I. General Senses (hot, cold, touch, pressure, pain and proprioception)

A. **Sensation** is the conscious or subconscious awareness of the internal and external conditions of the body.

B. Sensation is detected by sensory **receptors**.

1. Receptors are sensitive to specific "**changes**" in the internal or external environment.
2. Receptors differ in structure, threshold and location.

C. Categories

1. **Somatic senses** are senses associated with the skin (hot, cold, touch, pressure, pain) and **proprioceptive sensations** of muscles and joints. The receptors for somatic senses include:

a. Nociceptors

i. Consist of free nerve endings.
ii. Respond to any extreme stimuli, stimulated by tissue damage, low oxygen, and the chemical bradykinin.
iii. Found everywhere in the body except the brain.

b. Thermoreceptors

i. Consist of free nerve endings.
ii. Cold receptors are located in the epidermis and respond to temperatures between 50-60 degrees F. (temperatures below 50 degrees cause pain and a "freezing" sensation).
iii. Hot receptors are located in the dermis and respond to temperatures between 90 and 118 degrees F. (temperatures above 113 degrees cause pain and a "burning" sensation).

c. Mechanoreceptors

i. Consist of receptors that respond to mechanical stimulation (touch, pressure, vibration, etc.).
ii. Light touch
(a) **Meissner's corpuscles** are located in hairless portions of the skin.
(b) **Root hair plexuses** are free nerve endings wrapped around hair follicles to detect movement of body hair.
iii. Regular touch
(a) **Merkel disks** are located within the dermis of the fingertips, hands, lips and external genitalia.
iv. Pressure
(a) Pressure is a sustained sensation felt over a larger area than touch.
(b) **Pacinican corpuscles** are encapsulated within a multilayered connective tissue wrapping and are widely distributed throughout the body.

d. Proprioceptors

i. **Proprioceptors** are mechanoreceptors located within joints, tendons and muscles to monitor joint movement.
ii. Inform you as to the degree to which your muscle is contracted, the position of your joints, and the location of your head.
iii. Include
(a) **Golgi tendon organs** detect muscle tension.

(b) **Muscle spindles** detect stretch and movement of skeletal muscle tissue.

2. **Visceral senses** are senses associated with the conditions of body fluids and internal organs.
    a. **Nociceptors** are present.
    b. **Pressoreceptors** are found in the walls of certain blood vessels to detect changes in blood pressure (Aortic and Carotid Sinuses).
    c. **Chemoreceptors** detect changes in chemical concentrations such as oxygen, carbon dioxide and hydrogen ions (Aortic and Carotid Bodies).
    d. **Osmoreceptors** detect body fluid concentrations (hypertonic vs. hypotonic).
    e. **Glucoreceptors** detect blood sugar levels.

D. Receptor adaptation
1. When, after continuous stimulation, receptors fail to respond.
2. As receptors adapt the sensation may begin to fade or disappear.
3. Receptors vary in their ability to adapt.
    a. Fast adapters include thermoreceptors , pressure receptors and touch receptors.
    b. Slow adapters include nociceptors and proprioceptors.

E. Perception of sensation
1. When a sensory receptor is stimulated it initiates an impulse that terminates at the postcentral gyrus of the cortex.
2. The cortex specifically determines the source and kind of sensation.
3. It also determines the intensity of the sensation.
4. It then interprets this information and "**projects**" the sensation back to the source. (Sensation is completely cerebral!)

F. Abnormalities of perception
1. Referred pain
    a. Is the perception that pain is felt in a part of the body different from the part that is actually generating the pain (heart attack referred to left arm and jaw).
    b. Typically due to the convergence of sensory receptors. For example, sensory information from the heart and the left upper limb both feed into the spinal cord at the same level, making it more difficult for the brain to determine the exact source.

2. Phantom limb
    a. After a patient has had a limb amputated they continue to perceive sensations from the missing limb (pain, tickle, itch) and feel as though the limb is still there.
    b. The most commonly accepted theory states that the region of the brain that represents the missing limb can be invaded (rewired) to respond to stimuli from neighboring regions of the cortex.

II. Special Senses
A. The special senses include sight, hearing, taste, smell and balance.
B. Uses receptors that are housed in special structures (eye, ear, tongue, etc.)

III. Vision
A. Accessory structures
1. The lacrimal apparatus includes
    a. The **lacrimal gland** is located superiorly and lateral to the eyeball.
        i. Secrete tears through a **lacrimal duct** onto the surface of the eyeball.

ii. Tears moisten, lubricate and clean the surface of the eye. Also contains the enzyme **lysozyme** to kill bacteria.
   b. The tears flush across the surface of the eye and are drained into 2 **lacrimal canals** at the inner corner of the eye.
   c. These drain into the **nasolacrimal duct,** draining the tears into the nasal cavity.
   d. The parasympathetic nervous system controls secretion by the lacrimal glands.
2. Extrinsic muscles of the eye (skeletal muscle)
   a. There are 4 rectus muscles
      i. Superior, inferior, lateral and medial rectus muscles.
   b. There are 2 oblique muscles
      i. Superior and inferior obliques.
3. Conjunctiva
   a. A transparent mucous membrane that lines the eyelids and covers the anterior white of the eye.
   b. Lubricates and protects the anterior surface of the eye.
   c. **Conjunctivitis (pink-eye)** is an inflammation of the conjunctiva due to chemicals or microbes.

B. Layers of the eye
1. Sclera (the white of the eye)
   a. The tough, outermost layer of dense connective tissue.
   b. Provides support and gives shape to the eye.
   c. The extrinsic muscles attach to this layer of the eye.
2. Cornea
   a. The anterior extension of the sclera.
   b. A transparent, fibrous layer that helps focus light rays onto the retina (handles ¾ of the focusing capacity of the eye).
   c. Is well supplied with receptors.
   d. **Corneal opacity** is when the cornea loses its clarity.
3. Choroid
   a. The middle, vascular layer of the eye.
   b. Provides nutrition to the other layers.
   c. Is darkly pigmented with **melanin** to prevent internal reflection.
   d. Anteriorly becomes the **ciliary body** (ciliary process and the ciliary muscle).
      i. **Ciliary process** secretes **aqueous humor** into the anterior chamber of the eye.
         (a) Aqueous humor is a watery fluid that helps maintain the shape of the eye and nourishes the lens and cornea.
         (b) Drains into the **Canal of Schlemm**, an opening where the sclera and cornea meet.
         (c) **Glaucoma** results from blockage of this canal. As the aqueous humor builds up it leads to an increased intraocular pressure, damaging the photoreceptors of the eye and leading to blindness.
      ii. **Ciliary muscle** is a ring of smooth muscle that is attached to the lens via the **suspensory ligaments**.
         (a) Contraction and relaxation of this muscle alters the shape of the lens for viewing objects up close or at a distance.

(b) Changing the shape of the lens is referred to as the **accommodation reflex**.
(i) For viewing a distant object the ring of smooth muscle relaxes pulling outward on the lens flattening and decreasing the curvature of the lens. **Note**: light rays from a distant object are parallel to one another and need minimal bending.
(ii) Changing the muscle for viewing a distant object is controlled by the sympathetic nervous system.
(iii) For viewing a close object the ring of smooth muscle contracts, releasing tension on the lens allowing it to become rounder (greater curvature) to bend the light rays more. **Note**: light rays from a close object are divergent and need more bending to focus on the retina.
(iv) Changing the muscle for viewing a close object is controlled by the parasympathetic nervous system.

4. Iris
   a. The colored part of the eye.
   b. Controls the amount of light entering the eye.
   c. Consists of **circular** and **radial smooth muscles**.
   d. The **pupil** is the hole in the center of the iris.
   e. Changing the size of the pupil is the **pupillary light reflex**.
      i. In dim light the sympathetic nervous system stimulates the radial muscle to contract, dilating the pupil.
      ii. In bright light the parasympathetic nervous system stimulates the circular muscle to contract, constricting the pupil.
5. Lens
   a. A transparent structure that focuses light rays onto the retina.
   b. Composed of the protein **crystallin**.
   c. **Cataracts** are a clouding of the lens.
      i. Causes include UV light, steroids, and diabetes.
6. Retina
   a. The innermost layer of the eye covering the posterior ¾ of the eyeball.
   b. Composed of 3 layers of neurons.
      i. The **photoreceptor layer** is the outermost layer of neurons and consists of **rods** and **cones**.
      ii. Rods
         (a) Are found in their highest concentration in the peripheral portion of the retina.
         (b) Respond to dim light.
         (c) Vision in shades of gray.
         (d) Rods are associated with low visual acuity (clarity).
         (e) Rods contain a pigment known as **rhodopsin** that is broken apart when light hits it, initiating an impulse.
         (f) Vitamin A is required for the production of rhodopsin.
            (i) **Night blindness** can result due to a deficiency of Vitamin A.
      iii. Cones

(a) Are found in their highest concentration in the **fovea centralis**, a small depression within the **macula lutae** at the center of the retina.
(b) Respond to bright light.
(c) Vision in color.
(d) Cones are associated with high visual acuity.
(e) Cones contain the pigments **retinal** and 1 of 3 types of **photopsin** (yellow, green and blue).
(f) When in bright light the eye's lens system attempts to focus the light rays directly on the fovea.
(g) **Color blindness** can occur when an individual is missing one type of cone photopsin.

iv. Bipolar cell layer
(a) The cells that synapse with the photoreceptors.
(b) Bipolar cells transmit an impulse to the ganglion cells.

v. Ganglion cell layer
(a) Initiate an action potential when stimulated by the bipolar cells.
(b) The axons of the ganglion cells extend posteriorly to form the **optic nerve**.
(c) Where the optic nerve exits from the back of the eye forms the **optic disc**. No rods or cones are found at this location so it forms a **blind spot**.

C. Interior of the eye
1. The interior of the eye is filled anteriorly with the **aqueous humor** discussed above.
2. Posteriorly the eye is filled with **vitreous humor**.
a. Gelatinous in consistency.
b. Maintains the shape of the eye and holds the retina against the outer layers of the eye.
c. Formed during embryonic life.

D. Image formation
1. Light rays
a. When viewing a **distant object** (more than 20 feet away) the light rays reflected off of it will be traveling nearly **parallel** to one another when they hit the surface of the eye.
b. When viewing a **close object** (closer than 20 feet away) the light rays reflected off of it will be **divergent** to one another when they hit the surface of the eye.
c. In order to form a clear image the cornea, lens and vitreous humor all function in bending the light rays together to focus on the retina.
i. The bending of light rays is called **refraction**.
ii. The cornea does 75% of the bending of the rays while the lens is adjusted to focus the rest. You can think of the eye as a microscope with the cornea being the course adjustment and the lens the fine adjustment.

2. Refraction errors
a. Myopia (nearsightedness)
i. The eye can clearly focus on nearby objects but not distant objects.
ii. Occurs when an eyeball is too long or a lens is too rounded.
iii. Light rays focused in front of the retina instead of on the retina.

iv. Corrected with a concave lens.

b. Hyperopia (farsightedness)

i. The eye can clearly focus on distant objects but not on close objects.
ii. Occurs when an eyeball is too short or a lens is too flat.
iii. Light rays focused theoretically behind the retina instead of on the retina.
iv. Corrected with a convex lens.

c. Presbyopia

i. Hyperopia that develops with age.

d. Astigmatism

i. Occurs due to irregularities in the surface of the cornea or lens.

E. Creating a single image
1. In order to create a single image in the visual cortex most of the receptors stimulated in one eye must "correspond" to (match) the receptors stimulated in the other eye.
2. When looking at a distant object the eyes must be more or less parallel to one another to stimulate the matching points at the back of the eyes.
3. As you move closer to the object the eyes must rotate inward (becoming cross-eyed) in order to stimulate the matching points at the back of the eye. This process is called **convergence**.

F. The visual pathway
1. Begins with stimulation of the **photoreceptors** of the eyes (rods and cones), which signal **bipolar cells**, thereby initiating an impulse on **ganglion cells**.
2. The axons of the ganglion cells exit the eye as the **optic nerve**.
3. The optic nerves converge at the **optic chiasma** where axons from the medial portion of each eye cross over to join axons arising from the lateral portions of the opposite eye.
4. After the optic chiasma, the axons continue as the **optic tract**, terminating in the **thalamus**.
5. At the thalamus the neurons synapse with neurons that will carry the impulse to the **primary visual cortex** as the **optic radiations**.

IV. Hearing and Balance

A. The ear is divided into 3 main regions: outer ear, middle ear, and inner ear.

B. Outer ear
1. Begins at the **auricle (pinna**).
   a. Composed of elastic cartilage and covered with skin.
   b. Funnels sound waves into the **external auditory meatus**.
2. External auditory meatus
   a. Extends from the **auricle** to the **tympanic membrane**.
   b. Carved through the temporal bone.
   c. Lined with skin containing **ceruminous glands** (wax).
3. Tympanic membrane (eardrum)
   a. A thin, semitransparent membrane.
   b. Responsible for converting sound waves into mechanical motion.

C. Middle ear
1. Consists of a small, air-filled cavity within the temporal bone.
2. Connected to the upper part of the pharynx (throat) by the **eustachian (auditory) tube**.

a. Air flows through the Eustachian tube to equalize pressure within the middle ear.

3. Contains the **auditory ossicles** (the 3 smallest bones of the body)
    a. The **malleus (hammer)** is connected to the tympanic membrane.
    b. The **incus (anvil)** articulates with the malleus on one end and the stapes on the other end.
    c. The **stapes (stirrup)** attaches to the **oval window**.
    d. The articulations between the auditory ossicles allow them to amplify the mechanical motion created by the tympanic membrane.
    e. There are small muscles attached to the auditory ossicles which contract with loud sounds and speech to control movement of the bones and prevent damage to the receptors for hearing.
4. The **oval window** is located in the wall separating the middle and inner ear.

D. Inner ear
1. Divided into a **bony (osseous) labyrinth** and a **membranous labyrinth**.
    a. The bony labyrinth is a series of canals carved into the temporal bone creating the **cochlea**, **vestibule** and **semicircular canals**.
        i. The bony labyrinth is filled with a fluid known as **perilymph**.
    b. The membranous labyrinth is inside the bony labyrinth.
        i. Consists of a series of sacs and tubes that repeat the shape of the bony labyrinth.
        ii. Filled with a fluid known as **endolymph**.
2. The cochlea
    a. Divided into 3 channels
        i. The **cochlear duct** is in the middle.
            (a) Filled with **endolymph**.
        ii. The **scala vestibuli**
            (a) Is separated from the cochlear duct by the **vestibular membrane**.
            (b) Connected to the oval window at one end.
            (c) Filled with **perilymph**.
        iii. The **scala tympani**
            (a) Is separated from the cochlear duct by the **basilar membrane**.
            (b) Filled with **perilymph**.
            (c) Terminates at the **round window**. The round window dissipates sound waves after they have completed their movement through the inner ear.
            (d) At the apex of the cochlea the scala vestibuli and scala tympani are connected.
    b. Resting on the basilar membrane is the **Organ of Corti**, bathed in endolymph within the cochlear duct.
        i. Consists of supporting cells and **hair cells** (receptors for hearing).
        ii. The hair cells have their proximal ends attached to the basilar membrane and their distal ends in contact with the gelatinous **tectorial membrane**.

E. Physiology of hearing
1. Sound waves cause the tympanic membrane to vibrate.
2. This vibration is continued through the auditory ossicles.

3. Movement of the stapes vibrates the oval window generating waves within the perilymph of the scala vestibuli.
4. This fluid wave is transmitted to the scala tympani, causing the basilar membrane to vibrate and the hairs of the Organ of Corti to bend against the tectorial membrane. (Note: waves can also cause vibration of the basilar membrane by passing directly from the scala vestibuli through the vestibular membrane.)
5. Eventually the wave dissipates by hitting the round window.
6. The bending of the hairs stimulates the hair cells to release a neurotransmitter to initiate an impulse at synapsing sensory neurons.
7. The axons of these sensory neurons form the cochlear branch of the vestibulocochlear nerve (VIII).

F. Auditory pathway
1. Stimulation of hair cells initiates an impulse on the sensory neurons in the **cochlear branch** of the **vestibulocochlear nerve**.
2. The axons of the vestibulocochlear nerve terminate and synapse at the **medulla oblongata**.
3. These neurons travel from the **medulla oblongata** to the midbrain to synapse with neurons that travel to the **thalamus**.
4. Neurons then relay the impulse from the **thalamus** to the **primary auditory cortex**.

G. Pitch
1. Determined by the portion of the basilar membrane that vibrates.
2. The membrane at the base of the cochlea produces high-frequency (high-pitched) sounds.
3. The membrane at the apex of the cochlea produces low-frequency (low-pitched) sounds.

H. Loudness
1. The louder the sound the greater the vibration of the basilar membrane, resulting in the stimulation of a greater number of hair cells.

I. Hearing loss (sensorineural)
1. Commonly results form prolonged exposure to loud sounds damaging the hairs in the Organ of Corti.
2. May also be due to damage to any portion of the neural pathway or to the primary auditory cortex.

J. The Semicircular canals
1. Consist of 3 membranous canals attached to the vestibule.
2. Located at right angles to one another and filled with endolymph.
3. At one end of each canal is a swelling known as the **ampulla**.
4. Inside the **ampula** is the **crista ampullaris**.
    a. The **crista ampularis** consists of supporting cells and hair cells covered by a gelatinous mass known as the **cupula**.
    b. When the head moves, the endolymph within the semicircular canals lags behind dragging the cupula and bending the sensory hairs.
    c. Bending of the hairs causes the hair cells to release a neurotransmitter to stimulate synapsing sensory neurons.
    d. These sensory neurons carry the impulse along the **vestibular branch** of the **vestibulocochlear nerve**.

5. Due to their arrangement the semicircular canals maintain **dynamic equilibrium** by responding to rotational movements, and rapid turns of the head or body. Detecting rotational acceleration or deceleration.

K. The Vestibule
   1. The egg shaped cavity that separates the semicircular canals from the cochlea.
   2. Contains 2 membranous sacs called the **utricle** and **saccule** housing **macula** inside.
      a. The **maculae** consist of support cells and hair cells.
      b. The distal ends of the hairs are embedded within the gelatinous **otolithic membrane**.
         i. The **otolithic membrane** has **otoliths** (calcium carbonate crystals) imbedded within it.
      c. The macula of the utricle runs horizontally with the sensory hairs standing vertically, while in the saccule the macula runs vertically with horizontal hairs.
         i. Movement of the head allows gravity to pull on the otolithic membrane, bending the hairs and initiating impulses.
      d. The utricle and saccule function in maintaining **static equilibrium**.
         i. Provide information on the position of the head in space (relative to gravity).
         ii. Respond to tilting of the head and linear movement.
         iii. Respond to vertical acceleration (up and down in an elevator).

V. Smell
   A. Tied into emotions and memories more than any other sense.
   B. Provides 80% of your perception of food.
   C. The olfactory epithelium lining the upper portion of the nasal cavity has 3 types of cells associated with it.
      1. **Olfactory receptor cells** are neurons stimulated by odorant chemicals.
         a. **Olfactory hairs (cilia)** project from the end of the neuron and are embedded within the mucous lining the nasal cavity.
         b. These **olfactory hairs** will have **olfactory receptors** for the **odorant** chemicals to bind to in order to stimulate the neuron and initiate a nerve impulse.
         c. The axons of these olfactory receptor cells extend up through the **cribiform plate** of the **ethmoid bone** as **olfactory nerves** to synapse within the **olfactory bulb**.
      2. **Supporting cells** are columnar cells that surround the olfactory receptor cells.
         a. Provide support and nourishment for the olfactory receptor cells.
      3. **Basal stem cells** are located at the base of the epithelium.
         a. These cells undergo cell division and differentiate into new olfactory receptor cells every 1-2 months.
         b. The number of receptor cells declines with age resulting in a reduced ability to smell.
   D. Physiology of olfaction
      1. There must be an interaction between the odorant molecules and the receptors located on the olfactory hairs in order to initiate an impulse.
      2. Believed to be 7 primary odors.
         a. These primary odors can be put together in a variety of ways to generate as many as 10,000 different sensations.

E. Olfactory pathway
    1. Binding of an odorant chemical to an olfactory receptor initiates an impulse.
    2. This impulse travels along the axons of the **olfactory receptor cells (olfactory nerves)** up through the **cribiform plate** of the **ethmoid bone**.
    3. These axons synapse within the **olfactory bulbs** with neurons that form the **olfactory tract**.
    4. The neurons of the **olfactory tract** carry the impulse to the **primary olfactory area**.

VI. Taste
A. Consists of 5 primary tastes (sweet, sour, salty, bitter and umami).
    1. All other tastes are combinations of the 5 primary tastes.
B. The receptors for taste are located in **taste buds**.
    1. **Taste buds** are located on the **papillae** of the tongue (primarily), palate, pharynx and the cheeks of infants.
    2. Taste buds consist of 3 types of cells.
        a. **Gustatory receptor cells** have **gustatory hairs** extending to the external surface.
            i. The **gustatory hairs** have receptors for the taste chemicals to bind to, initiating an impulse.
        b. **Support cells** surround the **gustatory receptor cells**.
        c. **Basal cells** are located at the base of the taste bud.
            i. These continually divide and differentiate into new gustatory receptor cells that have a life span of approximately 1 week.
C. Gustatory pathway
    1. Sensations for taste are transmitted by 3 cranial nerves.
        a. The **facial nerve** supplies the anterior 2/3 of the tongue.
        b. The **glossopharyngeal nerve** supplies the posterior 1/3 of the tongue.
        c. The **vagus nerve** supplies the pharynx.
    2. From the taste buds impulses are transmitted to the **medulla oblongata**.
    3. Within the **medulla oblongata** the neurons synapse with other neurons that relay the impulse to the **thalamus**.
    4. After the **thalamus**, impulses terminate in the **primary gustatory cortex**.