SENSORY AND MOTOR MECHANISMS

# A. Sensing, Acting, and Brains

1. The brain’s processing of sensory input and motor output is cyclical rather than linear

* The way it ISN’T: sensing🡪 brain analysis🡪 action.
* The way it is: sensing, analysis, and action are ongoing and overlapping processes.
* Sensations begin as different forms of energy that are detected by sensory receptors.
* This energy is converted to action potentials that travel to appropriate regions of the brain.
* The limbic region plays a major role in determining the importance of a particular sensory input.

# B. Introduction To Sensory Reception

* **Sensations** are action potentials that reach the brain via sensory neurons.
* **Perception** is the awareness and interpretation of the sensation.

1. Sensory receptors transduce stimulus energy and transmit signals to the nervous system

* **Sensory reception** begins with the detection of stimulus energy by **sensory receptors**.
* **Exteroreceptors** detect stimuli originating outside the body.
* **Interoreceptors** detect stimuli originating inside the body.
* Sensory receptors convey the energy of stimuli into membrane potentials and the transmit signals to the nervous system.
* This involves: sensory transduction, amplification, transmission, and integration.
* **Sensory Transduction**.
* The conversion of stimulus energy into a change in membrane potential.
* **Receptor potential**
* **Amplification**.
* The strengthening of stimulus energy that is can be detected by the nervous system.
* May be a part of, or occur apart from, sensory transduction.
* **Transmission.**
* The conduction of sensory impulses to the CNS.
* Some sensory receptors must transmit chemical signals to sensory neurons.
* The strength of the stimulus and receptor potential affects the amount of neurotransmitter released by the sensory receptor.
* Some sensory receptors are sensory neurons.
* The intensity of the receptor potential affects the frequency of action potentials.
* **Integration**.
* The processing of sensory information.
* Begins at the sensory receptor.
* For example, **sensory adaptation** is a decrease in responsiveness to continued stimulation.
* For example, the sensitivity of a receptor to a stimulus will vary with environmental conditions.

2. Sensory receptors are categorized by the type of energy they transduce

* **Mechanoreceptors** respond to mechanical energy.
* For example, **muscle spindles** are an interoreceptor that responds to the stretching of skeletal muscle.
* For example, **hair cells** detect motion.
* **Pain receptors** = **nocioceptors**.
* Different types of pain receptors respond to different types of pain.
* Prostaglandins increase pain by decreasing a pain receptors threshold.
* Anti-inflammatories work by inhibiting prostaglandin synthesis.
* **Thermoreceptors** respond to heat or cold.
* Respond to both surface and body core temperature.
* **Chemoreceptors** respond to chemical stimuli.
* General chemoreceptors transmit information about total solute concentration.
* Specific chemoreceptors respond to specific types of molecules.
* Internal chemoreceptors respond to glucose, O2, CO2, amino acids, etc.
* External chemoreceptors are **gustatory receptors** and **olfactory receptors**.
* **Electromagnetic receptors** respond to electromagnetic energy.
* **Photoreceptors** respond to the radiation we know as visible light.
* Electroreceptors: some fish use electric currents to locate objects.

# C. Photoreceptors And Vision

* Most, if not all, animal photoreceptors may be homologous.

1. A diversity of photoreceptors has evolved among invertebrates

* **Eye cups** are among the simplest photoreceptors
* Detect light intensity and direction, but no image formation.
* The movement of a planarian is integrated with photoreception.
* Image-forming eyes.
* **Compound eyes** of insects and crustaceans.
* Each eye consists of **ommatidia**, each with its own light-focusing lens.
* This type of eye is very good at detecting movement.
* **Single-lens eyes** of invertebrates such as jellies, polychaetes, spiders, and mollusks.
* The eye of an octopus works much like a camera and is similar to the vertebrate eye.

**2. Vertebrates have single-lens eyes**

* Is structurally analogous to the invertebrate single-lens eye.
* **Sclera**: a tough white layer of connective tissue that covers all of the eyeball except the cornea.
* **Conjunctiva**: external cover of the sclera that keeps the eye moist.
* **Cornea**: transparent covering of the front of the eye.
* Allows for the passage of light into the eye and functions as a fixed lens.
* **Choroid**: thin, pigmented layer lining the interior surface of the sclera.
* Prevents light rays from scattering and distorting the image.
* Anteriorly it forms the **iris**.
* The iris regulates the size of the **pupil**.
* **Retina**: lines the interior surface of the choroid.
* Contains photoreceptors.
* Except at the optic disk (where the optic nerve attaches).
* The **lens** and **ciliary body** divide the eye into two cavities.
* The anterior cavity is filled with **aqueous humor** produced by the ciliary body.
* Glaucoma results when the ducts that drain aqueous humor are blocked.
* The posterior cavity is filled with **vitreous humor**.
* The lens, the aqueous humor, and the vitreous humor all play a role in focusing light onto the retina.
* **Accommodation** is the focusing of light in the retina.
* In squid, octopuses, and many fish this is accomplished by moving the lens forward and backward.
* In mammals accommodation is accomplished by changing the shape of the lens.
* The lens is flattened for focusing on distant objects.
* The lens is rounded for focusing on near objects.
* Photoreceptors of the retina.
* About 125 million **rod cells**.
* Rod cells are light sensitive but do not distinguish colors.
* About 6 million **cone cells**.
* Not as light sensitive as rods but provide color vision.
* Most highly concentrated on the fovea, an area of the retina that lacks rods.

3. The light-absorbing pigment rhodopsin triggers a signal-transduction pathway

* **Rhodopsin** (**retinal + opsin**) is the visual pigment of rods.
* The absorption of light by rhodopsin initiates a signal-transduction pathway.
* Color reception is more complex than the rhodopsin mechanism.
* There are three subclasses of cone cells, each with its own type of **photopsin**.
* Color perception is based on the brain’s analysis of the relative responses of each type of cone.
* In humans, colorblindness is due to a deficiency, or absence, of one or more photopsins.
* Inherited as an X-linked trait.

4. The retina assists the cerebral cortex in processing visual information

* Visual processing begins with rods and cones synapsing with **bipolar cells**.
* Bipolar cells synapse with **ganglion cells**.
* Visual processing in the retina also involves **horizontal cells** and **amacrine cells**.
* Vertical pathway: photoreceptors 🡪 bipolar cells 🡪 ganglion cells axons.
* Lateral pathways:
* Photoreceptors 🡪 horizontal cells 🡪 other photoreceptors.
* Results in **lateral inhibition**.
* More distant photoreceptors and bipolar cells are inhibited, which sharpens edges and enhances contrast in the image.
* Photoreceptors 🡪 bipolar cells 🡪 amacrine cells🡪 ganglion cells.
* Also results in lateral inhibition, this time of the ganglion cells.
* The optic nerves of the two eyes meet at the **optic chiasm**.
* Where the nasal half of each tract crosses to the opposite side.
* Ganglion cell axons make up the optic tract.
* Most synapses in the **lateral geniculate nuclei** of the thalamus.
* Neurons then convey information to the **primary visual cortex** of the optic lobe.

# D. Hearing And Equilibrium

**1. The mammalian hearing organ is within the ear**

* The **outer ear** includes the external pinna and the auditory canal.
* Collects sound waves and channels them to the **tympanic membrane**.
* From the tympanic membrane sound waves are transmitted through the **middle ear**.
* **Malleus 🡪 incus 🡪 stapes**.
* From the stapes the sound wave is transmitted to the **oval window** and on to the inner ear.
* **The eustachian tube** connects the middle ear with the pharynx.
* The **inner ear** consists of a labyrinth of channels housed within the temporal bone.
* The **cochlea** is the part of the inner ear concerned with hearing.
* Structurally it consists of the upper vestibular canal and the lower tympanic canal, which are separated by the cochlear duct.
* The vestibular and tympanic canals are filled with perilymph.
* The cochlear duct is filled with endolymph.
* The **organ of Corti** rests on the basilar membrane.
* The tectorial membrane rests atop the hair cells of the organ of Corti.
* From inner ear structure to a sensory impulse: follow the vibrations.
* The **round window** functions to dissipate the vibrations.
* Vibrations in the cochlear fluid 🡪 basilar membrane vibrates 🡪 hair cells brush against the tectorial membrane 🡪 generation of an action potential in a sensory neuron.
* **Pitch** is based on the location of the hair cells that depolarize.
* Volume is determined by the amplitude of the sound wave.

2. The inner ear also contains the organs of equilibrium

* Behind the oval window is a vestibule that contains the **utricle** and **saccule**.
* The utricle opens into three **semicircular canals**.
* The utricle and saccule respond to changes in head position relative to gravity and movement in one direction.
* Hair cells are projected into a gelatinous material containing otoliths.
* When the head’s orientation changes the hair cells are tugged on, sending nerve impulse along a sensory neuron.
* The semicircular canals respond to rotational movements of the head.
* The mechanism is similar to that associated with the utricle and saccule.

3. A lateral line system and inner ear detect pressure waves in most fishes and aquatic amphibians

* Fishes and amphibians lack cochleae, eardrums, and openings to the outside.
* However, they have saccules, utricles, and semicircular canals.
* Most fish and amphibians have a **lateral line system** along both sides of their body.
* Contains mechanoreceptors that function similarly to the mammalian inner ear.
* Provides a fish with information concerning its movement through water or the direction and velocity of water flowing over its body.

4. Many invertebrates have gravity sensors and are sound-sensitive

* **Statocysts** are mechanoreceptors that function in an invertebrates sense of equilibrium.
* Statocyst function is similar to that of the mammalian utricle and saccule.
* Sound sensitivity in insects depends on body hairs that vibrate in response to sound waves.
* Different hairs respond to different frequencies.
* Many insects have a tympanic membrane stretched over a hollow chamber.

# E. Chemoreception – Taste And Smell

1. Perceptions of taste and smell are usually interrelated

* Taste receptors in insects are located on their feet.
* In mammals, taste receptors are located in **taste buds,** most of which are on the surface of the tongue.
* Each taste receptor responds to a wide array of chemicals.
* It is the pattern of taste receptor response that determines perceived flavor.
* In mammals, olfactory receptors line the upper portion of the nasal cavity.
* The binding of odor molecules to olfactory receptors initiates signal-transduction pathways involving a G-protein-signaling pathway and, often, adenylyl cyclase and cyclic AMP.

# F. Movement And Locomotion

* **Locomotion** is active movement from one place to another.

1. Locomotion requires energy to overcome friction and gravity

* A comparison of the energy costs of various modes of locomotion.
* Swimming.
* Since water is buoyant, gravity poses less of a problem for swimming than for other modes of locomotion.
* However, since water is dense, friction is more of a problem.
* Fast swimmers have fusiform bodies.
* For locomotion on land, powerful muscles and skeletal support are more important than a streamlined shape.
* When hopping, the tendons in a kangaroo’s legs store and release energy like a spring that is compressed and released – the tail helps in the maintenance of balance.
* When walking, having one food on the ground helps in the maintenance of balance.
* When running, momentum helps in the maintenance of balance.
* Crawling requires a considerable expenditure of energy to overcome friction – but maintaining balance is not a problem.
* Gravity poses a major problem when flying.
* The key to flight is the aerodynamic structure of wings.
* Cellular and Skeletal Underpinning of Locomotion.
* On a cellular level, all movement is based on contraction.
* Either the contraction of microtubules or the contraction of microfilaments.

2. Skeletons support and protect the animal body and are essential to movement

* **Hydrostatic skeleton**: consists of fluid held under pressure in a closed body compartment.
* Form and movement is controlled by changing the shape of this compartment.
* The hydrostatic skeleton of earthworms allows them to move by **peristalsis**.
* Advantageous in aquatic environments and can support crawling and burrowing.
* Does not allow for running or walking.
* **Exoskeletons**: hard encasements deposited on the surface of an animal.
* Mollusks are enclosed in a calcareous exoskeleton.
* The jointed exoskeleton of arthropods is composed of a cuticle.
* Regions of the cuticle can vary in hardness and degree of flexibility.
* About 30 – 50% of the cuticle consists of **chitin**.
* Muscles are attached to the interior surface of the cuticle.
* This type of exoskeleton must be molted to allow for growth.
* **Endoskeletons** consist of hard supporting elements within soft tissues.
* Sponges have spicules.
* Echinoderms have plates composed of magnesium carbonate and calcium carbonate.
* Chordate endoskeletons are composed of cartilage and bone.
* The bones of the mammalian skeleton are connected at joints by ligaments.

3. Physical support on land depends on adaptations of body proportions and posture

* In the support of body weight, posture is more important than body proportions.

**4. Muscles move skeletal parts by contracting**

* Muscles come in antagonistic pairs.
* Structure and Function of Vertebrate Skeletal Muscle.
* The **sarcomere** is the functional unit of muscle contraction.
* **Thin filaments** consist of two strands of actin and one tropomyosin coiled about each other.
* **Thick filaments** consist of myosin molecules.

5. Interactions between myosin and actin generate force during muscle contractions

* The **sliding-filament** model of muscle contraction.

6. Calcium ions and regulatory proteins control muscle contraction

* At rest, **tropomyosin** blocks the myosin binding sites on actin.
* When calcium binds to the **troponin complex,** a conformational change results in the movement of the tropomyosin-tropinin complex and exposure of actin’s myosin binding sites.
* But, wherefore the calcium ions?
* Follow the action potential.
* When an action potential meets the muscle cell’s **sarcoplasmic reticulum** (**SR**) stored Ca2+ is released.

7. Diverse body movements require variation in muscle activity

* An individual muscle cell either contracts completely or not all.
* Individual muscles, composed of many individual muscle fibers, can contract to varying degrees.
* One way variation is accomplished is by varying the frequency of action potentials that reach the muscle from a single motor neuron.
* Graded muscle contraction can also be controlled by regulating the number of **motor units** involved in the contraction.
* **Recruitment** of motor neurons increases the number of muscle cells involved in a contraction.
* Some muscles, such as those involved in posture, are always at least partially contracted.
* Fatigue is avoided by rotating among motor units.
* Fast and Slow Muscle Fibers.
* **Fast muscle fibers** are adapted for rapid, powerful contractions.
* Fatigue relatively quickly.
* **Slow muscle fibers** are adapted for sustained contraction.
* Relative to fast fibers, slow fibers have.
* Less SR, so Ca2+ remains in the cytosol longer.
* More mitochondria, a better blood supply, and **myoglobin**.

• Other Types of Muscle.

* In addition to skeletal muscle, vertebrates have cardiac and smooth muscle.
* **Cardiac muscle**: similar to skeletal muscle.
* **Intercalated discs** facilitate the coordinated contraction of cardiac muscle cells.
* Can generate their own action potentials.
* Action potentials of long duration.
* **Smooth muscle:** lacks the striations seen in both skeletal and cardiac muscle.
* Contracts with less tension, but over a greater range of lengths, than skeletal muscle.
* No T tubules and no SR.
* Ca2+ enters the cytosol via the plasma membrane.
* Slow contractions, but with more control over contraction strength than with skeletal muscle.
* Found lining the walls of hollow organs.
* Invertebrate muscle cells are similar to vertebrate skeletal and smooth muscle cells.