BIOH111

- Cell Module
- Tissue Module
- Skeletal system
- Muscle system
- Nervous system
- Endocrine system
- Integumentary system
Textbook and required/recommended readings

- Sensations: Principles of anatomy and physiology. Tortora et al; 14\textsuperscript{th} edition: Chapter 16; sections 16.1 and 16.2

- Special senses: Principles of anatomy and physiology. Tortora et al; 14\textsuperscript{th} edition: Chapter 17; sections 17.1, 17.2, 17.3 and 17.4
BIOH111 – NERVOUS SYSTEM MODULE

- Session 15 (Lectures 23 and 24) – Organisation and histology of the nervous system
- Session 16 (Lectures 25 and 26) – Function of neurons: conduction of nerve impulses
- Session 17 (Lectures 27 and 28) – CNS: Brain anatomy and function
- Session 18 (Lectures 29 and 30) – Sensations and special senses
- Session 19 (Lectures 31 and 32) – Spinal cord anatomy and physiology
- Session 20 (Lectures 33 and 34) – Spinal nerves and somatic sensory and motor pathways
- Session 21 (Lectures 35 and 36) – Autonomic nervous system: anatomy and function
Preparation for next session

- Complete any missing concepts and linking words from Session 17

- Review:
  - plasma membrane and receptors
  - neuron structure and function
  - structural neuron classification
  - sensory area of cerebrum
Objectives

Lecture 29:

- Sensation
  - Explain the concept of sensation and sensory modalities
  - Describe the different types of somatic sensations

Lecture 30:

Special Senses:

- Olfaction
  - Describe anatomy of olfaction and relate it to its physiology and olfactory pathway

- Gustation
  - Describe anatomy of gustation and relate it to its physiology and gustatory pathway

- Vision
  - Describe anatomy of eye and accessory organs
  - Describe image formation and relate it to vision physiology and vision pathway

- Hearing and equilibrium
  - Describe ear anatomy
  - Relate ear anatomy to physiology of hearing and hearing pathways
  - Define different equilibrium states and relate the ear anatomy and physiology to each state
SENSATION

- Sensation is a conscious or unconscious awareness of external or internal stimuli.
- The components of the brain interact to receive sensory input, integrate and store the information, and transmit motor responses.
- Perception is the conscious awareness & interpretation of a sensation.

Are there any sensations we can not perceive? If yes – which ones and why not?
SENSORY MODALITIES

- Sensory Modality: unique type of sensation; property by which one sensation is distinguished from another.

- 2 classes of sensations
  1. General senses: include both somatic and visceral senses
     - Somatic: tactile, thermal, pain and proprioceptive sensations
     - Visceral: provide information about conditions within internal organs (e.g. stretch, pressure)
  2. Special senses: smell, taste, vision, hearing and equilibrium (balance); anatomically distinct
PROCESS OF SENSATION

- Sensory receptors are selective for only one type of stimulus
- Steps in process of sensation:
  1. stimulation of the receptor - e.g. touch
  2. conversion of stimulus into a graded potential
  3. generation of AP – when does this happen?
  4. integration of sensory input by the CNS
Steps in process of sensation

Sensory Receptors

1. Chemical stimulus
   - Receptor protein
   - Ion channel
   - Change in membrane potential
   - Signal to integrating center
   - (a) Chemoreceptors

2. Pressure stimulus
   - Ion channel
   - Change in membrane potential
   - Signal to integrating center
   - (b) Mechanoreceptors

3. Light stimulus
   - Ion channel
   - Change in membrane potential
   - Signal to integrating center
   - (c) Photoreceptors

4. To central nervous system
   - Afferent neuron
   - Direction of action potential
   - Voltage-gated calcium channel
   - Receptor protein for transmitter
   - Transmitter
   - Sensory receptor cell
   - Ca²⁺ (promotes transmitter release)

5. Stimulus
SENSORY RECEPTOR CLASSIFICATIONS

1. **Structural classification**: based on nerve appearance; 3 types:
   
a) **First-order sensory neuron with free nerve endings** – e.g. pain, tickle, itch, temperatures
   
b) **First-order sensory neuron with encapsulated nerve endings**: e.g. touch, pressure & vibration
   
c) **Sensory Receptors synapse with the first order sensory neuron**: e.g. vision, hearing, taste and smell

2. **Functional classification**: based on stimulus detected; several types:
   
   - mechanoreceptors, thermoreceptors, nociceptors, photoreceptors; chemoreceptors

3. **Classification by location**: 3 types:
   
a) **Exteroceptors**: near surface of body, receive external stimuli; e.g. hearing, vision, pressure and pain
   
b) **Interoceptors**: monitors internal environment (BV or viscera); not conscious except for pain or pressure
   
c) **Proprioceptors**: senses body position & movement; found in muscle, tendon, joint & internal ear
1. Structural classification

(a) First-order sensory neuron with free nerve endings

Cold stimulus

Free nerve endings (dendrites)

Axon

Nerve impulses

Propagate into CNS

(b) First-order sensory neuron with encapsulated nerve endings

Pressure stimulus

Dendrite

Encapsulated nerve ending

Axon

(c) Sensory receptor synapses with first-order sensory neuron

Sugar molecule

Receptor potential

Gustatory (taste) receptor

Synaptic vesicle

Neurotransmitter

Nerve impulses

Propagate into CNS

Bare dendrites

dendrites enclosed in connective tissue capsule

Separate sensory cells that respond to sensation
2. Functional classification

- **Mechanoreceptors**: detect pressure or stretch; touch, pressure, vibration, hearing, proprioception, equilibrium & blood pressure
- **Thermoreceptors**: detect temperature
- **Nociceptors** detect damage to tissues
- **Photoreceptors** detect light
- **Chemoreceptors** detect molecules; e.g. taste, smell & changes in body fluid chemistry
ADAPTATION OF SENSORY RECEPTORS

- Adaptation: tendency for the generator or receptor potential to decrease in amplitude during a maintained constant stimulus.
  - decrease in responsiveness of a receptor: e.g. bad smells disappear, very hot water starts to feel only warm
  - potential amplitudes decrease during a maintained, constant stimulus
Variability in tendency to adapt:

- Rapidly adapting receptors: specialized for detecting changes; e.g. smell, pressure, touch
- Slowly adapting receptors: nerve impulses continue as long as the stimulus persists; e.g. pain, body position
SOMATIC SENSATIONS

- **Sensation** from the skin, muscles, bones, tendons and joints. Initiated due to activation of a number of distinct **somatic** receptors that respond specifically to changes in heat, cold, touch, pressure, limb position, limb movement or pain.

- Classification of somatic sensations:
  1. Tactile sensations – touch, pressure, vibration, itch and tickle
  2. Pain
  3. Proprioceptive
Touch

- Crude touch: ability to perceive that something has simply touched the skin

- Discriminative (fine) touch: provides specific information about a touch sensation such as location, shape, size, and texture of the source of stimulation.

- Rapidly adapting receptors: corpuscles of touch (Meissner’s corpuscles) and hair root plexuses

- Slowly adapting receptors: Type I cutaneous mechanoreceptors (tactile or Merkel discs) and type II cutaneous mechanoreceptors (end organs of Ruffini)
Pressure and Vibration

- **Pressure**: sustained sensation that is felt over a larger area than touch; longer lasting; less variation in intensity
  - Receptors: type II cutaneous mechanoreceptors and lamellated (Pacinian) corpuscles

- **Vibration** sensations: result from rapidly repetitive sensory signals from tactile receptors
  - Receptors: corpuscles of touch and lamellated corpuscles
Itch and Tickle

- **Itching** is chemical stimulation of free nerve endings.
- **Tickle** is stimulation of free nerve endings only by someone else.
- Itch and tickle receptors are free nerve endings.
PAIN

- Provides information about noxious and damaging stimuli; helps protect from greater damage
- Receptors: nociceptors (free nerve ending); sensory neurons transmitting messages of painful stimuli, secrete glutamate and substance P.

- Types of pain:
  1. Acute pain
  2. Chronic pain
  3. Nerve pain
  4. Referred pain
Acute pain – occurs rapidly after stimulus applied; no feeling in deeper tissues; sharp/fast/pricking pain; impulses conducted by A fibres.

Chronic pain – begins after a second and gradually increases in intensity; longer and deeper; burning/arching/throbbing; impulses conducted by C fibres.
Nerve pain – no stimulus needed; sharp, shooting pain; nerves damaged in some way and initiate nerve impulses from that point down; no treatment available
Referred pain

- **Visceral pain** that is felt just deep to the skin overlying the stimulated organ or in a surface area far from the organ.
- Skin area & organ are served by the same segment of the spinal cord.
  - Heart attack is felt in skin along left arm since both are supplied by spinal cord segment T1-T5.
PROPRIOCEPTIVE SENSATIONS

- **Proprioceptors** allow us to perceive the position of the body and its parts. Three main types of proprioceptors:

1. **muscle spindles**: detect muscle movement
2. **Golgi tendon organs**: determine stretch in tendons
3. **joint receptors**: detect movement in ligaments

- Sensory information is sent to cerebellum & cerebral cortex
  - signals project from muscle, tendon, joint capsules & hair cells in the vestibular apparatus
1. Muscle spindles

- **Structure**: specialized intrafusal muscle fibers enclosed in a connective tissue capsule and innervated by A-type gamma motor neurons

- **Function**: spindle sensory fiber monitors changes in muscle length

- Stretching of the muscle ➔ stretches the muscle spindles ➔ sending sensory information back to the CNS ➔ activation of gamma motor neuron ➔ contraction
2. Golgi tendon organs

- **Structure**: encapsulated bundle of collagen fibers laced with sensory fibers; found at junction of tendon & muscle

- **Function**: when the tendon is overly stretched, sensory signals head for the CNS & resulting in the muscle’s relaxation
3. Joint receptors

- **Ruffini corpuscles**: found in joint capsule: respond to pressure; slowly adapting

- **Pacinian corpuscles**: found in connective tissue around the joint: respond to acceleration & deceleration of joints; rapidly adapting
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SPECIAL SENSES

- Smell, taste, vision, hearing and equilibrium
- Housed in complex sensory organs

Chemical senses:
- Interaction of molecules with receptor cells
- Olfaction (smell) and gustation (taste)
- Both project to cerebral cortex & limbic system, so evoke strong emotional reactions
ANATOMY OF OLFACCTION (SMELL)

- **Receptors**: first-order, bipolar neurons in the nasal epithelium in the superior portion of the nasal cavity of the olfactory pathway.

- **Supporting cells**: epithelial cells of the mucous membrane lining the nose

- **Basal cells**: stem cells (replace receptors monthly)

- **Olfactory (Bowman’s) glands**: produce mucus

- Both epithelium & glands innervated by cranial nerve VII.
PHYSIOLOGY OF OLFACCTION

- Stimulus (molecule) triggers graded potential that can develop into action potential
- Adaptation (decreasing sensitivity) to odours occurs quickly, and the threshold of smell is low: only a few molecules of certain substances need be present in air to be smelled

- cAMP as secondary messenger
ANATOMY OF GUSTATION (TASTE)

- Taste requires dissolving of substances
- Four classes of stimuli--sour, bitter, sweet, and salty
  - Other “tastes” are a combination of the four taste sensations plus olfaction.
- 10,000 taste buds found on tongue, soft palate & larynx; Found on sides of circumvallate & fungiform papillae
- 3 cell types: supporting, receptor & basal cells
Anatomy of taste buds

- An oval body consisting of 50 receptor cells surrounded by supporting cells
- A single gustatory hair projects upward through the taste pore
- Basal cells develop into new receptor cells every 10 days.
Receptor potentials developed in gustatory hairs cause the release of neurotransmitter that gives rise to nerve impulses; mechanism:

- dissolved substance contacts gustatory hairs
- receptor potential results in neurotransmitter release
- nerve impulse formed in 1st-order neuron

Complete adaptation in 1 to 5 minutes; thresholds for tastes vary among the 4 primary tastes (most sensitive to bitter (poisons); least sensitive to salty and sweet)
ANATOMY OF VISION

- Accessory structures of the eye:

  1. Eyelids or palpebrae
     - protect & lubricate
     - epidermis, dermis, CT, orbicularis oculi m., tarsal glands (oily secretions), conjunctiva (palpebral & bulbar; stops at corneal edge)

  2. Lacrimal Apparatus
     - about 1 ml of tears produced per day that spread over eye by blinking
     - contains bactericidal enzyme called lysozyme

  3. Extrinsic eye muscles
Extrinsic eye muscles

- Six muscles that insert on the exterior surface of the eyeball
  - Innervated by CN III, IV or VI.
- 4 rectus muscles: superior, inferior, lateral and medial
- 2 oblique muscles: inferior and superior
THE LENS

- Avascular; clear capsule & perfectly transparent
- Crystallins: crystalline proteins arranged like layers in onion
- Lens held in place by suspensory ligaments
- Focuses light on fovea
CAVITIES OF THE INTERIOR OF EYEBALL

1. Anterior cavity (anterior to lens)
   • filled with aqueous humor
   • 2 chambers
     – anterior chamber between cornea and iris
     – posterior chamber between iris and lens

2. Posterior cavity (posterior to lens)
   • filled with vitreous body (jellylike)
   • formed once during embryonic life
AQUEOUS HUMOUR

- Continuously produced by ciliary body

- Flows from posterior chamber into anterior through the pupil

- Scleral venous sinus
  - canal of Schlemm
  - opening in white of eye at junction of cornea & sclera
  - drainage of aqueous humor from eye to bloodstream
ANATOMY OF THE EYEBALL

- The eye is constructed of three layers:
  1. Fibrous Tunic (outer layer)
  2. Vascular Tunic (middle layer)
  3. Nervous Tunic (inner layer)
FIBROUS TUNIC – the cornea

- **Transparent and avascular**
- **Structure:** 3 layers
  - Nonkeratinized stratified squamous epithelium
  - collagen fibers & fibroblasts
  - simple squamous epithelium
  - Nourished by tears & aqueous humor
- **Function:** helps focus light (refraction)
  - astigmatism
FIBROUS TUNIC – the sclera

- “White” of the eye
- **Structure**: dense irregular connective tissue layer
  - collagen & fibroblasts
- At the junction of the sclera and cornea is an opening (scleral venous sinus)
- Posteriorly pierced by Optic Nerve (CNII)

- **Function**: Provides shape & support
VASCULAR TUNIC - choroid & ciliary body

- **Choroid**
  - **Structure:** pigmented epithelial cells (melanocytes) & blood vessels; black pigment in melanocytes absorb scattered light
  - **Function:** provides nutrients to retina

- **Ciliary body**
  - ciliary processes
    - folds on ciliary body
    - secrete aqueous humor
  - ciliary muscle
    - smooth muscle that alters shape of lens
VASCULAR TUNIC - iris & pupil

- **Structure**: colored portion of eye; shape of flat donut suspended between cornea & lens; hole in center of iris is called pupil

- **Function**: regulation of amount of light entering eye

- **Autonomic reflexes**:
  - Parasympathetic: circular muscle fibers contract in bright light to shrink pupil
  - Sympathetic: radial muscle fibers contract in dim light to enlarge pupil
NERVOUS TUNIC - retina

- Pigmented and vascular
- Posterior 3/4 of eyeball
- Optic disc
  - optic nerve exiting back of eyeball
- Central retina blood vessels
  - fan out to supply nourishment to retina
  - visible for inspection
Layers of retina

- Retina has two layers:
  1. Pigmented epithelium
     - nonvisual portion
     - absorbs stray light & helps keep image clear
  2. Neural layer: 3 layers of neurons (outgrowth of brain)
     - photoreceptor layer
     - bipolar neuron layer
     - ganglion neuron layer

- 2 other cell types: found within bipolar neuron layer; form lateraly directed neural circuits; modify the signal
  - horizontal cells
  - amacrine cells
Layers of retina – photoreceptor layer

- 2 photoreceptor cells that differ in the shapes of their outer segments differ:
  1. Rods: specialized for black-and-white vision in dim light and permit us to see shapes and movement
  2. Cones: specialized for color vision and sharpness of vision (high visual acuity) in bright light; blue, green and red cones
Layers of retina – fovea, lutea and optic disc

- **Macula lutea**: in the exact center of the posterior portion of the retina, corresponding to the visual axis of the eye.
- **Central fovea**: area of sharpest vision because of the high concentration of cones (NO rods present)
- **Optic disc**: area that contains no cones or rods; blind spot
PHYSIOLOGY OF VISION

- Photopigments: integral membrane proteins (opsin) + derivative of vitamin A (retinal); undergo structural changes upon light absorption.

- There are four different opsins (3 total for cones RGB – 1 per cone; 1 for rods - rhodopsin)

- Retinal is the light absorbing part of all visual photopigments.
1. Light penetrates retina
2. Light leads to conformational change in photopigment in rods & cones; these cells transduce light into membrane potential and release neurotransmitters
3. Rods & cones excite bipolar cells; bipolar cells excite ganglion cells; axons of ganglion cells form optic nerve leaving the eyeball (blind spot)
4. Optic nerve leaving the eyeball to thalamus & then the primary visual cortex
Retinal processing of visual information

- **Convergence**
  - one cone cell synapses onto one bipolar cell produces best visual acuity
  - 600 rod cells synapse on single bipolar cell increasing light sensitivity although slightly blurry image results
  - 126 million photoreceptors converge on 1 million ganglion cells

- **Horizontal and amacrine cells**
  - horizontal cells enhance contrasts in visual scene because laterally inhibit bipolar cells in the area
  - amacrine cells excite bipolar cells if levels of illumination change
MAJOR PROCESSES OF IMAGE FORMATION

- Refraction of light (bending)
  - by cornea & lens
  - light rays must fall upon the retina

- Accommodation of the lens
  - changing shape of lens so that light is focused

- Alteration of the pupil size
  - Constriction or dilation to alter amount of light entering the posterior chamber
CONVERGENCE OF THE EYES

- Binocular vision in humans has both eyes looking at the same object.
- As you look at an object close to your face, both eyeballs must turn inward.
  - In convergence, the eyeballs move medially so they are both directed toward an object being viewed.
  - Required so that light rays from the object will strike both retinas at the same relative point.
  - Extrinsic eye muscles must coordinate this action.
HEARING AND EQUILIBRIUM

One organ  2 major functions
ANATOMY OF THE EAR REGION

Frontal section through the right side of the skull showing the three principal regions of the ear:

- **External ear**
- **Middle ear**
- **Internal ear**

Key structures:

- **Temporal bone**
- **Malleus**
- **Incus**
- **Semicircular canal**
- **Internal auditory canal**
- **Vestibulocochlear (VIII) nerve**
- **Vestibular branch**
- **Cochlear branch**
- **Cochlea**
- **Helix**
- **Auricle**
- **Lobule**
- **Elastic cartilage**
- **Cerumen**
- **External auditory canal**
- **Eardrum**
- **Stapes in oval window**
- **Round window (covered by secondary tympanic membrane)**
- **To nasopharynx**
- **Auditory tube**
External ear

- **Structure:**
  - **auricle or pinna:** elastic cartilage covered with skin
  - **external auditory canal:** curved 1” tube of cartilage & bone leading into temporal bone; ceruminous glands produce cerumen = ear wax
  - **tympanic membrane or eardrum:** epidermis, collagen & elastic fibers, simple cuboidal epithelia

- **Function:** external (outer) ear collects sound waves and passes them inwards
Middle ear cavity

- Air filled cavity in the temporal bone
- Separated from external ear by eardrum and from internal ear by oval & round window
- 3 ear ossicles connected by synovial joints
  - malleus attached to eardrum, incus & stapes attached by foot plate to membrane of oval window
- Auditory tube leads to nasopharynx
  - helps to equalize pressure on both sides of eardrum
Inner ear - bony labyrinth

- **Structure:** set of tubelike cavities in temporal bone: semicircular canals (at approximately right angles), vestibule and cochlea lined with periosteum & filled with perilymph

- **Function:** surrounds & protects Membranous Labyrinth
**Inner ear - membranous labyrinth**

- **Structure**: set of membranous tubes containing sensory receptors for hearing & balance: utricle, saccule, ampulla, 3 semicircular ducts & cochlea

- **Function**: hearing and balance
Cochlear anatomy

- Cochlea is divided into three channels by partitions that together have the shape of the letter Y:
  - Scala vestibule
  - Scala tympani
  - Scala media

- **Organ of Corti**: organ of hearing; structure: Microvilli make contact with tectorial membrane (gelatinous membrane); basal sides of inner hair cells synapse with 1st order sensory neurons whose cell body is in spiral ganglion.
Nerve

- Vestibulocochlear nerve CN VIII
  - vestibular branch consists of 3 parts: ampullary, utricular, and saccular nerves
  - cochlear branch has spiral ganglion in bony modiolus
1. Auricle collects sound waves
2. Eardrum vibrates (e.g. slow vibration in response to low-pitched sounds)
3. Ossicles vibrate since malleus is attached to the eardrum
4. Stapes pushes on oval window producing fluid pressure waves (4a)
5. Pressure fluctuations inside cochlear duct move the hair cells against the tectorial membrane; microvilli on hair cells are bent producing receptor potentials and release of neurotransmitters to the underlying nerves
EQUILIBRIUM (BALANCE)

- **Static equilibrium**
  - maintain the position of the body (head) relative to the force of gravity
  - **macula receptors** within saccule & utricle

- **Dynamic equilibrium**
  - maintain body position (head) during sudden movement of any type—rotation, deceleration or acceleration
  - **crista receptors** within ampulla of semicircular ducts
ANATOMY OF EQUILIBRIUM

- Semicircular ducts with ampulla, utricle & saccule
ANATOMY OF STATIC EQUILIBRIUM - OTOLITHIC ORGANS

- The maculae of the utricle and saccule are the sense organs of static equilibrium.
- Cell types in the macula region
  - hair cells with stereocilia (microvilli) & one cilia (kinocilium)
  - supporting cells that secrete gelatinous layer
- Gelatinous otolithic membrane contains calcium carbonate crystals called otoliths that move when head is tipped
PHYSIOLOGY OF STATIC EQUILIBRIUM

Movement of stereocilia or kinocilium results in the release of neurotransmitter onto the vestibular branches of the vestibulocochlear (VIII) nerve

E.g. tilting and keeping head upright
ANATOMY OF DYNAMIC EQUILIBRIUM - MEMBRANOUS SEMICIRCULAR DUCTS

○ The three semicircular ducts, along with the saccule and utricle maintain dynamic equilibrium.
  • anterior, posterior & horizontal ducts detect different movements (combined 3-D sensitivity)

○ The cristae in the semicircular ducts are the primary sense organs of dynamic equilibrium. Crista = hair cells covered with cupula (gelatinous material)
PHYSIOLOGY OF DYNAMIC EQUILIBRIUM

- Nerve signals to the brain are generated indicating which direction the head has been rotated
- E.g.: detection of rotational movement
Recap of Session 18

Different types of sensations require different structures to recognise them

General senses are recognised all over the body and internal organs and are classified as somatic and visceral; somatic general senses are classified into tactile, thermal, pain and proprioceptive sensations

Special senses have developed specific organs to receive and recognize specific sensation; classified into smell, vision, hearing and equilibrium; for each special sense we have covered anatomy (structure; i.e. where the sensation is received and recognised) and physiology (function; i.e. how the sensation is received and recognised)
Preparation for next session

- Complete any missing concepts and linking words from Session 18

- Review:
  - vertebral column
  - divisions of nervous system, specifically CNS
  - classification of neurons
  - myelinated and unmyelinated axons
  - ependymal cells
  - proprioceptors
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