Overview: Sensing and Acting

- Bats use sonar to detect their prey.
- Moths, a common prey for bats, can detect the bat's sonar and attempt to flee.
- Both organisms have complex sensory systems that facilitate survival.
- These systems include diverse mechanisms that sense stimuli and generate appropriate movement.

Can a moth evade a bat in the dark?

Sensory receptors transduce stimulus energy and transmit signals to the CNS, central nervous system

- All stimuli represent forms of energy.
- *Sensation involves converting energy into a change in the membrane potential of sensory receptors*.
- Sensations are *action potentials* that reach the brain via sensory neurons.
- The brain interprets sensations, giving the perception of stimuli.

Sensory Pathways

- Functions of sensory pathways: sensory reception, transduction, transmission, and integration.
- For example, stimulation of a stretch receptor in a crayfish is the first step in a sensory pathway.

Sensory Reception and Transduction

- Sensations and perceptions begin with **sensory reception**, detection of stimuli by sensory receptors.
- **Sensory receptors** can detect stimuli outside and inside the body.

- **Sensory transduction** is the conversion of stimulus energy into a change in the membrane potential of a sensory receptor.
- This change in membrane potential is called a **receptor potential.**
- Many sensory receptors are very sensitive: they are able to detect the smallest physical unit of stimulus.
  - For example, most light receptors can detect a photon of light.

Transmission

- After energy has been transduced into a receptor potential, some sensory cells generate the **transmission** of action potentials to the CNS.
- Sensory cells without axons release neurotransmitters at synapses with sensory neurons.
- Larger receptor potentials generate more rapid action potentials.

- **Integration** of sensory information begins when information is received.
- Some receptor potentials are integrated through summation.

Perception

- **Perceptions** are the brain's construction of stimuli.
- Stimuli from different sensory receptors travel as action potentials along different neural pathways.
- The brain distinguishes stimuli from different receptors by the area in the brain where the action potentials arrive.

Amplification and Adaptation

- **Amplification** is the strengthening of stimulus energy by cells in sensory pathways.
- **Sensory adaptation** is a decrease in responsiveness to continued stimulation.

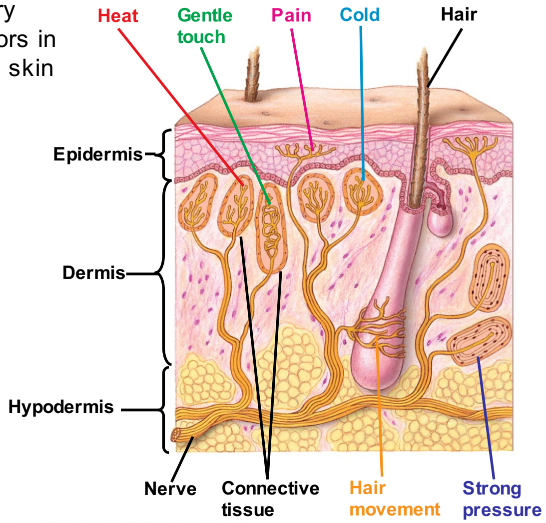
Types of Sensory Receptors

- 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.
- The sense of touch in mammals relies on mechanoreceptors that are dendrites of sensory neurons.

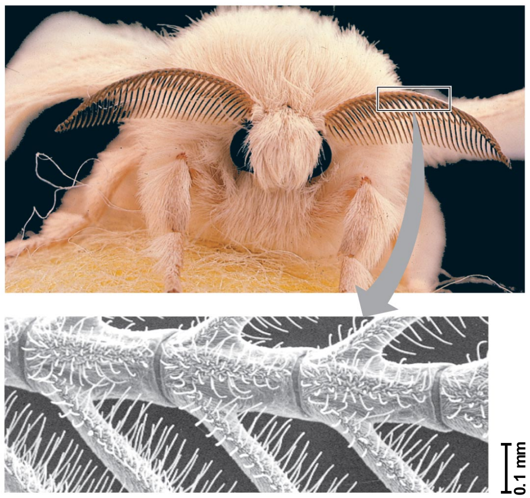
Sensory receptors in human skin



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.

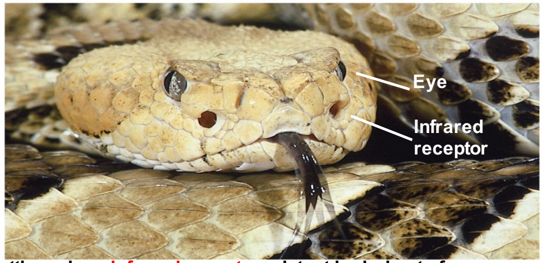
Chemoreceptors in an insect



Electromagnetic Receptors

- **Electromagnetic receptors** detect electromagnetic energy such as light, electricity, and magnetism. Photoreceptors are electromagnetic receptors that detect light.
- Some snakes have very sensitive infrared receptors that detect body heat of prey against a colder background.
- Many mammals, such as whales, appear to use Earth's magnetic field lines to orient themselves as they migrate.

Specialized electromagnetic receptors



(a) Rattlesnake – infrared receptors detect body heat of prey

(b) Beluga whales sense Earth's magnetic field – as they navigate migrations.

Thermoreceptors & 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.

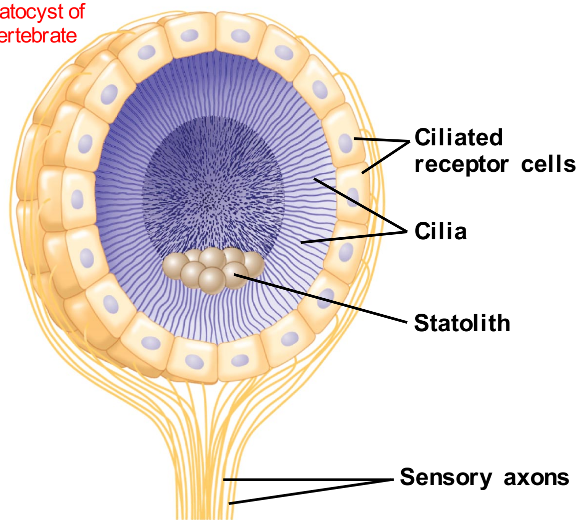
The mechanoreceptors responsible for hearing and equilibrium detect moving fluid or settling particles

- Hearing and perception of body equilibrium are related in most animals.
- Settling particles or moving fluid are detected by mechanoreceptors.

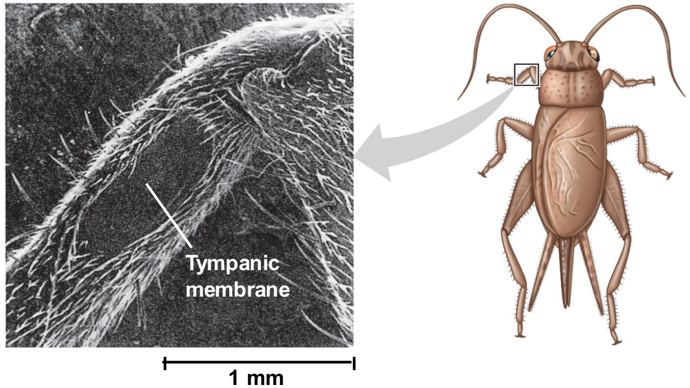
Sensing Gravity and Sound in Invertebrates

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

The statocyst of an invertebrate



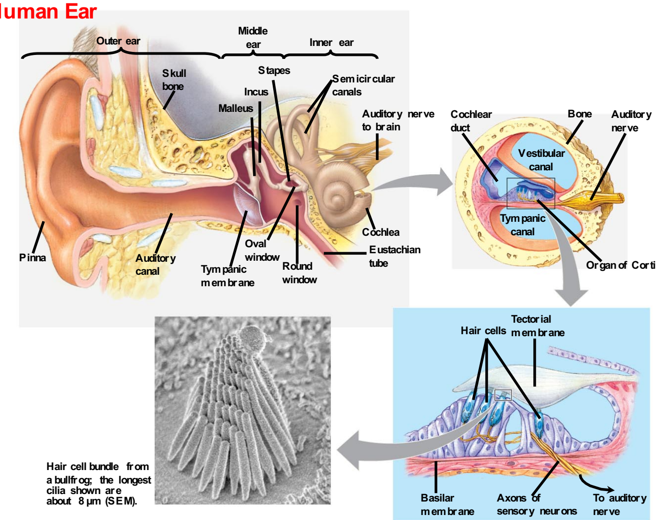
Many arthropods sense sounds with body hairs that vibrate or with localized “ears” consisting of a tympanic membrane and receptor cells



Hearing and Equilibrium in Mammals

- In most terrestrial vertebrates, sensory organs for hearing and equilibrium are closely associated in the ear.

Human Ear

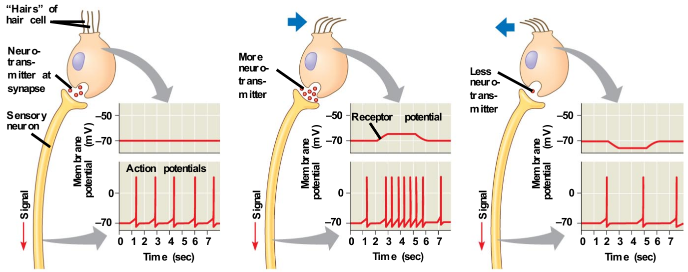


Hearing

- Vibrating objects create percussion waves in the air that cause the tympanic membrane to vibrate.
- **Hearing** is the perception of sound in the brain from the vibration of air waves.
- 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.
- Pressure waves in the canal cause the basilar membrane to vibrate, bending its hair cells.
- This bending of hair cells depolarizes the membranes of mechanoreceptors and sends action potentials to the brain via the auditory nerve.

Sensory reception by hair cells.



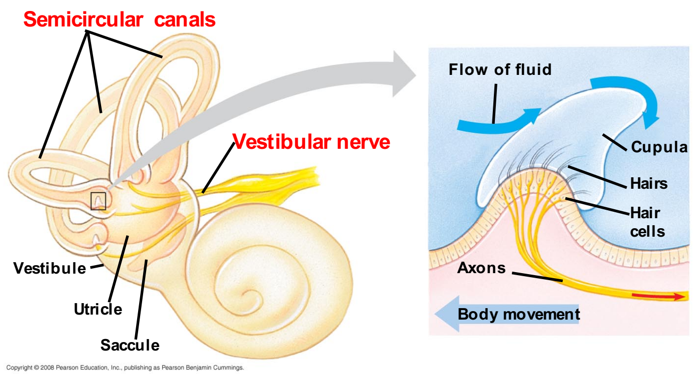
(a) No bending of hairs (b) Bending of hairs in one direction (c) Bending of hairs in other direction

- The ear conveys information about sound waves:
- *Volume* = amplitude of the sound wave
- *Pitch* = frequency of the sound wave
- The cochlea can distinguish pitch because the basilar membrane is not uniform along its length.
- Each region vibrates most vigorously at a particular frequency and leads to excitation of a specific auditory area of the cerebral cortex.

Equilibrium

- Several organs of the inner ear detect body position and balance:
  - The **utricle** and **saccule** contain granules called otoliths that allow us to detect gravity and linear movement.
  - Three ***semicircular canals*** contain fluid and allow us to detect angular acceleration such as the turning of the head.

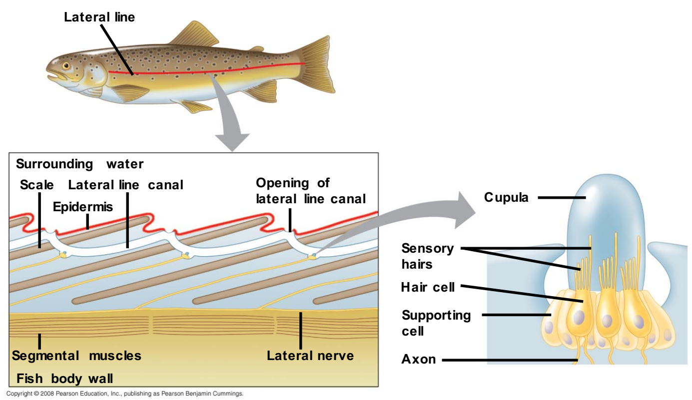
Organs of equilibrium in the inner ear



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.

The lateral line system in a fish has mechanorecptors that sense water movement



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.

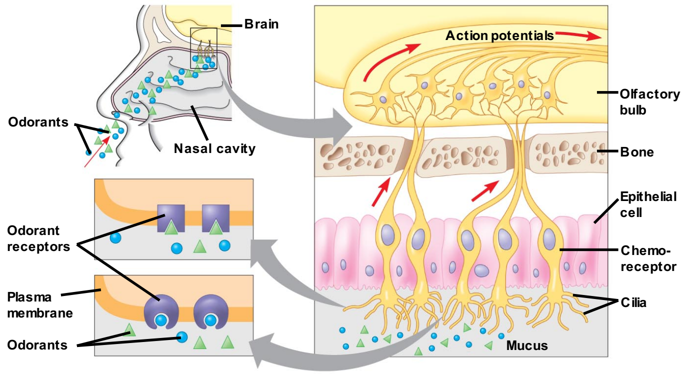
Taste in Mammals

- 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).
- Each type of taste can be detected in any region of the tongue.
- When a taste receptor is stimulated, the signal is transduced to a sensory neuron. Each taste cell has only one type of receptor.

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.

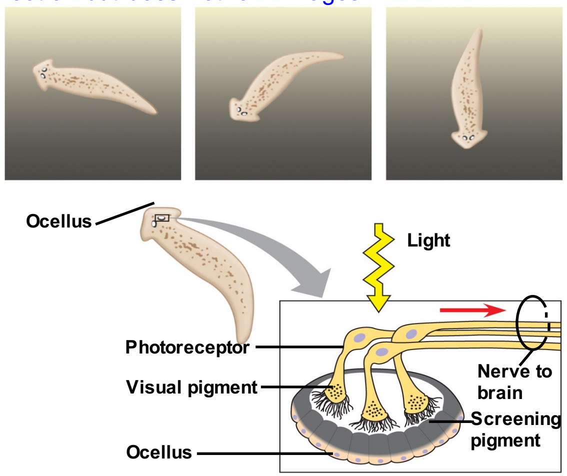
Smell in humans



Similar mechanisms underlie vision throughout the animal kingdom

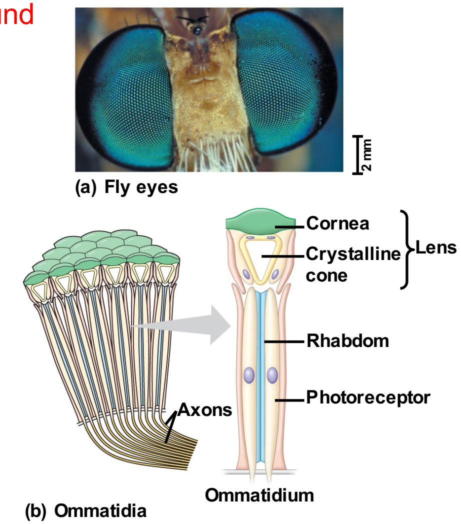
- Many types of light detectors have evolved in the animal kingdom.
- Most invertebrates have a light-detecting organ.
- One of the simplest is the eye cup of planarians, which provides information about light intensity and direction but does not form images.

Eye cup of planarians provides information about light intensity and direction but does not form images.



- Two major types of image-forming eyes have evolved in invertebrates: the compound eye and the single-lens eye.
- **Compound eyes** are found in insects and crustaceans and consist of up to several thousand light detectors called **ommatidia.**
- Compound eyes are very effective at detecting movement.

Compound eyes



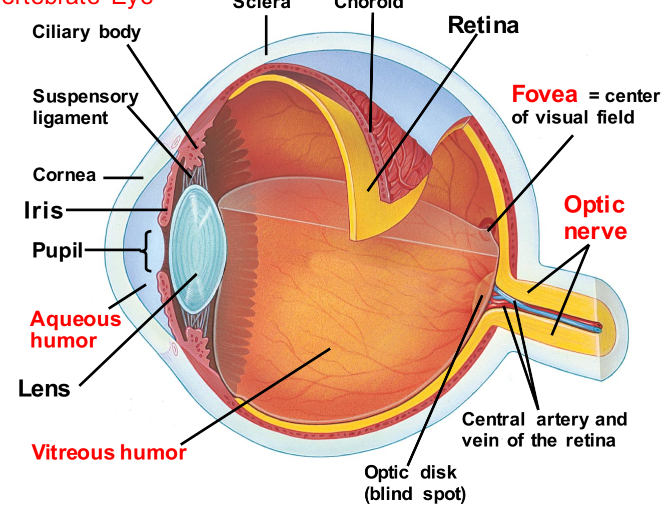
- **Single-lens eyes** are found in some jellies, polychaetes, spiders, and many molluscs.
- They work on a camera-like principle: the **iris** changes the diameter of the **pupil** to control how much light enters.
- In vertebrates the eye detects color and light, but the brain assembles the information and perceives the image.

Structure of the Eye

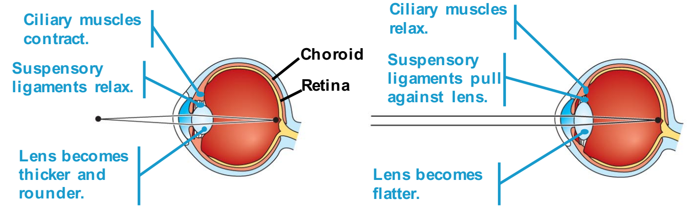
- Main parts of the vertebrate eye:
  - The sclera: white outer layer, including **cornea**
  - The choroid: pigmented layer
  - The iris: regulates the size of the pupil
  - The retina: contains photoreceptors
  - The lens: focuses light on the retina
  - The optic disk: a blind spot in the retina where the optic nerve attaches to the eye.

- The eye is divided into two cavities separated by the lens and **ciliary body**:
  - The anterior cavity is filled with watery **aqueous humor**
  - The posterior cavity is filled with jellylike **vitreous humor**
- The ciliary body produces the aqueous humor.

Vertebrate Eye



Humans and other mammals focus light by changing the shape of the lens.



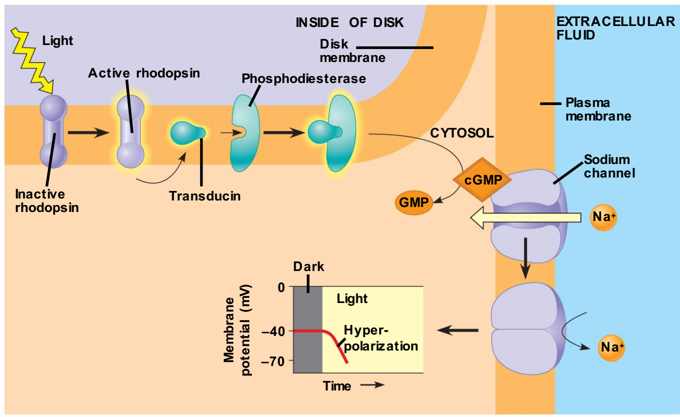
(a) **Near vision** (accommodation) (b) **Distance vision**

- The human retina contains two types of photoreceptors: rods and cones
- **Rods** are light-sensitive but don't distinguish colors.
- **Cones** distinguish colors but are not as sensitive to light.
- In humans, cones are concentrated in the **fovea**, the center of the visual field, and rods are more concentrated around the periphery of the retina.

Sensory Transduction in the Eye

- Each rod or cone contains visual pigments consisting of a light-absorbing molecule called **retinal** bonded to a protein called an **opsin.**
- Rods contain the pigment **rhodopsin** (retinal combined with a specific opsin), which changes shape when absorbing light.
- Once light activates rhodopsin, cyclic GMP breaks down, and Na^+ channels close.
- This hyperpolarizes the cell.

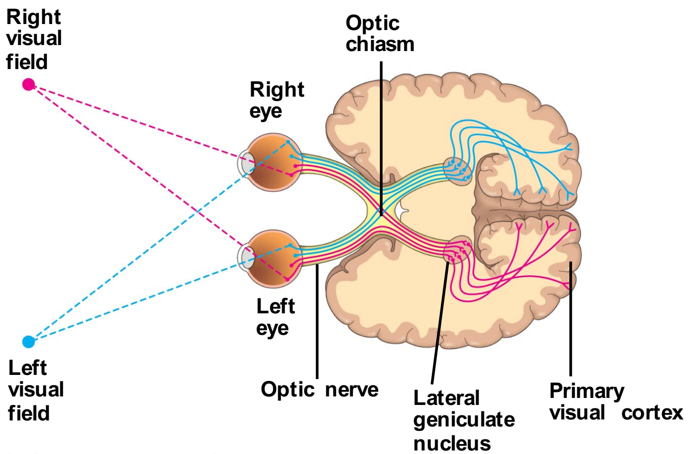
Receptor potential production in a rod cell



Processing of Visual Information

- In humans, three pigments called photopsins detect light of different wave lengths: red, green, or blue.
- Processing of visual information begins in the retina.
- Absorption of light by retinal triggers a signal transduction pathway.

Neural pathways for vision



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*.

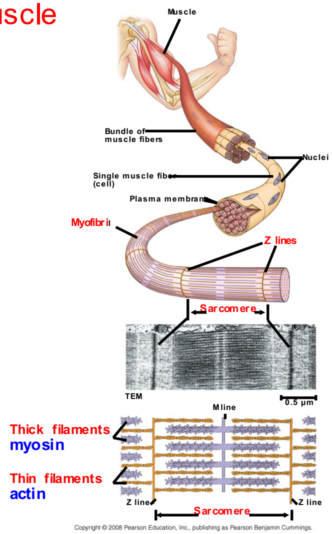
Vertebrate *Skeletal Muscle*

- Vertebrate **skeletal muscle** 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.

- The myofibrils are composed to two kinds of *myofilaments*:
  - **Thin filaments** consist of two strands of actin and one strand of regulatory protein
  - **Thick filaments** are staggered arrays of myosin molecules

- *Skeletal muscle* is also called ***striated muscle*** because the regular arrangement of myofilaments creates a pattern of light and dark bands.
- The functional unit of a muscle is called a ***sarcomere***, and is bordered by *Z lines*.

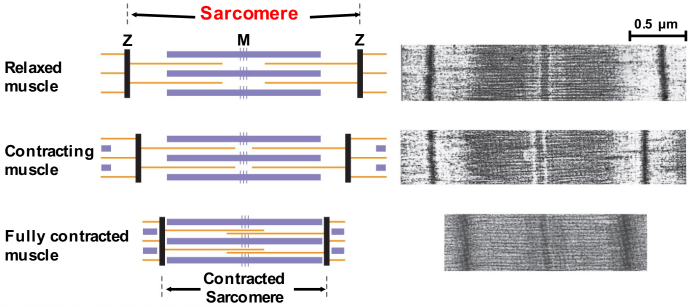
Skeletal Muscle



The Sliding-Filament Model of Muscle Contraction

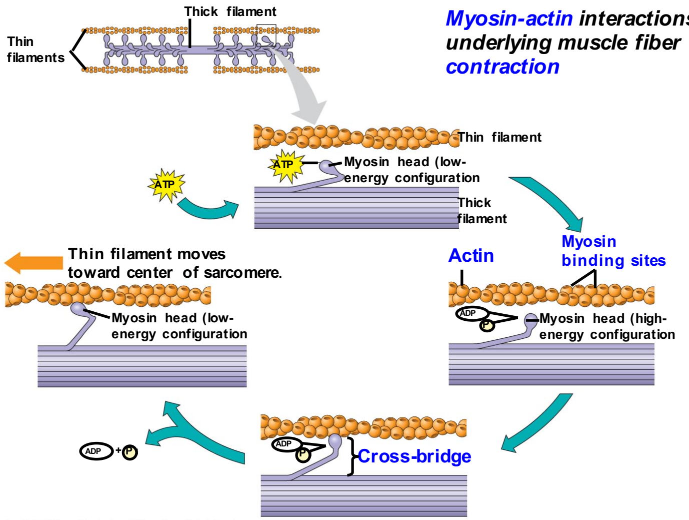
- According to the **sliding-filament model**, filaments slide past each other longitudinally, producing more overlap between thin and thick filaments.

The sliding-filament model of muscle contraction



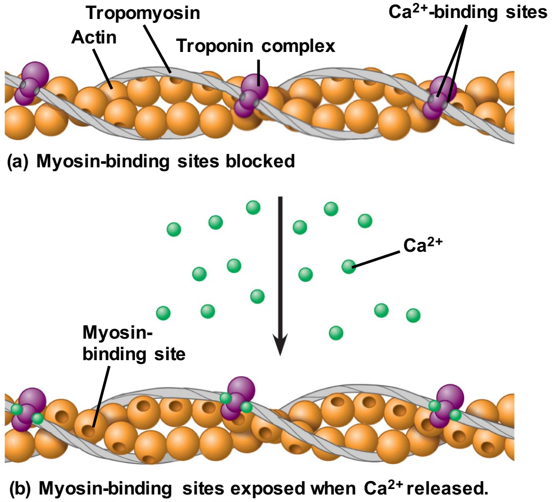
- The sliding of filaments is based on interaction between actin of the thin filaments and myosin of the thick filaments.
- The "head" of a myosin molecule binds to an actin filament, forming a cross-bridge and pulling the thin filament toward the center of the sarcomere.
- Glycolysis and aerobic respiration generate the ATP needed to sustain muscle contraction.

Myosin-actin interactions underlying muscle fiber contraction

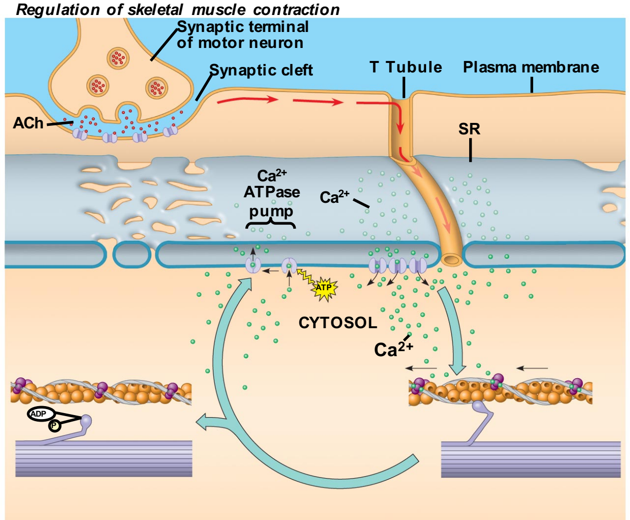


The Role of Calcium and Regulatory Proteins

- A skeletal muscle fiber contracts only when stimulated by a motor neuron.
- When a muscle is at rest, myosin-binding sites on the thin filament are blocked by the regulatory protein **tropomyosin.**
- *Myosin-binding sites exposed when Ca^{2+} released*.



- The synaptic terminal of the motor neuron releases the *neurotransmitter acetylcholine*.
- Acetylcholine *depolarizes* the *muscle*, causing it to produce an *action potential*.



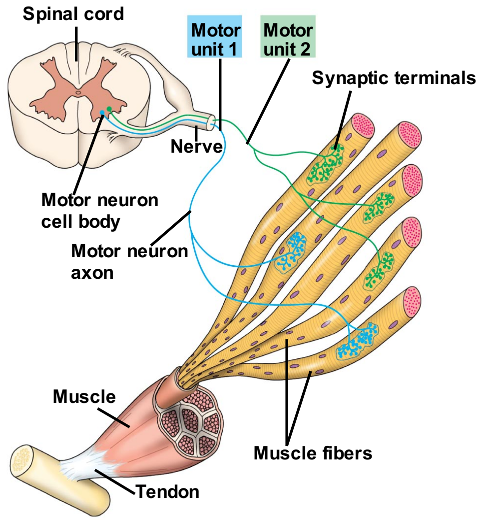
- *Action potentials* travel to the *interior* of the muscle fiber along *transverse (T) tubules*.
- The action potential along T tubules causes the *sarcoplasmic reticulum* **(SR)** to *release* Ca^{2+}
- The Ca^{2+} binds to the troponin complex on the thin filaments.
- This binding *exposes myosin-binding sites* and allows the cross-bridge cycle to proceed.

Nervous Control of Muscle Tension

- Contraction of a whole muscle is graded, which means that the extent and strength of its contraction can be voluntarily altered.
- There are two basic mechanisms by which the *nervous system produces graded contractions*:
  - Varying the number of fibers that contract
  - Varying the rate at which fibers are stimulated.

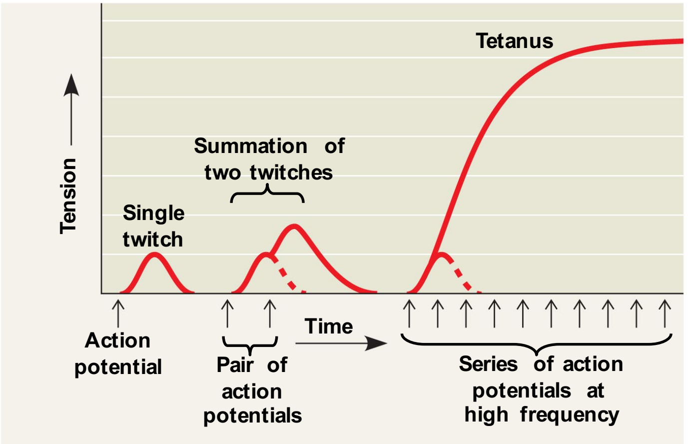
- In a vertebrate skeletal muscle, each branched muscle fiber is innervated by one motor neuron.
- Each motor neuron may synapse with multiple muscle fibers.
- A **motor unit** consists of a single motor neuron and all the muscle fibers it controls.

***Motor units** in a vertebrate skeletal muscle*



- **Recruitment** of multiple motor neurons results in stronger contractions.
- A twitch results from a single action potential in a motor neuron.
- More rapidly delivered action potentials produce a graded contraction by summation.
- **Tetanus** is a state of smooth and sustained contraction produced when motor neurons deliver a volley of action potentials.

Summation of twitches



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.
- Most skeletal muscles contain both slow-twitch and fast-twitch muscles in varying ratios.

Other Types of Muscle

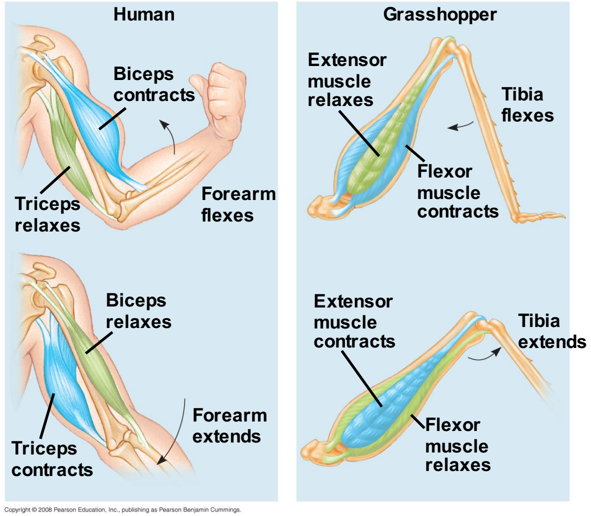
- In addition to skeletal muscle, vertebrates have cardiac muscle and smooth muscle.
- **Cardiac muscle**, found only in the heart, consists of striated cells electrically connected by **intercalated disks.**
- Cardiac muscle can generate action potentials without neural input.

- In **smooth muscle**, found mainly in walls of hollow organs, contractions are relatively slow and may be initiated by the muscles themselves.
- Contractions may also be caused by stimulation from neurons in the autonomic nervous system.

Skeletal systems transform muscle contraction into locomotion

- Skeletal muscles are attached in antagonistic pairs, with each member of the pair working against the other
- The skeleton provides a rigid structure to which muscles attach.
- Skeletons function in support, protection, and movement.

The interaction of antagonistic muscles and skeletons in movement



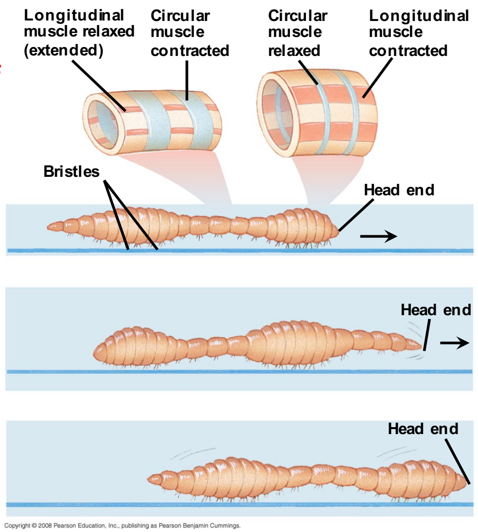
Types of Skeletal Systems

- The three main types of skeletons are:
  - Hydrostatic skeletons (lack hard parts)
  - Exoskeletons (external hard parts)
  - Endoskeletons (internal hard parts)

Hydrostatic Skeletons

- A **hydrostatic skeleton** consists of fluid held under pressure in a closed body compartment
- This is the main type of skeleton in most cnidarians, flatworms, nematodes, and annelids.
- Annelids use their hydrostatic skeleton for **peristalsis**, a type of movement on land produced by rhythmic waves of muscle contractions.

Crawling by peristalsis



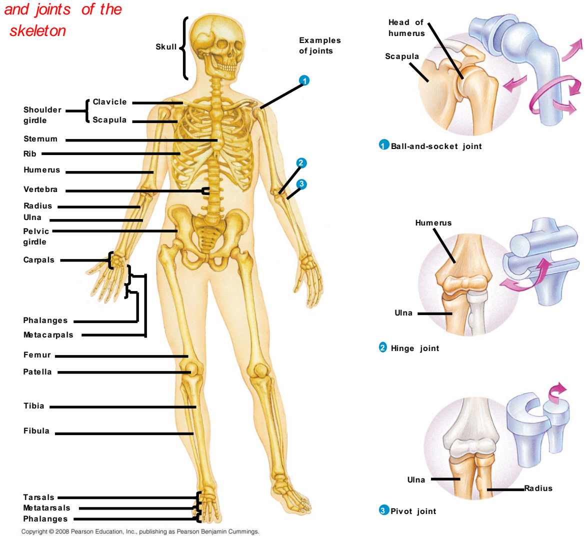
Exoskeletons

- An **exoskeleton** is a hard encasement deposited on the surface of an animal.
- Exoskeletons are found in most molluscs and arthropods.
- Arthropod exoskeletons are made of cuticle and can be both strong and flexible.
- The polysaccharide **chitin** is often found in arthropod cuticle.

Endoskeletons

- An **endoskeleton** consists of hard supporting elements, such as bones, buried in soft tissue
- Endoskeletons are found in sponges, echinoderms, and chordates.
- A mammalian skeleton has more than 200 bones.
- Some bones are fused; others are connected at joints by ligaments that allow freedom of movement.

Bones and joints of the human skeleton



Types of Locomotion

- Most animals are capable of **locomotion**, or active travel from place to place.
- In locomotion, energy is expended to overcome friction and gravity.
- In water, friction is a bigger problem than gravity. Fast swimmers usually have a streamlined shape to minimize friction.

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.

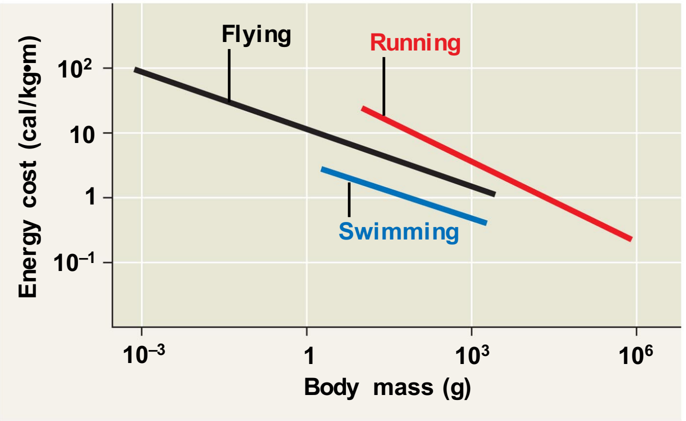
Energy-efficient locomotion on land

Flying

- 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

What are the energy costs of locomotion?

RESULTS



You should now be able to:

1. Distinguish between the following pairs of terms: sensation and perception; sensory transduction and receptor potential; tastants and odorants; rod and cone cells; oxidative and glycolytic muscle fibers; slow-twitch and fast-twitch muscle fibers; endoskeleton and exoskeleton.
2. List the five categories of sensory receptors and explain the energy transduced by each type.

3. Explain the role of mechanoreceptors in hearing and balance.
4. Give the function of each structure using a diagram of the human ear.
5. Explain the sliding-filament model of muscle contraction.
6. Explain how a skeleton combines with an antagonistic muscle arrangement to provide a mechanism for movement.