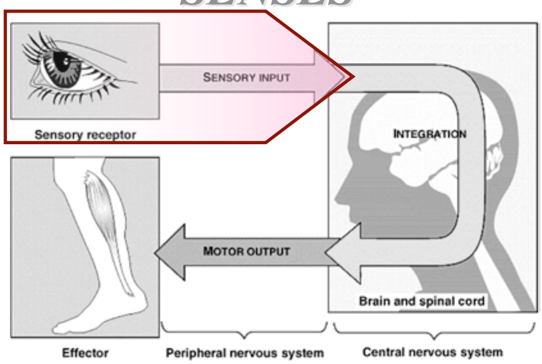
SENSES



Sensory Receptors (Sensors)

- **Transducer**: a structure that converts a stimulus into a graded depolarization.
- Physiological transducers are derived from specialized dendrites, often associated with modified epithelia.

1. **Exteroceptors**: sense external stimuli
   a) **passive** — sense environmental stimuli
   b) **active** — sense self-generated stimuli
      - bat sonar, flashlight fish, knife fish electric fields.
2. **Interoceptors**: sense internal body condition

Types of Sensory Receptors: Mechanisms of Transduction

1. **Chemoreceptors**
2. **Mechanoreceptors**
3. **Thermoreceptors**
4. **Photoreceptors**
5. **Other Electromagnetic Receptors**

Types of Sensory Receptors: Mechanisms of Transduction

1. **Chemoreceptors**: chemical stimulus binds to specific binding protein on cell surface ➠ open ion gates ➠ depolarization.

- Interoceptors
  - Blood glucose, fatty acids, pH
  - Nocioceptors — chemicals released by damaged cells (pain)
- Exteroceptors (special senses)
  - Olfaction (smell)
  - Gustation (taste)

Types of Sensory Receptors: Mechanisms of Transduction

2. **Mechanoreceptors**: physical distortion of cell membrane ➠ open ion gates ➠ depolarization.

- Interoceptors
  - Propioceptors — muscles, tendons, joints
  - Visceral stretch receptors
  - Blood pressure, osmotic pressure
- Exteroceptors (cutaneous senses)
  - Touch & pressure
- Exteroceptors (special senses)
  - Auditory “hair cells”
  - Equillibrium “hair cells”

Types of Sensory Receptors: Mechanisms of Transduction

3. **Thermoreceptors**: temperature-induced change of membrane protein ➠ open ion gates ➠ depolarization.

- Interoceptors
  - Body temperature $[B_T]$ — hypothalamus
- Exteroceptors (cutaneous senses)
  - Hot & cold sensations
    (“Cold” is a perception, not a real physical entity.)

Types of Sensory Receptors: Mechanisms of Transduction

4. **Photoreceptors**: light absorbed by pigment-protein ➠ close ion gates ➠ hyperpolarization.

- Exteroceptors (special senses)
  - Vision — retina rods & cones

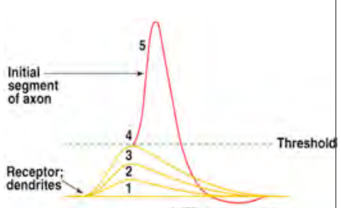
Types of Sensory Receptors: Mechanisms of Transduction

5. **Other Electromagnetic Receptors:** EM energy absorbed by special metallo-protein complexes ➠ transduction mechanism unclear

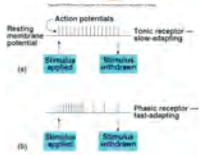
- Electromagnetic fields
- Infrared radiation

Generator Potentials

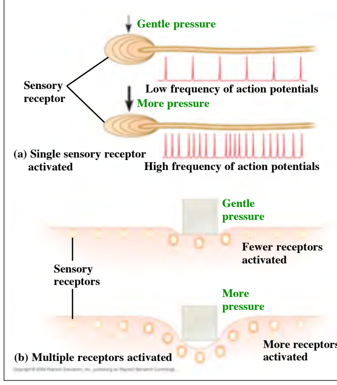
- In response to stimulus, sensory nerve endings produce a local graded change in membrane potential.
- Potential changes are called receptor or generator potential.
- Must be cummulative to threshhold before decay



- Phasic response:
  - Generator potential increases with increased stimulus, then as stimulus continues, generator potential size diminishes.
- Tonic response:
  - Generator potential proportional to intensity of stimulus.

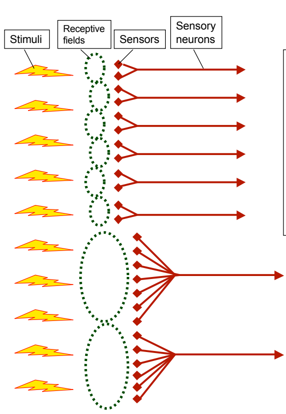


afferent transmission of stimulus **intensity**



1. **Frequency modulation**
   - Stronger stimuli result in **more frequent** action potentials
     - Amplitude not changed!
2. **Receptor recruitment**
   - Stronger stimuli may result in transduction by more sensors
     - More sensory neurons send signals

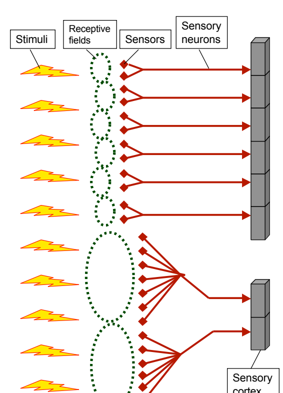
Convergence



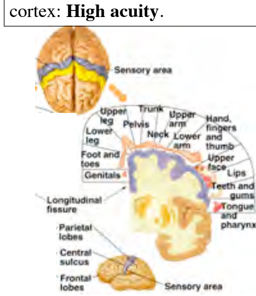
Low convergence: few receptors converge on a single sensory neuron.
High acuity: many small receptive fields per given area distinguish among individual stimuli.
But **low sensitivity**.

High convergence: many receptors converge on a single sensory neuron.
High sensitivity: many stimuli summed within a single receptive field.
But **low acuity**.

Convergence



Low convergence: more sensory neurons from a given area connect to more cells of the sensory cortex: **High acuity**.



Perception of Senses

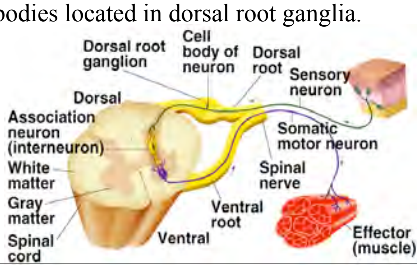
- ***Law of Specific Nerve Energies*: "Any stimulation of a sensory neuron is perceived according to that nerve's adequate stimulus."**
- **Adequate stimulus:** the normal type and intensity of stimulus that would cause stimulation of that neuron's sensory receptor.
- I.e., "it's all in your head!" Anything that stimulates the sensor, sensory neuron, or sensory cortex will be interpreted by the brain to be the sensation normally transduced or transmitted by those structures.
- Examples of misinterpretation:
  - "Seeing stars" from eye trauma
  - Tinnitus: "ringing in your ears"
  - Phantom pain in amputees
  - Referred pain from visceral trauma
  - "Hot" spices

Sensations

- Somatesthetic senses ("body feeling") — vertebrates, via spinal nerves
  - Cutaneous senses
  - Visceral senses
  - Proprioceptors
- Special senses — via cranial nerves
  - Gustatory (taste)
  - Olfactory (smell)
  - Auditory (hearing)
  - Equilibrium
  - Vision

Somatesthetic Sensory Neurons

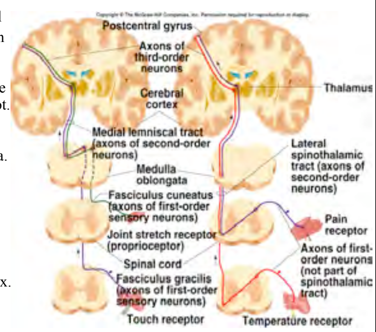
- Spinal sensory neurons: pseudounipolar neurons with cell bodies located in dorsal root ganglia.



Ascending Somatesthetic Spinal Tracts

Spinothalamic tracts: the three-sensory-neuron trail

1. First order sensory neuron travels from cutaneous receptors, proprioceptors or visceral receptors to the CNS via spinal dorsal root. Axon either terminates at spinal cord or ascends ipsilateral tract to medulla.
2. Second order sensory neuron crosses to contralateral side and ascends to thalamus.
3. Third order sensory neuron ascends from thalamus to sensory cortex. (Remaining on contralateral side.)



Cutaneous Sensations

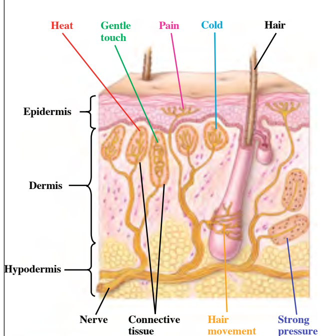


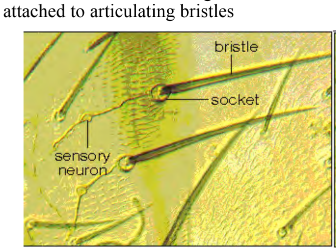
Fig. 50-3

- Mediated by dendritic nerve endings of different sensory neurons.
- Mostly in the dermis. But some in basal stratum of epidermis.
- Thermoreceptors: heat and cold
  - More receptors respond to cold than warm.
- Nociceptors (pain)
- Mechanoreceptors — free
  - Touch
  - Slow adapting (tonic)
- Mechanoreceptors — encapsulated
  - Touch & pressure
  - Rapidly adapting (phasic)

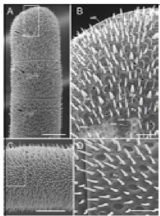
Cutaneous-like Sensations through a cuticle

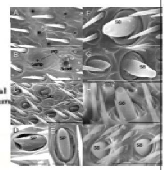
Arthropods

- Mechanoreceptors — dendritic nerve endings of sensory neurons attached to articulating bristles



Antenna **sensilla**

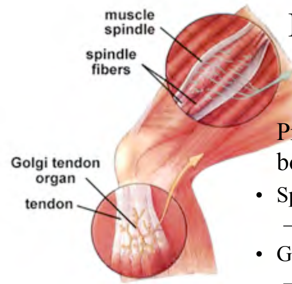




The seven types of sensory structures on the antennae:
a. Small thick-walled hair
b. Thick-walled peg
c. Slender thin-walled peg
d. Large thin-walled peg
e. Pore plate
f. Pit organ
g. Pit organ

Magnified view of one of the pore plates on the worker bee's antenna

Proprioceptors

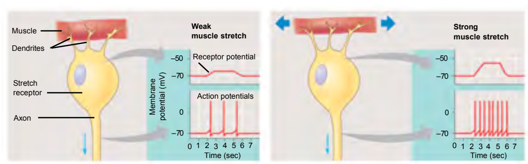


Proprioceptors:
body positioning sensors

- Spindles within muscles
  - Maintain muscle tension
- Golgi organs in tendons
  - Inhibitory reflex; prevents overexertion of muscle
- Ligament stretch receptors
  - Detect degree of joint extension/flexion

Transduction in stretch receptors

- A stretch receptor in a crayfish abdominal muscle



(a) Crayfish stretch receptors have dendrites embedded in abdominal muscles. When the abdomen bends, muscles and dendrites stretch, producing a receptor potential in the stretch receptor. The receptor potential triggers action potentials in the axon of the stretch receptor. A stronger stretch produces a larger receptor potential and higher requency of action potentials.

Figure 49.2a

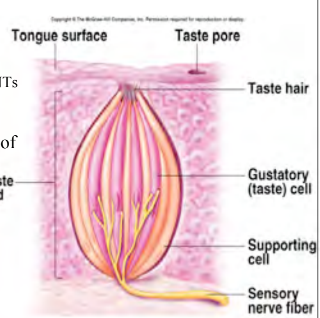
Chemoreception

- Taste & smell food — primal importance
  - palatibility
  - hunting
- Smell conspecifics
  - sexual **pheromones**
    - elephants & insects use (Z)-7-dodecen-1-yl acetate)
  - kin recognition
    - wasp nestmates
    - ant trails

Taste

Gustation: Sensation of taste.

- Epithelial cell receptors clustered in barrel-shaped taste buds.
  - Apical microvilli (taste hairs) increase surface area for chemoreception.
  - Stimulated taste cells release NTs to stimulate sensory neuron.
- Each taste bud has taste cells only responding to one class of dissolved chemical stimulus.
- 1° sensory neuron from taste bud via cranial nerves to medulla oblongata.
  2° neuron to thalamus.
  3° neuron to sensory cortex.



Taste Myth

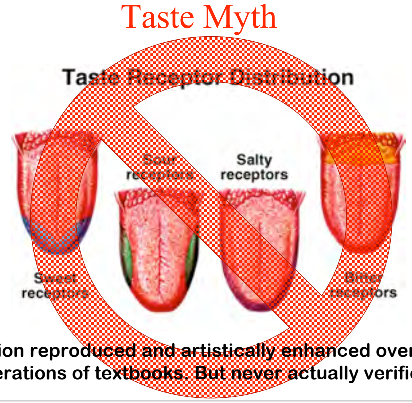


Illustration reproduced and artistically enhanced over many generations of textbooks. But never actually verified!

Gustatory Sensilla

Insect taste chemoreception via hollow sensory hairs (**sensilla**) primarily on legs and mouth-parts.

EXPERIMENT Insects taste using gustatory sensilla (hairs) on their feet and mouthparts. Each sensillum contains four chemoreceptors with dendrites that extend to a pore at the tip of the sensillum. To study the sensitivity of each chemoreceptor, researchers immobilized a blowfly (*Phormia regina*) by attaching it to a rod with wax. They then inserted the tip of a microelectrode into one sensillum to record action potentials in the chemoreceptors, while they used a pipette to touch the pore with various test substances.

RESULTS Each chemoreceptor is especially sensitive to a particular class of substance, but this specificity is relative; each cell can respond to some extent to a broad range of different chemical stimuli.

CONCLUSION Any natural food probably stimulates multiple chemoreceptors. By integrating sensations, the insect's brain can apparently distinguish a very large number of tastes.

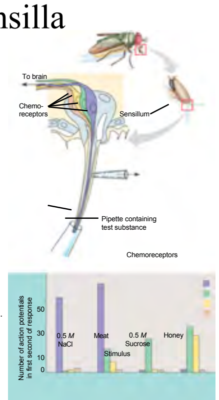
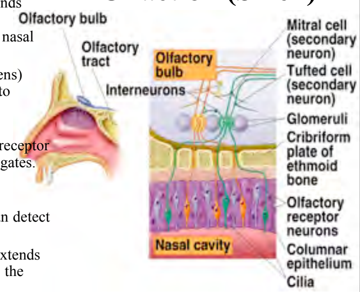


Figure 49.13

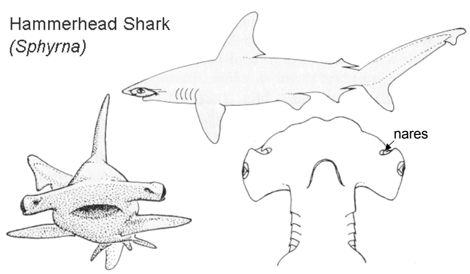
Olfaction (Smell)

- Bipolar sensory neuron extends ciliated dendrites into nasal epithelium, exposing tips to nasal mucus.
- Odorant molecules (odorogens) dissolve in mucus and bind to dendritic receptor proteins.
- Intracellular amplification: odorogen bound to a single receptor protein may open many ion gates. Very sensitive response!
- Very large variety of chemoreceptors. Humans can detect >10,000 different odors!
- First order sensory neuron extends across nasal plate of skull to the olfactory bulb.
- Second order sensory neurons travel via the olfactory tract (Cr-I) directly to the olfactory cortex in the frontal & temporal lobes.
  — Bypass thalamic filter!



- Olfactory tract branches also to limbic system — odorant arousal of memories and base emotions!

Directional olfaction in hammerhead sharks



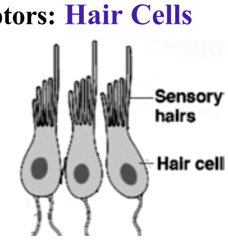
Olfactory Chemoreception in Invertebrates

- Chemoreceptor organs in antennae, tentacles, mouthparts, ovipositor, legs, everywhere!
- Two of the most sensitive and specific chemoreceptors known are present in the antennae of the male silkworm moth

Figure 49.4

Special Mechanoreceptors: Hair Cells

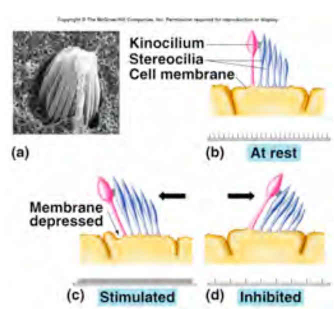
- NOT associated with hair!!!
- Special sensory epithelium
  - Rigid stereocilia look "hairy".
  - Deflection of stereocilia cause depolarization of associated sensory dendrites.
- Used as the principle components of a variety of sensory structures.



Hair cell from a vertebrate vestibular apparatus

Special Mechanoreceptors: Hair Cells

- Hair cell receptors:
  - **Stereocilia** and **kinocilium**:
    - When stereocilia bend toward kinocilium; membrane depolarizes and stimulates dendrites.
    - When bend away from kinocilium; hyperpolarization occurs and inhibits dendrites.
  - Frequency of APs carries information about movement.



Pressure & Sound Waves

- Pressure waves move through water & air.
- Reveal location of food or other individuals.
- May be used to communicate.

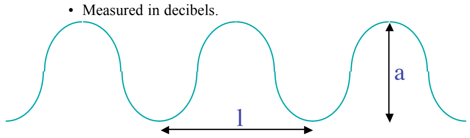
Communication Sound Sources

- Mammal w/ **vocal chords** in **larynx**
- Song bird w/ muscular **syrinx**
- Arthropod **stridulation** w/ legs or wings

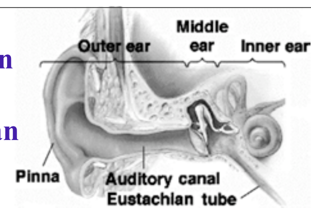
Ears and Hearing

- Sound waves travel in all directions from their source.
- Waves are characterized by frequency and intensity.
  - Frequency:

    - Measured in hertz (cycles per second).
    - Pitch is directly related to frequency.
      - Greater the frequency the higher the pitch.
  - Intensity (loudness):
    - Directly related to amplitude of sound waves.
    - Measured in decibels.



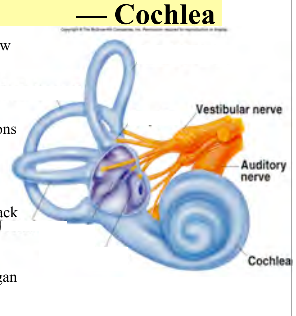
Sound conduction in the mammalian ear



Outer Ear	Middle Ear
• Sound waves are funneled by the pinna (auricle) into the external auditory meatus. • External auditory meatus channels sound waves to the tympanic membrane. – Increases sound wave intensity.	• Cavity between tympanic membrane and oval window of the cochlea. • Vibrations transferred through 3 bones: malleus to incus to stapes – Provides protection and prevents nerve damage. Muscle can pull stapes from oval window to dampen vibrations.

Sound Transduction in the Inner Ear — Cochlea

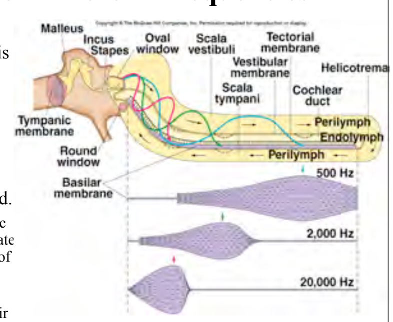
- Vibrations by stapes on the oval window produces pressure waves that displace perilymph fluid within the cochlea.
- Pressure wave corresponding in frequency and amplitude to the vibrations travel through the perilymph, down the scala vestibuli on one side and back up the scala tympani on the other side.
- The pressure waves traveling up and back squeeze the cochlear duct between the scalae.
- "Hair cell" mechnoreceptors of the Organ of Corti in the cochlear duct are stimulated by the compression.



The cochlea "unwound" for clarity of illustration

Effects of Different Frequencies

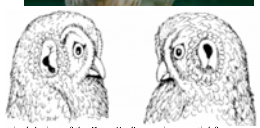
- Displacement of basilar membrane is central to pitch discrimination.
- Waves in basilar membrane reach a peak at different regions depending upon pitch of sound.
- The location of specific sets of hair cell stimulate correlates to the pitch of the vibration.
- The degree of compression on the hair cells correlates with the amplitude of the vibration.



The cochlea "unwound" for clarity of illustration

Binaural Localization

- Azimuth (right/left):
  - Interaural time difference (ITD)
  - Big head —"head shadowing"
- Front/back:
  - Asymmetrical pinnae
- Elevation (up/down):
  - Cock head
  - Asymmetrical ears
  - Uneven ear height



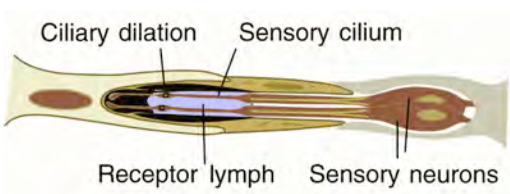
- The asymmetrical design of the Barn Owl's ears is essential for pinpointing its prey in the dark. (From: *Biological Anomalies: Birds*)

Snake hearing

- **Snakes lack external ears & middle ear bones.**
- **They do have a cochlea & hair cells.**
- **They hear airborne sounds through skin; Substrate-borne vibrations through jaw.**

Vibration sensors in Arthropods

- **chordotonal organs** — analogous to hair cells
- Esp. in legs and antennae. But may be anywhere.
- Sensory cilia vibrate like strings of piano.
  - Chitin granule in dilation increases momentum.



Insects Ears

- Sounds vibrate body hairs or **tympanum** (membrane) on front or rear legs, or on abdomen.
  - Abdominal tympani pressed against tracheal air sacs
- Sensed by **chordotonal organs** .

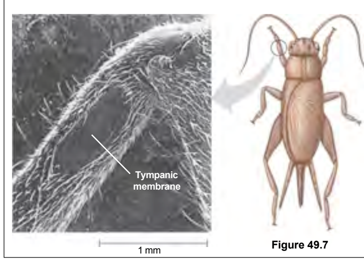
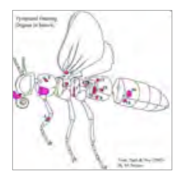


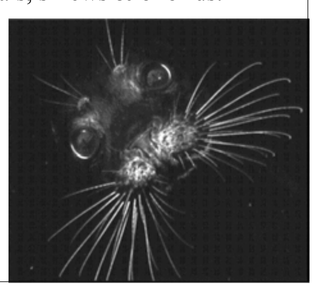
Figure 49.7



ECHOLOCATION — Active hearing

- Rudimentary in seals, shrews & oilbirds.

Infrared film shows muzzle is warm, keeping nerves sensitive and skin supple for vibrissae movement.



ECHOLOCATION — Active hearing

- Sophisticated in bats & whales

- for prey location, navigation, communication.
- *low pulse rate* for navigation.))))))
- *high pulse rate* for detail of objects.))))))))))))

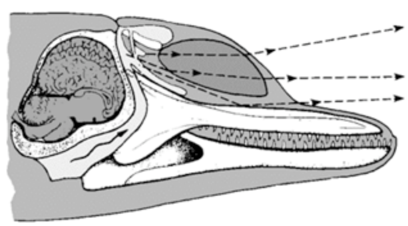
Active vs. Passive Hearing

Bats & Moths

- Active hearing — bats echolocate flying moths.
  - Detect moth-size prey w/in ~3m
- Passive hearing — moths listen for bat clicks.
  - flee if low pulse rate
  - drop when high pulse rate

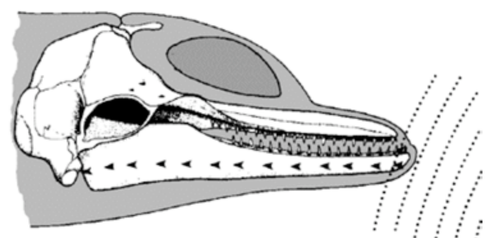
Odontocetes

- clicks & whistles are focused by melon



Odontocetes

- Returning echo is transmitted through jaw



Odontocetes & Fish

- Echo reflects off prey's swim bladder.
- Herring & shad detect ultrasound:
  - with their swim bladder
  - take evasive action

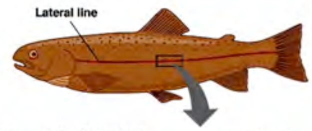
Pressure & Baroreception

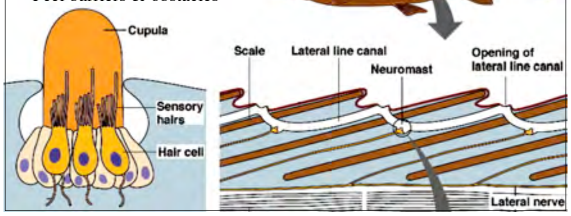
- Not well understood
- Aquatic
  - Plankton & fish sense and adjust for depth.
  - Distension of swim bladder or pneumocyst?
- Land
  - Bats sense air pressure & emerge from caves only when conditions good for insect prey.

Neuromasts & the Lateral Line System

Sense vibrations and pressure waves through dense aquatic medium.

- Locate prey
- Avoid predators
- Coordinate schooling
- Navigate currents
- Feel barriers & obstacles





Facial extensions of the lateral line system in sharks

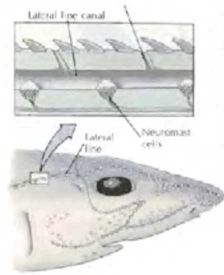
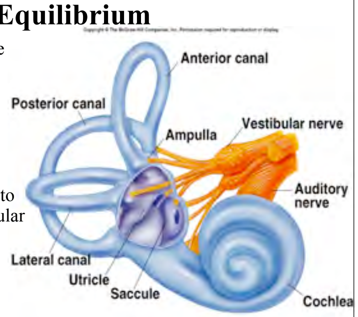


FIGURE 25-10 Sensory canals and receptors in a shark. The lateral line sensors, called neuromasts, are sensitive to disturbances in the water, enabling the shark to detect nearby objects by reflected waves in the water.

Hickman et al. 1994

Vestibular Apparatus and Equilibrium

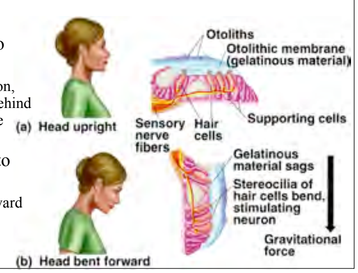
- Sensory structures of the vestibular apparatus is located within the membranous labyrinth.
  - Filled with endolymph.
- Equilibrium and acceleration (including orientation with respect to gravity) is due to vestibular apparatus.
- Vestibular apparatus consists of 2 parts:
  - Otolith organs:
    - Utricle and saccule.
  - Semicircular canals.



Utricle and Saccule

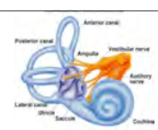
- Utricle and saccule provide information about linear acceleration.
- Chambers lined with hair cells covered in a gelatinous membrane.
- This otolithic ("ear rocks") membrane is impregnated with calcium carbonate crystals to increase its mass and therefore its inertia and gravitational drag.

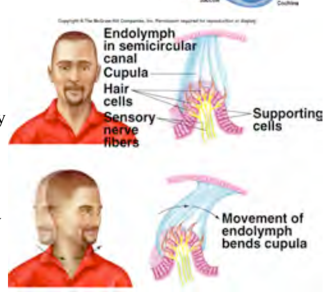
- Utricle: More sensitive to horizontal acceleration.
  - During forward acceleration, otolithic membrane lags behind hair cells, so stereocilia are pushed backward.
- Saccule: More sensitive to vertical acceleration.
  - Stereocilia are pushed upward when person descends.



Semicircular Canals

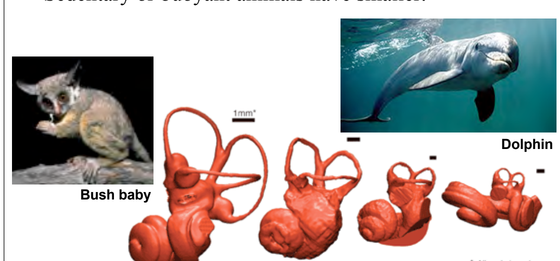
- Provide information about rotational acceleration.
  - Project in 3 different planes.
- Each canal contains a semicircular duct.
- At the base is the crista ampullaris, where sensory hair cells are located.
  - Hair cell processes are embedded in the cupula.
- Endolymph provides inertia so that the sensory processes will bend in direction opposite to the angular acceleration.





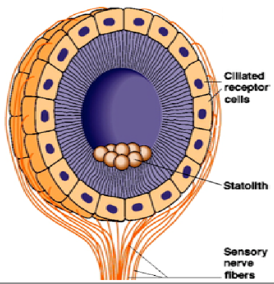
Semicircular Canal Variations

- More agile animals (arboreal or aerial) have bigger semicircular canals.
- Sedentary or buoyant animals have smaller.



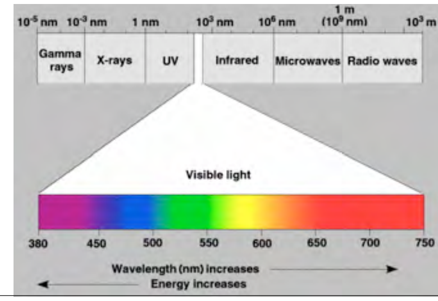
Invertebrate Statocysts

- **Statocysts** have hair cells depressed by **statoliths**.
- work the same way as vertebrate saccule & utricle



Vision

- Rods & cones in the **retina** transduce energy in the electromagnetic spectrum.
  - Only wavelengths of 400–700 nm constitute visible light to humans.



Vision

Functions:

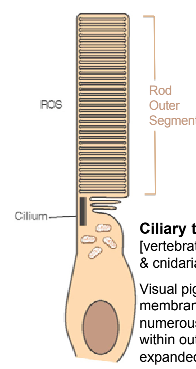
» Prey detection.
  Predator detection.
  Mate detection.

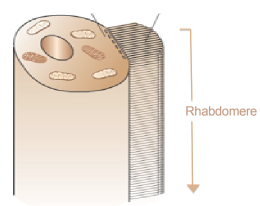
» Location positioning & navigation.
  Orientation & maneuvering.

» Photokinesis — increased activity in the presence of light.
  Phototaxis — movement toward or away from light source.

» Photoperiod & biological rhythms.
  – Diurnal
  – Seasonal

Photoreceptor Cell Types





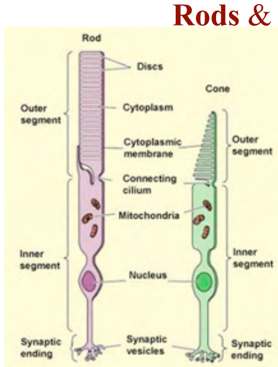
Ciliary type:
[vertebrates & cnidarians]

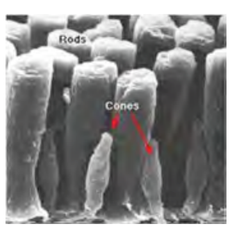
Visual pigment in membrane of numerous parallel discs within outer segment of expanded cilium

Microvillar type:
[most invertebrates]

Visual pigment in membrane of numerous parallel microvilli (**rhabdomere**)

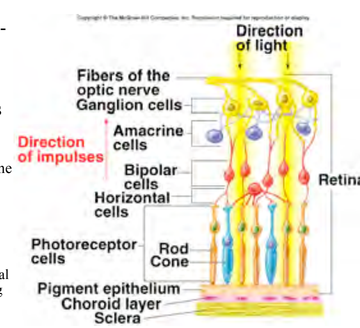
Vertebrate Ciliary Photoreceptors
Rods & Cones

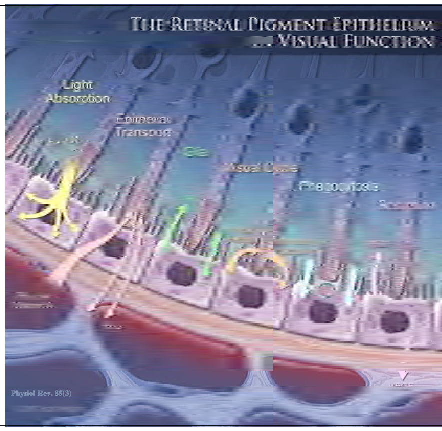




Vertebrate Retina

- Consists of single-cell-thick pigmented epithelium, layers of other neurons, and photoreceptor neurons (rods and cones).
  - Neural layers are forward extension of the brain.
  - Neural layers face outward, toward the incoming light.
    - Light must pass through several neural layers before striking the rods and cones.





Effect of Light on Visual Pigment

- Rods and cones are activated when light produces chemical change in visual pigment. Visual pigment in rods is **rhodopsin**.
  - Bleaching reaction:
    - Changes shape when it absorbs light.
    - Initiates changes in ionic permeability to produce APs in ganglionic cells.

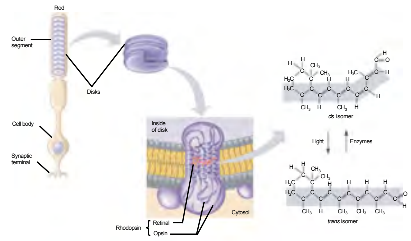


Figure 49.20a, b

Electrical Activity of Retinal Cells

- Ganglion cells and amacrine cells are only neurons that produce action potentials (neural impulses).
  - Rods and cones; bipolar cells, horizontal cells secrete excitatory or inhibitory neurotransmitters
- In dark, photoreceptors release inhibitory NT that hyperpolarizes bipolar neurons.
- Light inhibits photoreceptors from releasing inhibitory NT.
- Releases bipolar cells to produce EPSPs in ganglion cells to transmit APs.
- **Dark current**:
  - Rods and cones contain many Na^+ channels that are open in the dark.
    - Causes slight membrane depolarization in dark, causing release of inhibitory NT .

Electrical Activity of Retinal Cells

(continued)

- Na^+ channels rapidly close in response to light.
  - Absorption of single photon of light can block Na^+ entry:
    - Hyperpolarizes and release less inhibiting NT.
      - Light can be transduced & perceived.

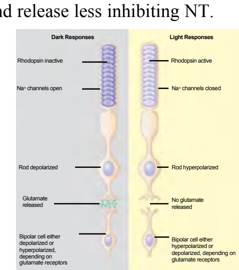
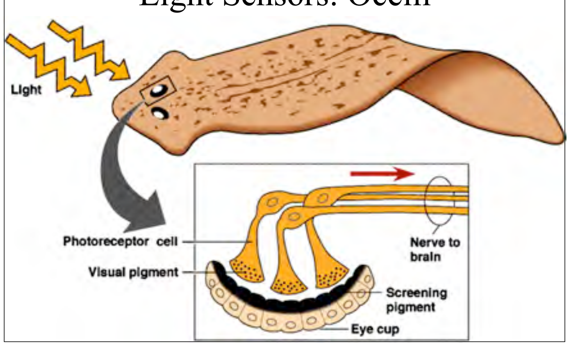


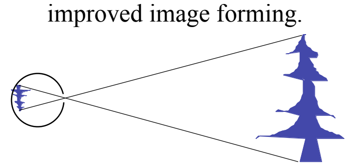
Figure 49.22

Light Sensors: Ocelli



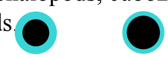
Light Sensors: Cup-shaped Eyes

- The deeper the cup, the more directional the vision.
- Pinhole eyes, lenses, and lens focusing allow for improved image forming.

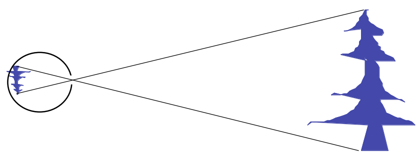


Light Sensors: Camera Eye

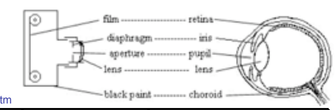
- Vertebrates, cephalopods, cubozoan cnidarians, & some annelids



- **Pupil** surrounded by light-regulating **iris**

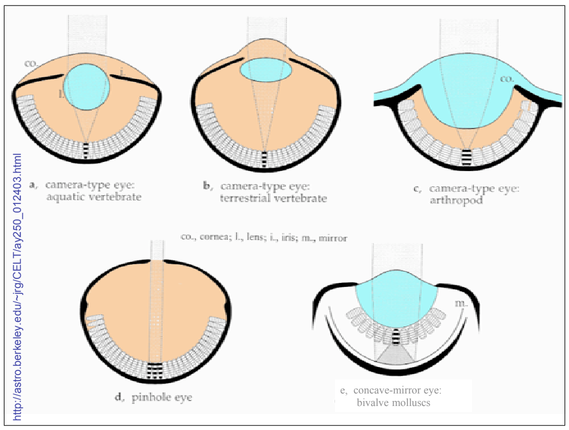


Light Sensors: Camera Eye



http://library.thinkquest.org/28030/eyeevo.htm

	Function	Camera	Eye
Similarities			
1.	opening for light to enter	aperture	pupil
2.	control the amount of light entering camera/eye	diaphragm control size of aperture	iris muscles control size of pupil
3.	refract light	glass biconvex lens	mainly cornea; lens, aqueous & vitreous humor
4.	object of light action to form image	photosensitive chemicals on film	Photoreceptors (rods & cones) in retina
5.	absorb excessive light to prevent multiple images formation	dark internal surface	pigmented, dark choroid
Difference			
1.	focusing mechanism	change distance between lens & film	change shape/focal length of lens



Compound Eyes

- Major eye type in arthropods
- Also in some annelids & bivalve molluscs (convergence?)

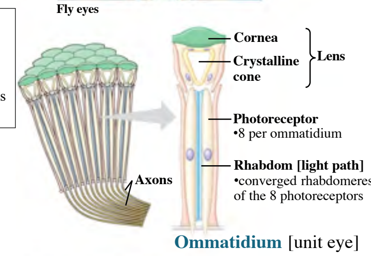
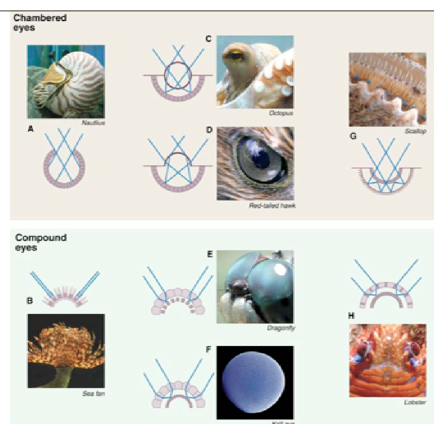
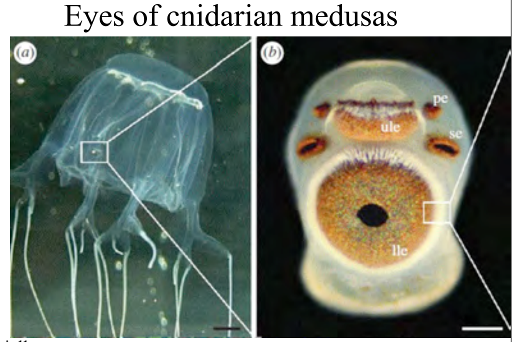


Fig. 50-17



Eyes of cnidarian medusas

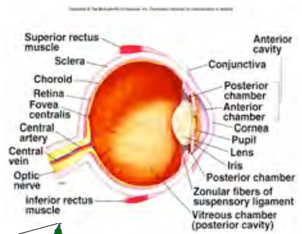


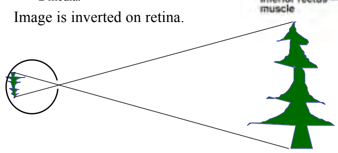
Box jelly

- Four rhopalia — each with six eyes
  - Pair of pit eyes; pair of slit eyes, pair of camera eyes

Refraction

- Light that passes from a medium of one density into a medium of another density (bends).
- Refractive index (degree of refraction) depends upon:
  - Comparative density of the 2 media.
    - Refractive index of air = 1.00.
    - Refractive index of cornea = 1.38.
  - Curvature of interface between the 2 media.
- Image is inverted on retina.

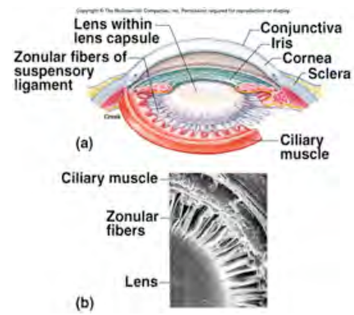




"Camera eye" – pupil surrounded by light-regulating iris

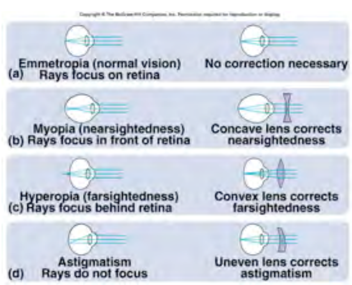
Accommodation

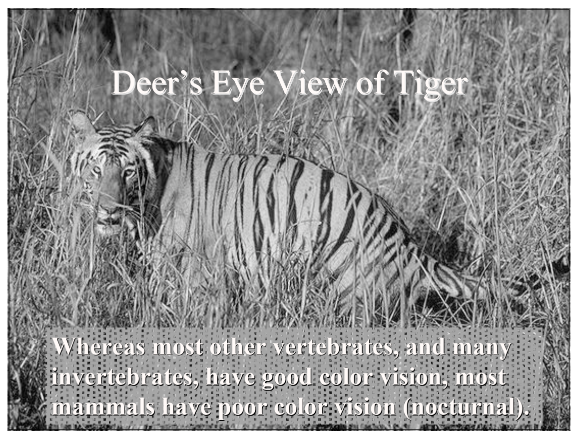
- Ability of the eyes to keep the image focused on the retina as the distance between the eyes and object varies.



Visual Acuity

- Sharpness of vision.
- Depends upon resolving power:
  - Ability of the visual system to resolve 2 closely spaced dots.
  - Myopia (nearsightedness):
    - Image brought to focus in front of retina.
  - Hyperopia (farsightedness):
    - Image brought to focus behind the retina.
  - Astigmatism:
    - Asymmetry of the cornea and/or lens.
    - Images of lines of circle appear blurred.





Exceptional Mammals: "Old World" Primates High-precision Color vision

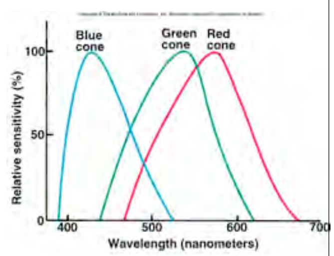
blue scrotum changes w/ breeding state

Cones and Color Vision

- Cones have much less convergence than do rods.
- Therefore, cones are less sensitive than rods to light.
- And thus cones provide greater visual acuity.
- Cones also provide color vision.
- High light intensity bleaches out the rods, and color vision with high acuity is provided by cones.
- Trichromatic theory of color vision:
  - 3 types of cones: red, green, and blue [RGB].
    - According to the region of visual spectrum absorbed.
    - All other colors detected as a blend of these three.

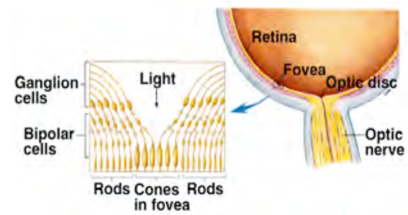
Cones and Color Vision (continued)

- Each type of cone contains retinene associated with photopsins.
  - Photopsin protein is unique for each of the 3 cone pigment.
- Each cone absorbs different wavelengths of light.

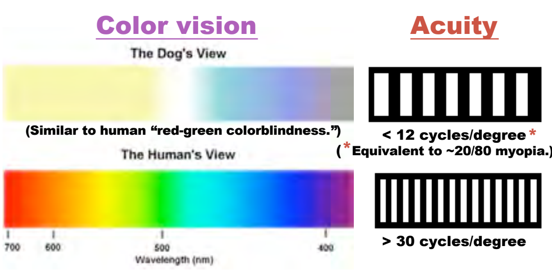


Visual Acuity and Sensitivity

- Each eye oriented so that image falls within fovea centralis.
  - Fovea only contain cones.
    - Degree of convergence of cones in fovea is 1:1 (no convergence highest acuity).
  - Peripheral regions contain both rods and cones.
    - Degree of convergence of rods is much higher (high convergence higher sensitivity).
  - Visual acuity greatest and sensitivity lowest when light falls on fovea.



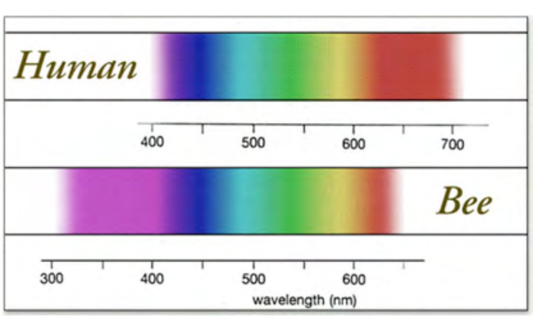
Dichromatic vs. Trichromatic Cones



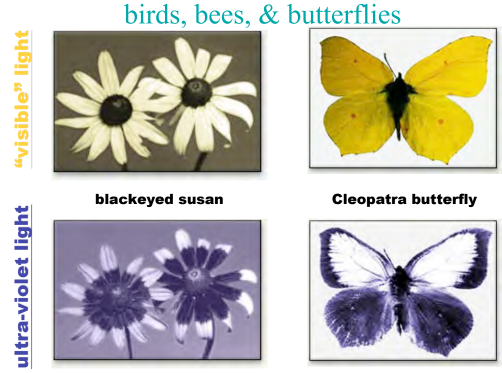
Dichromatic vs. Trichromatic Cones

- Cats respond to the colors purple, blue, green and (weakly) to yellow.
  - Red, orange and brown colors appear to fall outside cats color range, and are most likely seen as dark to mid shades of gray.
- Humans also see more color saturation, meaning we not only see more colors, but we see colors more intensely or vibrantly than do most mammals.

Color Vision – Extended Spectrum



Color Vision – Extended Spectrum
birds, bees, & butterflies



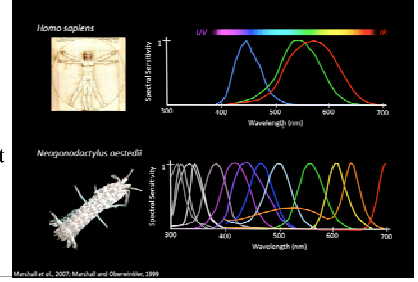
Color Vision

inferred from cone types in retina

ANIMAL	THE COLORS THEY SEE
SPIDERS (jumping spiders)	ULTRAVIOLET AND GREEN
INSECTS (bees)	ULTRAVIOLET, BLUE, YELLOW
CRUSTACEANS (crayfish)	BLUE AND RED
CEPHALOPODS (octopi and squids)	BLUE ONLY
FISH	MOST SEE JUST TWO COLORS
AMPHIBIANS (frogs)	MOST SEE SOME COLOR
REPTILES (snakes)	SOME COLOR AND INFRARED
BIRDS	FIVE TO SEVEN COLORS
MAMMALS (cats)	TWO COLORS BUT WEAKLY
MAMMALS (dogs)	TWO COLORS BUT WEAKLY
MAMMALS (squirrel)	BLUES AND YELLOWS
MAMMALS (primates-apes and chimps)	SAME AS HUMANS
MAMMALS (African monkeys)	SAME AS HUMANS
MAMMALS (South American monkeys)	CAN'T SEE RED WELL

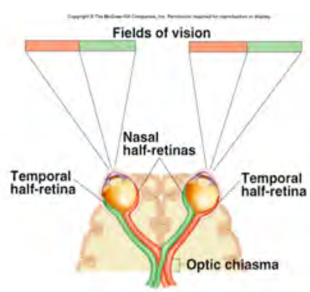
Mantis Shrimp: Extraordinary Eyes

- Up to 16 different receptor types!
- Can sense polarized light
- Stereo vision in each eye!

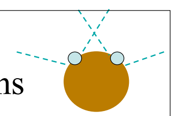


Visual Field

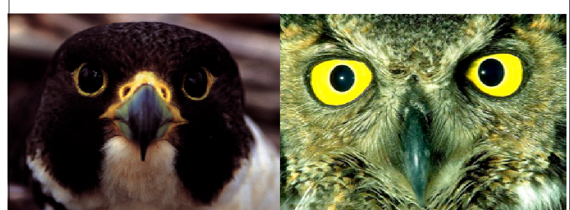
- Image projected onto retina is reversed in each eye.
- Cornea and lens focus the right part of the visual field on left half of retina.
- Left half of visual field focus on right half of each retina.

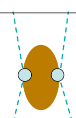


Eye Specializations



- Predators have forward eyes for stereovision

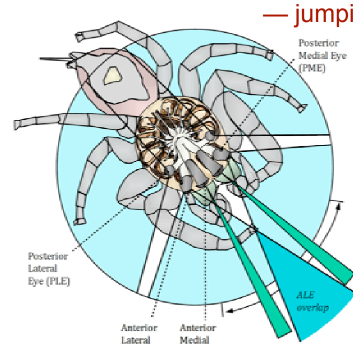




Eye Specializations

- Prey have eyes on side of head for wide field.

Extreme stereovision & peripheral vision — jumping spiders



- 4 pairs of eyes
  - AME: high resolution
  - ALE: stereovision
  - PME & PLE: peripheral vision
- tetrachromatic color (including UV)

Eye Specializations

- **Raptors** have two fovea
  - one at top of 8X eye for good downward vision

Tapetum lucidum

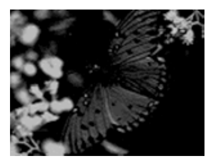
- Reflective layer behind retina
- Present in most vertebrate eyes except in primates and diurnal squirrels & birds.
- Provides “second chance” for photoreceptors to encounter light signal
- Increases sensitivity >6x
- Sacrifices acuity

In a pig’s eye!

The combination of the tapetum lucidum and elliptical pupils permit cats to see extremely well in near darkness

Night vision (identical illumination)

- In human:



- In cat:

Reflections of an odd-eyed cat

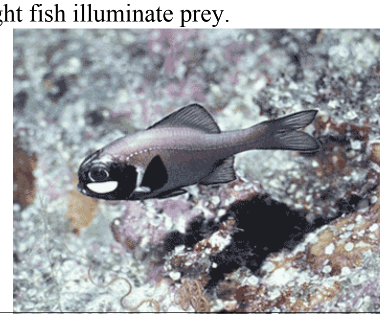
- Different amounts of melanin in the iris absorb/scatter different wavelengths of light on the way in, and the way out.

ambient light

flash light

Active Sensing w/ Light

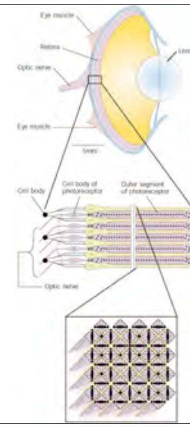
- Flashlight fish illuminate prey.



Bioluminescent Bacteria & Light

- Insects, dinoflagellates, & deep sea fish/squid lure prey & signal mates.

lanternfish



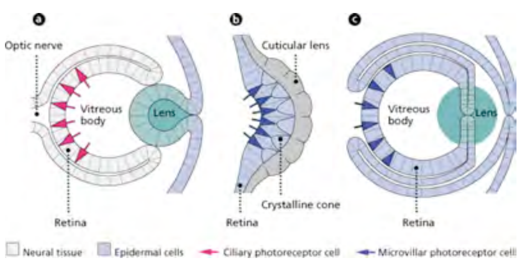
Photoreception Weirdos

- Cephalopod retina is inverted
  - rods & cones face light.

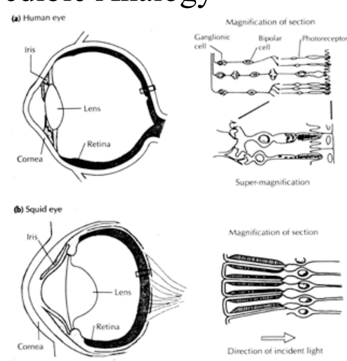
http://astro.berkeley.edu/~jrg/CELT/ay250_012403.html

Different eyes / Different tissues

vertebrate | arthropod | cephalopod

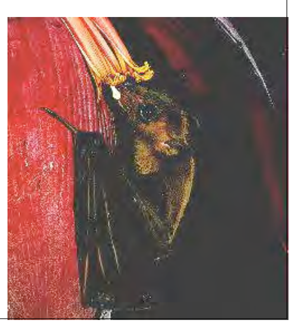


Incredible Analogy



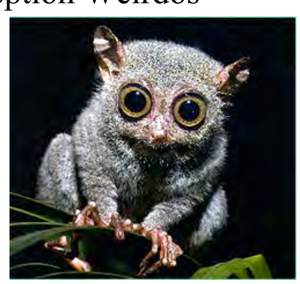
Photoreception Weirdos

- Wrinkled retinas
  - Fruit bats have small folds in their retinas
  - Increases surface area for photoreceptors



Photoreception Weirdos

- The tarsier of Southeast Asia has the largest eyes relative to body size of any living creature.
  - The eyes are so enormous that they cannot be moved in their sockets.
  - To compensate, tarsiers can swivel their necks 180 degrees in either direction.
  - has the vision, speed and reflexes to catch small prey in pitch darkness.



Spookfish — primary & secondary eyes

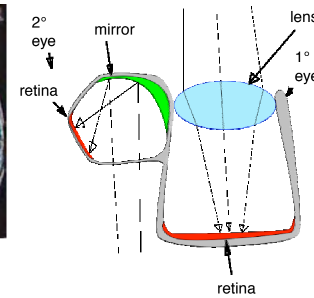
Light reflecting from the 1° dorsal-oriented retinas

Light reflecting from the 2° ventral-oriented retinas

http://www.wired.com/wiredscience/2009/01/mirroreyes/

Spookfish — primary & secondary eyes

Focusing mirror in the 2° eye

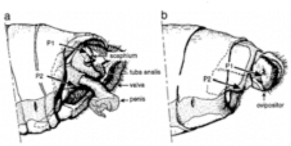


http://www.wired.com/wiredscience/2009/01/mirroreyes/

Photoreception Weirdos

Extraocular Photoreceptors

- Butterfly genitals
  - Japanese *Papilio* swallowtails
  - get parts aligned

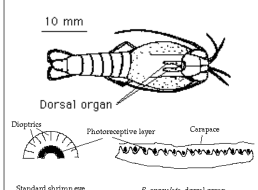


- Left side view of the abdominal tip of both sexes. Location of two pairs of **genital photoreceptors**, **P1** and **P2**, is indicated by arrows; (a) male and (b) female
- *BioScience* 51(3):219-225. 2001

Photoreception Weirdos

Extraocular Photoreceptors

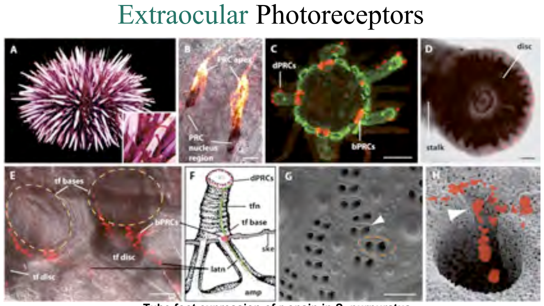
- Backs of eyeless deep-sea vent shrimp
  - Originally thought to sense IR from vents
  - But sensitive to green/blue light



"Naked retina" of dorsal organ contains 2-8x more visual pigment than a normal shrimp eye.

Photoreception Weirdos

Extraocular Photoreceptors



Tube foot expression of r-opsin in S. purpuratus.

Ullrich-Lüter E M et al. PNAS 2011;108:8367-8372

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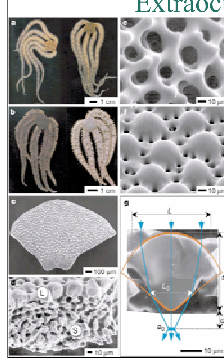
PNAS

Photoreception Weirdos

Extraocular Photoreceptors

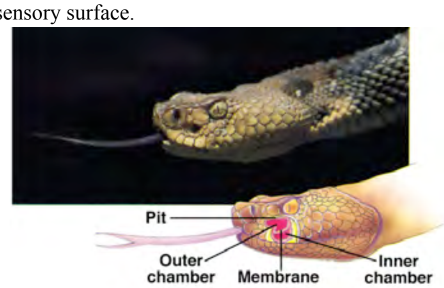


the "black brittlestar" *Ophiocoma wendtii*

- Calcite plates form precise micro-lenses
- Focus light onto photoreceptors
- **Much of aboral surface a giant compound eye!**
- Photoreceptors shielded by iris-like chromatophores in daylight

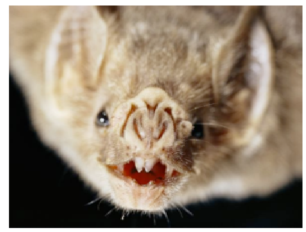
Pit Organs Sense ***Infrared*** (Heat)

- "pit vipers" (rattlesnakes), boas & pythons.
- Like a pinhole camera: infrared image focused on sensory surface.



Pit Organs of Vampire Bats

- **Only known mammal w/ IR sensors**
- **3 leaf-pits surrounding nares**
- **Detect cutaneous vessels by "hot-spots" on warm-blooded prey.**



Electrical Sensing

- Electroreceptor cells response to fluctuations in environmental electric fields.
- Used in:
  - Prey Detection
    - Sense electric fields created by muscle activity of hidden prey.
  - Navigation
    - Sense distortions in a self-generated field.
    - Map patterns of saltwater currents.
  - Communication
    - Signaling mates, territoriality, identity.

Electrical Prey Detection

- Monotremes (egg-laying mammals):
  - platypus bill
  - echidna snout

  - Detect crustacean prey during nocturnal aquatic foraging.
  - Eyes, nostrils and ears are all closed when underwater!
  - May consume half its weight in prey!

Ampullae of Lorenzini

Sharks & rays.

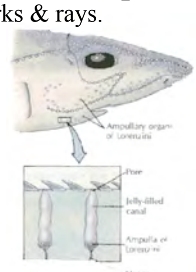
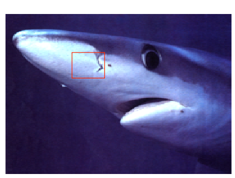


FIGURE 18-8 Sensory canals and receptors in a shark. The ampullae of Lorenzini respond to weak electric fields, and possibly to temperature, water pressure, and salinity.



Relative importance of electroception & olfaction in lungfish

Lungfish use bioelectric cues

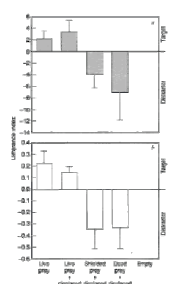
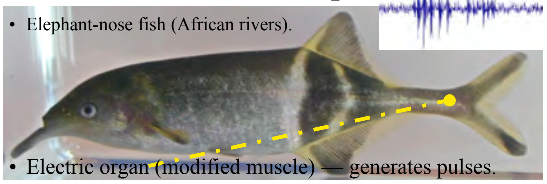


FIGURE 12.8 The results of experiments demonstrating that Australian lungfish can locate their prey by using the electrical field generated by any living organism in seawater. The results are shown as a difference index, which is the amount of foraging activity above the target, the hidden chamber where the prey was located, and the distractor, the region of the aquarium to which the prey's odor was displaced. A positive score indicates that the fish were foraging above the target; a negative score indicates that the fish were foraging over the distractor. The distractor indexes are shown for (a) the foraging intensity and (b) the foraging accuracy of each treatment. Although the lungfish can and do use chemical cues to locate prey, bioelectric cues are more important. (From Watt, Evans, and Joss 1999.)

Active Electro-reception

- Elephant-nose fish (African rivers).

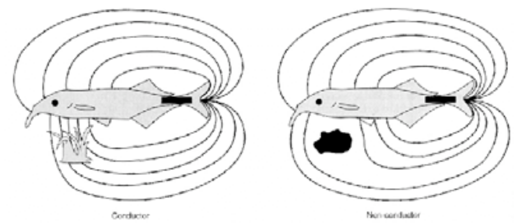


- Electric organ (modified muscle) — generates pulses.
- Electroreceptors — three types
  1. mormyromasts — detect the electric organ discharge.
     - navigate and detect movement in murky water.
  2. knollen organs — detect the electric organ discharge of other elephant nose fish.
     - communication and finding mates.
  3. ampullary receptors — detect the low frequency electric fields emitted by other aquatic animal to probe for prey.

Active Electro-reception

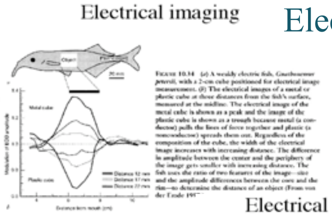
The field generated by the fish is distorted by nearby objects.

- Objects less conductive than water (e.g., rocks) spread the lines of force out.
  - Electrical "bright spot"
- Objects more conductive (other animals) draw the lines together.
  - Electrical "dark spot"



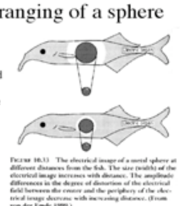
Electroreception Imaging

Electrical imaging



Electrical ranging of a sphere

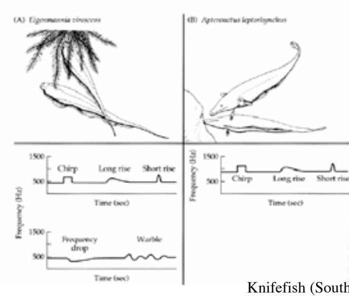
Distance can be determined from the magnitude of the field distortion, and the size of the distortion.



Electrocommunication

EOD courtship

(* EOD: electric organ discharge)



Knifefish (South American rivers)

Electrogeneration & Predation

- Better known electric eels and electric rays create more powerful (10–1000V) electric organ discharges to stun prey. — Not sensory.

Electric eel
Electrophorus electricus

Electric organ has up to 6000 electrocytes and produces 720 volts

Magnetic Fields & Migration

- Magnetite (iron oxide) for navigation in:
  - bacteria
  - bees
  - migratory birds
  - sea turtles
  - cetaceans