Sensory and Motor Mechanisms

Chapter 50

Sensory Pathways

• Sensory pathways have four basic functions in common
  – Sensory reception
  – Transduction
    • Sensory transduction is the conversion of stimulus energy into a change in the membrane potential of a sensory receptor
  – Transmission
  – Integration

Transmission

• Some sensory receptors are specialized neurons while others are specialized cells that regulate neurons

Perception

• Perceptions are the brain's construction of stimuli
• Stimuli from different sensory receptors travel as action potentials along dedicated neural pathways
• The brain distinguishes stimuli from different receptors based on the area in the brain where the action potentials arrive
• Amplification is the strengthening of stimulus energy by cells in sensory pathways
• Sensory adaptation is a decrease in responsiveness to continued stimulation
Types of Sensory Receptors

- Based on energy transduced, sensory receptors fall into five categories
  - Mechanoreceptors
  - Chemoreceptors
  - Electromagnetic receptors
  - Thermoreceptors
  - Pain receptors

Mechanoreceptors

- Mechanoreceptors sense physical deformation caused by stimuli such as pressure, stretch, motion, and sound.

Chemoreceptors

- General chemoreceptors transmit information about the total solute concentration of a solution.
- Specific chemoreceptors respond to individual kinds of molecules.
- When a stimulus molecule binds to a chemoreceptor, the chemoreceptor becomes more or less permeable to ions.
- The antennae of the male silkworm moth have very sensitive specific chemoreceptors.

Electromagnetic Receptors

- Electromagnetic receptors detect electromagnetic energy such as light, electricity, and magnetism.
- Some snakes have very sensitive infrared receptors that detect body heat of prey against a colder background.
- Many animals apparently migrate using the Earth’s magnetic field to orient themselves.

Thermoreceptors and Pain Receptors

- Thermoreceptors, which respond to heat or cold, help regulate body temperature by signaling both surface and body core temperature.
- In humans, pain receptors, or nociceptors, are a class of naked dendrites in the epidermis.
- They respond to excess heat, pressure, or chemicals released from damaged or inflamed tissues.
The mechanoreceptors responsible for hearing and equilibrium detect moving fluid or settling particles:

- Most invertebrates maintain equilibrium using mechanoreceptors located in organs called statocysts.
- Statocysts contain mechanoreceptors that detect the movement of granules called statoliths.

Many arthropods sense sounds with body hairs that vibrate or with localized "ears" consisting of a tympanic membrane and receptor cells.

Hearing:

- Vibrating objects create percussion waves in the air that cause the tympanic membrane to vibrate.
- The three bones of the middle ear transmit the vibrations of moving air to the oval window on the cochlea.
- These vibrations create pressure waves in the fluid in the cochlea that travel through the vestibular canal.

Equilibrium:

- Several organs of the inner ear detect body movement, position, and balance:
  - The utricle and saccule contain granules called otoliths that allow us to perceive position relative to gravity or linear movement.
  - Three semicircular canals contain fluid and can detect angular movement in any direction.

- The ear conveys information about:
  - Volume, the amplitude of the sound wave.
  - Pitch, the frequency of the sound wave.
- The cochlea can distinguish pitch because the basilar membrane is not uniform along its length.
- Each region of the basilar membrane is tuned to a particular vibration frequency.
Hearing and Equilibrium in Other Vertebrates

- Unlike mammals, fishes have only a pair of inner ears near the brain.
- Most fishes and aquatic amphibians also have a **lateral line system** along both sides of their body.
- The lateral line system contains mechanoreceptors with hair cells that detect and respond to water movement.

Visual receptors on diverse animals depend on light-absorbing pigments

- Animals use a diverse set of organs for vision, but the underlying mechanism for capturing light is the same, suggesting a common evolutionary origin.

### Compound Eyes

- Insects and crustaceans have **compound eyes**, which consist of up to several thousand light detectors called **ommatidia**.
- Compound eyes are very effective at detecting movement.

### Light-Detecting Organs

- A pair of ocelli called eyespots are located near the head.
- These allow planarians to move away from light and seek shaded locations.

### Single-Lens Eyes

- **Single-lens eyes** are found in some jellies, polychaetes, spiders, and many molluscs.
- They work on a camera-like principle: the iris changes the diameter of the **pupil** to control how much light enters.
- The eyes of all vertebrates have a single lens.
Processing of Visual Information in the Retina

- Processing of visual information begins in the retina
- In the dark, rods and cones release the neurotransmitter glutamate into synapses with neurons called bipolar cells
- Bipolar cells are either hyperpolarized or depolarized in response to glutamate
- In the light, rods and cones hyperpolarize, shutting off release of glutamate
- The bipolar cells are then either depolarized or hyperpolarized

Processing of Visual Information in the Brain

- The optic nerves meet at the optic chiasm near the cerebral cortex
- Sensations from the left visual field of both eyes are transmitted to the right side of the brain
- Sensations from the right visual field are transmitted to the left side of the brain

The senses of taste and smell rely on similar sets of sensory receptors

- In terrestrial animals
  - Gustation (taste) is dependent on the detection of chemicals called tastants
  - Olfaction (smell) is dependent on the detection of odorant molecules
- In aquatic animals there is no distinction between taste and smell
- Taste receptors of insects are in sensory hairs called sensilla, located on feet and in mouth parts

Taste in Mammals

- In humans, receptor cells for taste are modified epithelial cells organized into taste buds
- There are five taste perceptions: sweet, sour, salty, bitter, and umami (elicited by glutamate)
- Researchers have identified receptors for each of the tastes except salty
- Researchers believe that an individual taste cell expresses one receptor type and detects one of the five tastes
Smell in Humans

- Olfactory receptor cells are neurons that line the upper portion of the nasal cavity
- Binding of odorant molecules to receptors triggers a signal transduction pathway, sending action potentials to the brain
- Humans can distinguish thousands of different odors
- Although receptors and brain pathways for taste and smell are independent, the two senses do interact

Vertebrate Skeletal Muscle

- Vertebrate skeletal muscle moves bones and the body and is characterized by a hierarchy of smaller and smaller units
- A skeletal muscle consists of a bundle of long fibers, each a single cell, running parallel to the length of the muscle
- Each muscle fiber is itself a bundle of smaller myofibrils arranged longitudinally
  - Thin filaments consist of two strands of actin and two strands of a regulatory protein
  - Thick filaments are staggered arrays of myosin molecules

The physical interaction of protein filaments is required for muscle function

- Muscle activity is a response to input from the nervous system
- The action of a muscle is always to contract; extension is passive

The Sliding-Filament Model of Muscle Contraction

- The sliding of filaments relies on interaction between actin and myosin
- The “head” of a myosin molecule binds to an actin filament, forming a cross-bridge and pulling the thin filament toward the center of the sarcomere
- Muscle contraction requires repeated cycles of binding and release
- Glycolysis and aerobic respiration generate the ATP needed to sustain muscle contraction
Types of Skeletal Muscle Fibers

Oxidative and Glycolytic Fibers
- Oxidative fibers rely mostly on aerobic respiration to generate ATP
- These fibers have many mitochondria, a rich blood supply, and a large amount of myoglobin
- Myoglobin is a protein that binds oxygen more tightly than hemoglobin does

Fast-Twitch and Slow-Twitch Fibers
- Slow-twitch fibers contract more slowly but sustain longer contractions
- All slow-twitch fibers are oxidative
- Fast-twitch fibers contract more rapidly but sustain shorter contractions
- Fast-twitch fibers can be either glycolytic or oxidative

In producing its characteristic mating call, the male toadfish can contract and relax certain muscles more than 200 times per second.
Skeletal systems transform muscle contraction into locomotion

- Skeletal muscles are attached in antagonistic pairs, the actions of which are coordinated by the nervous system
- The skeleton provides a rigid structure to which muscles attach
- Skeletons function in support, protection, and movement

Types of Skeletal Systems

- The three main types of skeletons are
  - Hydrostatic skeletons (lack hard parts)
    - most cnidarians, flatworms, nematodes, and annelids
  - Exoskeletons (external hard parts)
    - most molluscs and arthropods
  - Endoskeletons (internal hard parts)
    - sponges to mammals

Locomotion on Land

- Walking, running, hopping, or crawling on land requires an animal to support itself and move against gravity
- Diverse adaptations for locomotion on land have evolved in vertebrates

Swimming

- In water, friction is a bigger problem than gravity
- Fast swimmers usually have a sleek, torpedo-like shape to minimize friction
- Animals swim in diverse ways
  - Paddling with their legs as oars
  - Jet propulsion
  - Undulating their body and tail from side to side, or up and down

Flying

- Active flight requires that wings develop enough lift to overcome the downward force of gravity
- Many flying animals have adaptations that reduce body mass
  - For example, birds lack teeth and a urinary bladder, as well as large bones with air-filled regions
Energy Costs of Locomotion

- Animals specialized for swimming expend less energy per meter traveled than equivalently sized animals specialized for flying or running.
- Large animals travel more efficiently than smaller animals adapted to the same mode of transport.

![Energy Costs of Locomotion Graph](image)