that a single type of receptor cell cannot produce both high sensitivity and high resolution. Therefore, two types of visual receptors, namely rods and cones, are needed.

J. Color vision

1. Color vision is made possible by three sets of cones named for the absorption peaks of their photopsins: blue (peak at 420 nm), green (peak at 531 nm), and red (peak at 558 nm). These overlap to give flexibility for detecting light of varying wavelengths.
2. Some people have inherited mutations that cause them to exhibit color blindness; the most common form is red-green color blindness resulting from a lack of either red or green cones

K. The visual projection pathway

1. The optic nerves converge and form the optic chiasm. Beyond this, the fibers continue as optic tracts. Hemidecussation occurs within the chiasm.
2. Optic tracts pass around the hypothalamus to the lateral geniculate body of the thalamus. Second-order neurons arise here and form the optic radiation of fibers in the cerebrum. These

project to the primary visual cortex of the occipital lobe. A conscious perception of the image occurs there

L. Refraction and refractive apparatus of the eye.

The bending of light rays is called refraction. Refractive apparatus of the eye is formed by cornea, sclera, aquamous humor and vitreous humor. As light enters the eye, it is first refracted by the cornea, next by the anterior curvature of the lens and by the posterior curvature of the lens.

M. Accomodation

The process by which the curvature of the human lens is increased is called accomodation

1. near point
2. far point
3. amplitude of accomodation
4. emmetropic eye
5. mechanism of accommodation, ligaments of lens and muscles of cilliary body take role in accommodation
6. presbyopia is physiological process in which ability of accommodation is decreased

N. Formation of an image

1. The iris contains two sets of muscles.

a. The pupillary constrictor narrows the pupil to admit less light to the eye.

b. The pupillary dilator widens the pupil to admit more light.

c. Pupillary constriction in response to light is called the photopupillary reflex.

2. The bending of light rays.

3. The near response, adjustment to close range vision, involves three processes.

a. Convergence of the eyes orients the visual axis of each eye toward the object in order to focus on the fovea centralis of each eye.

b. Constriction of the pupil adjusts the amount of light and reduces spherical aberration.

c. Accommodation of the lens is a change in curvature that allows a person to focus on a nearby object.

O. Common defects of the image – forming mechanism

1. Farsightednes - hyperopia
2. Nearsightednes – myopia
3. Astigmatism
4. Rules of correction.
5. Types of lenses: biconvex lenses, biconcave lenses, toric and cylindric lenses

II.Physiology of hearning

A. The Nature of Sound

1. Hearing is a response to vibrating air molecules. Sound is any audible vibration of molecules.

2. A vibrating object sets up vibrations in nearby air molecules, which travel to the eardrum and cause it to vibrate.

3. Human ears can hear frequencies from 20 to 20,000 Hz, but are most sensitive to frequencies ranging from 1,500 to 4,000 Hz.

4. Loudness is the perception of amplitude of frequency.

a. Loudness is expressed in decibels (dB). Sounds of 120–140 dB causing pain in most people.

b. Prolonged exposure to sounds greater than 90 dB can cause permanent hearing loss.

B. Ear structure

1. External and middle ear

The outer ear consists of two parts: auricule and auditory canal. The outer auricle focuses vibrations toward the auditory canal and eardrum. The auditory canal leads to the eardrum, and is lined with protective ceruminous glands and hairs. The middle ear lies in an air-filled tympanic cavity in the temporal bone. The eardrum (tympanic membrane) separates the outer ear from the middle ear, and is highly sensitive to pain. Three small bones: the malleus, the incus, the stapes span the distance between the tympanic membrane and the inner ear. The stapes is suspended by a ligament into the oval window of the inner ear. Two muscles of the middle ear, the stapedius and tensor tympani serve protective functions (tympanic reflex). The function of the auditory ossicles is to concentrate the energy from the eardrum to a smaller oval window, overcoming the resistance of the endolymph. The ossicles and eardrum are protected by the tympanic reflex in response to loud noises, but it is not effective for sudden loud noises. The middle-ear muscles tighten up before you speak to protect your ears from the volume of your own voice

2. Inner ear

The inner ear is found within a bony labyrinth. Passageways within the bone are lined with membranous labyrinth. Between bone and membrane is a fluid called perilymph; endolymph fills the membranous labyrinth. The labyrinths begin at a chamber called the vestibule which contain the organs of equilibrium. Anterior to the vestibule is the cochlea, the organ of hearing, which has three fluid-filled chambers. First is scala vestibuli. It is superior chamber and begins near the oval window. The inferior scala tympani terminates at the round window. Between scala tympani and scala vestibuli there is cochlear duct which is bounded by the vestibular membrane on the top and basilar membrane on the bottom. The cochlear duct contains endolymph; the other two chambers contain perilymph. The basilar membrane supports the organ of Corti containing hair cells, each with stereocilia. The tips of the stereocilia shear against an overlying tectorial membrane. Within the organ of Corti, inner hair cells (IHCs) send actual hearing impulses. Outer hair cells (OHCs) adjust the response of the cochlea to different frequencies.

C. Conduction of sound energy

1. Impedance mismaching – transformation of sound stimulus from air medium (middle ear) to fluid medium (ear)

2. Impedance maching

a. Amplification of sound energy (ratio between tympanic membrane surface and footplate of stapes, leverage of ossicular chain)

b. Reduction of sound pressure (middle ear muscle contraction on excessively loud sounds)

D. Conversion of stimulus energy – auditory transduction

1. Corti organ movement

a. Traveling wave (sound movement from scala vestibuli to scala tympani > basilar membrane vibration > stimulation of Corti organ)

b. Basilar and tectorial membrane vibration

c. Organ of Corti vibration

d. Movement of stereocilia

e. Polarization of stereocilia

2. Potentials of the receptor

a. Endolymph (high concentration of K, low Na) electrically positive in comparison to perilymph (high concentration of Na, low K)

b. Hair cells (high concentration of K) electrically negative in comparison to perilymph

c. Sodium-potassium pump– depolarization and hyperpolarization

d. Release of synaptic transmitter

E. Stimulation of Cochlear Hair Cells

1. Auditory ossicles vibrate against the oval window, which sets up vibrations within the fluid-filled inner ear. The endolymph of the cochlear duct vibrates, causing the hair cell stereocilia to move against the tectorial membrane.
2. Bending the stereocilia causes depolarization of the hair cell; bending in the opposite direction closes the potassium ion channel while the cell hyperpolarizes. The hair cell releases neurotransmitter during depolarization, generating an action potential to the cochlear nerve.
F. Encoding information
1. Frequency
2. Intensity
3. Inhibitory innervation
4. Commissural connections – commissural vestibulovestibular fibers – vestibular compensation
5. Other afferent connections – from spinal cord, reticular formation , visual system
G. Vestibulo-thalamo-cortical network – motion perception, spacial orientation, motor control, ventral posterolateral, ventral posteroinferior, posterior nuclear group of the thalamus; cortex – postcentral gyrus
H. The Auditory Projection Pathway
1. Sensory dendrites lead from cochlear hair cells to bipolar neurons in the spiral ganglion to the cochlear nerve to the medulla.
2. Some neurons continue to higher centers of the brain.
3. The temporal lobe is the site of conscious sound perception.

III. Balance physiology
1. The original function of the vertebrate ear was for equilibrium. The sense of equilibrium in humans is divided into static equilibrium and dynamic equilibrium.
2. Both the saccule and the utricle within the vestibule have a patch of hair cells and supporting cells called a macula. There are two such patches per ear, one in the saccule and one in the utricle. These help in the perception of the orientation of the head when the body is stationary.
a. Each hair cell within the maculae has 40–70 stereocilia and one motile true cilium, called a kinocilium. The tips of these extensions are embedded in the gelatinous otolithic membrane, which is weighted with otoliths.
b. When the position of the head changes, the otoliths shift, causing the hair cells to bend, and generate a nerve signal.
3. Rotational acceleration is detected by three endolymph-filled semicircular ducts, each of which houses an ampulla. Within the ampulla is a mound of hair cells with supporting cells called the crista ampullaris. Hair cells are embedded in a gelatinous cupula that responds to motion, bending the stereocilia and stimulating hair cells.
4. Hair cells for the sense of equilibrium synapse with the vestibular nerve, which joins the vestibulocochlear nerve. From there, impulses travel to the vestibular nucleus of the pons. From there, projection fibers lead to the spinal cord and to brainstem nuclei that control eye movements.

IV. Sense Organs
A. General properties of Receptors.
1. A receptor is a structure responsible for detection of a stimulus. Structures of receptors include simple nerve endings as well as complex sense organs.
2. All receptors change stimulus energy into nerve energy. The effect of a stimulus on a receptor is to produce a receptor potential or voltage change.

3. If the receptor potential reaches threshold, the stimulus triggers the firing of nerve impulses to the central nervous system (CNS).
4. Sensory receptors transmit four kinds of information: stimulus modality, location, intensity, and duration.
a. Modality refers to the type of stimulus or sensation it produces (vision, taste, etc.).
b. Location is also indicated by which nerve fibers are firing. Brain is able to identify the site of stimulation.
c. Intensity can be encoded by firing frequencies of nerve fibers, recruitment of more fibers, and stimulation of fibers that vary in their thresholds.
d. Duration is encoded in the way nerve fibers change their firing frequencies over time.
B. Classification of Receptors
1. Receptors can be classified according to stimulus modality.
a. Chemo receptors respond to chemicals.
b. Thermo receptors respond to temperature changes
c. Nociceptors are pain receptors and sense tissue damage.
d. Mechanoreceptors respond to a physical change in their shape.
e. Photoreceptors respond to light.
2. Senses can be classified by whether they are general or special senses.
a. General senses (also called somatic, somatosensory, or somesthetic) are widely distributed throughout the body. They are responsible for detection of touch, pressure, heat, cold, and pain, as well as many other stimuli that we do not consciously perceive. Very often they are simple nerve endings.
b. The special senses are limited to the head, including vision, hearing, equilibrium, taste, and smell. Their structure is more complicated.
3. Receptors can be also classified according to the origins of their stimuli.
a. Interoceptors detect changes from internal organs.
b. Proprioceptors register position changes and movement of the body or its parts.
c. Exteroceptors detect external changes.
d. Telereceptors detect external changes from long distances
C. General Senses
General senses consist of unencapsulated nerve endings and encapsulated nerve endings
1. Unencapsulated nerve endings are sensory dendrites.
a. Free nerve endings are abundant in epithelial and connective tissues. They include thermoreceptors and nociceptors.
b. Merkel discs are flattened nerve endings at the base of the epidermis that sense light touch and pressure.
c. Hair receptors (peritrichial endings) consist of dendrites wrapped around hair follicles, and are stimulated when the hair is touched.
2. Encapsulated nerve endings are dendrites wrapped in glial cells or fibroconnective tissue.
a. Tactile (Meissner) corpuscles occur in the dermal papillae of the skin, especially in the hairless areas (fingertips, nipples, lips, genitals). They consist of 2–3 nerve fibers within a mass of connective tissue, and are phasic receptors.
b. Krause end bulbs are similar to tactile corpuscles. They occur in mucous membranes.
c. Lamellated (pacinian) corpuscles occur both in certain areas of the viscera and deep within the dermis of the hands, feet, breasts, and genitals. They consist of a core of nerve fibers wrapped in Schwann cells. They are phasic for deep pressure and vibration.
d. Ruffini corpuscles, containing a few nerve fibres are located in the dermis, subcutaneous tissue, and joint capsules. They respond tonically to heavy pressure and movement.
D. Somesthetic Projection Pathways
1. A first-order neuron refers to the afferent neuron in a sensory pathway.

2. In the medulla, first-order neurons synapse with second-order neurons that decussate to the opposite side of the brain to the thalamus.
3. At the thalamus, second-order neurons synapse with third-order neurons that project to the somesthetic cortex of the postcentral gyrus.
4. Pathways for heat and cold perception travel first to the spinal cord where they synapse with second-order neurons on the way to the brain.
E. Pain
1. Nociceptors are pain receptors widely distributed in the human body. They are not found only in the brain. They are especially numerous in the skin and mucous membranes. There are two types of nociceptors corresponding to different pain sensations.
a. Fast pain, the sharp, stabbing feeling perceived at the time of injury, is carried on myelinated pain fibers.
b. Slow, diffuse and dull pain is carried on unmyelinated pain fibers.
2. Pain is also classified according to its point of origin.
a. Somatic pain arises from the skin, muscles, and joints, and can be superficial or deep.
b. Visceral pain can be caused by stretch, chemicals and ischemia and it is less localized due to fewer nociceptors in the viscera.
c. Nociceptors are stimulated by a number of chemicals releasing from damaged tissues. Bradykinin is one of the most potent stimulators.
3. Pain signals traveling on first-order neurons travel to an interneuron hooked up to the spinothalamic tract, then to the thalamus, which relays the signal to the cerebral cortex.
4. Pain signals also travel up the spinoreticular tract to the reticular formation where the state of arousal may be affected.
5. Referred pain occurs when pain fibers from deep tissues merge with those of the skin, and follow the same pathway to the thalamus. Knowledge of the origins of referred pain can be a useful diagnostic tool.
6. The CNS has analgesic mechanisms that help alleviate the pain of childbirth, for example.
a. Oligopeptides with analgesic qualities are the enkephalins, endorphins, and dynorphins.
b. The endogenous opiates act as neuromodulators to block the transmission of pain and produce feelings of pleasure.
c. The reticular formation may also moderate sensitivity to pain by means of endorphins.
d. Some interneurons of the dorsal horn inhibit second-order neurons of the pain pathway, especially after receiving input from touch fibers.
F. Taste
1. Structure of the taste buds
a. The taste buds are receptors of taste. They are located on the tongue near lingual papillae.
b. Lingual papillae divide into four types.
c. Filiform papillae have no taste buds.
d. Foliate papillae occur along the back lateral edge of the tongue and house few taste buds.
e. Fungiform papillae are located in the apex with about five taste buds each.
f. Vallate papillae, surrounded by deep trenches, are located at the back of the tongue.
g. Taste buds are composed of taste cells, supporting cells, and basal cells.
h. The taste cells support microvilli called taste hairs that have surface receptors for chemicals (flavors) in food.
i. Taste cells divide by mitosis and live for 7–10 days. They synapse with neurons.
2. Physiology of taste buds
a. To be tasted, molecules need water because they have to be dissolved in it.
b. Human taste buds distinguish five general types of taste: salty, sweet, sour, bitter, and umami.
c. The flavor of food also involves smell, texture, and appearance.

3. Projection Pathways
a. Cranial nerves VII, IX, and X send taste sensations to the gustatory nucleus of the medulla oblongata. Signals are then relayed either to other brainstem nuclei involved with autonomic reflexes (gagging and the like) or to the thalamus.
b. The thalamus signals the gustatory cortex.
G. Smell
1. The olfactory mucosa contain very sensitive receptors for smell within the roof of the nasal cavity. Olfactory mucosa contains 10–20 million olfactory cells, each of which bears 10–20 cilia called olfactory hairs. These have binding sites for odor molecules and lie in a thin layer of mucus.
2. Olfactory cells are the only sensory neurons that lie in direct contact with the outside environment and are replaced about every 60 days.
3. Physiology of the olfactory cells
a. To be detected, chemicals must be volatile and water soluble.
b. When an odor molecule binds with a specific receptor, a second messenger is produced, opening ion channels in the membrane. Sodium ions enter the cell and depolarize it, creating a receptor potential.
c. Olfactory receptors are quick to adapt.
d. Some odors, such as the ammonia smell of smelling salts, stimulate nociceptors that trigger the trigeminal nerve.
4. Projection Pathways
a. Olfactory fibers pass through the cribriform plate to the olfactory bulbs to the olfactory tracts.
b. These tracts follow a complex pathway that involves the medial temporal lobes.
c. Olfactory signals reach the cortex before the thalamus if the person is unaware of them.
d. Conscious awareness of smell travels through the thalamus to the neocortex in the frontal lobes.
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