Ch 10: Sensory Physiology, Part 1

Key Points

Receptor transduction

Receptive fields and perception

Phasic and tonic receptors

Different somatosensory modalities

Five special senses

Classification of Sensory System by Structural Complexity

Somatic (= general) senses

1. **Touch**
2. **Temperature**
3. **Nociception**
4. **Itch**
5. **Proprioception**

Special senses

1. **Vision**
2. **Hearing**
3. **Taste**
4. **Smell**
5. **Equilibrium**

Conscious vs. Unconscious

Sensory Receptors - Overview

- are transducers → convert stimuli into graded potential (receptor potential)
- are of various complexity *Fig 10-1*
- react to particular forms of stimuli
  - Chemoreceptors
  - _____
  - _____
  - _____

Sensory Transduction

- **Converts Stimulus into graded potential = receptor potential.**
  - **Threshold**
- **If receptor potential above threshold ⇒ AP**
  - **"Adequate Stimulus"**
- **Receptor potential in non-neural receptors ⇒ change in membrane potential influences NT release**

Complexity Range of Receptors

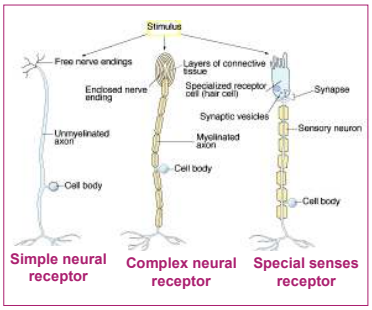


Fig 10-1

Receptor is part of neuron:

↓

AP triggered if receptor potential above threshold

Specialized receptor cell:

↓

Amount of NT released ∝ stimulus strength

4 Types of Sensory Receptors

1. **Chemo-** (specific ligands) **and Osmo-** (conc. of solutes)
2. **Mechano-** (touch, pressure, vibration, stretch)
3. **Thermo-** (temp. change)
   - **Cold receptors lower than body temp.**
   - **Warm receptors (37 - 45ºC) > 45ºC ?**
4. **Photo-** (light)

How could you create an excitatory signal in a neuron?

. . . an inhibitory signal?

Receptive Fields

- **Each 1° sensory neuron picks up information from a receptive field**
- **Often convergence onto 2° sensory neuron ⇒ summation of multiple stimuli**
- **Size of receptive field determines sensitivity to stimulus → Two point discrimination test (see lab)**

Fig 10-2

Fig 10-3

Sensory Pathway

Stimulus
⇩
Sensory receptor (= transducer)
⇩
Afferent sensory neurons
⇩
CNS
⇩
Integration, perception

CNS Distinguishes 4 Stimulus Properties

- Modality (nature) of stimulus
  - Type of receptor
- Location
  - lateral inhibition (fig 10-6)
  - population coding)
- Intensity
- Duration

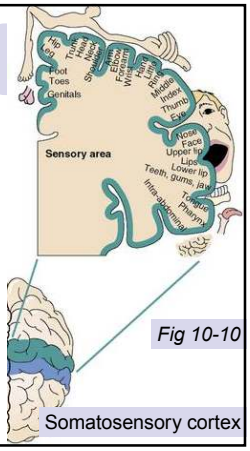


Fig 10-10

Intensity & Duration of Stimulus

- **Intensity** is coded by # of receptors activated and frequency of AP coming from receptor
- **Duration** is coded by duration of APs in sensory neurons
- Sustained stimulation leads to adaptation
  - **Tonic receptors**
  - **Phasic receptors**

(p 334)

Tonic Receptors

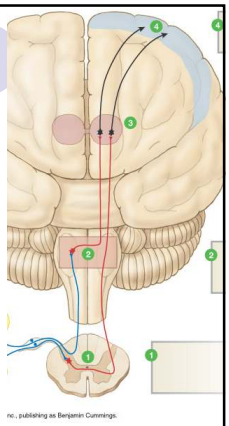
- Slow or no adaptation
- Continuous signal transmission for duration of stimulus
- Monitoring of parameters that must be continually evaluated, e.g.:
  baroreceptors

Phasic Receptors

- Rapid adaptation
- Cease firing if strength of a continuous stimulus remains constant
- Allow body to ignore constant unimportant information, e.g.:
  - Smell

Somatic Senses

- **Primary sensory neurons** from receptor to spinal cord or medulla
- **Secondary sensory neurons** always cross over (in spinal cord or medulla) → thalamus
- **Tertiary sensory neurons** → somatosensory cortex (post central gyrus)

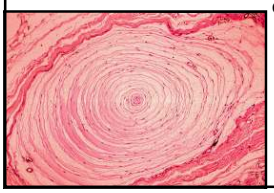


Touch Receptors

Free or encapsulated dendritic endings

In skin and deep organs, *e.g.*: Pacinian corpuscles

- concentric layers of c.t. ⇒ large receptive field detect vibration



opens mechanically gated ion channel

rapid adaptation ⇒ *receptor type?*

Temperature Receptors

- **AKA thermoceptors or thermorecetors**
- **Free dendritic endings in hypodermis**
- **Function in thermoregulation**
- **Cold receptors (< body temp.)**
- **Warm receptors (> body temp.)**
- **Test if more cold or warm receptors in lab**
- **Adaptation only between 20 and 40°C**
- **Nociceptors activated if T > 45°C**

Nociceptors

- **Free dendritic endings**
- **Activation by strong, noxious stimuli -** *Function?*
- **3 categories:**
  - **Mechanical**
  - **Thermal** *(menthol and cold / capsaicin and hot)*
  - **Chemical (includes chemicals from injured tissues)**
    - Inflammatory Pain
- **May activate 2 different pathways:**
  - Reflexive protective – integrated in spinal cord
  - Ascending to cortex (pain or pruritis)

Pain

- **Aβ, and AΔ fibers mediate pain**
- **C fibers mediate pruritis**
- **Fast (Aδ fibers) pain is sharp**
- **Slow pain (C) is throbbing**
- **Ascend to limbic system and hypothalamus**Emotional Distress
  - Modulation
- Gate Control Theory: We can inhibit the pain response (fig 10-12c)
- Pain control
  - NSAIDs (inhibit COX)
  - Opiates (inhibit NT release)

Referred Pain

Pain in organs is poorly localized

⇩

May be displaced if

⇩

Multiple 1° sensory neurons converge on single ascending tract

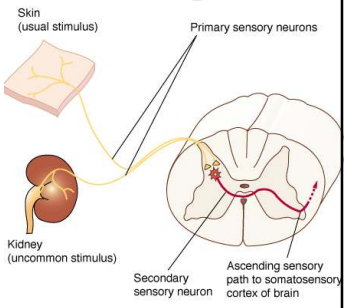
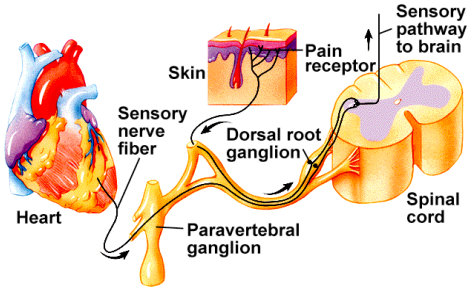


Fig 10-13

Referred Pain: Heart



Special Senses: Smell and Taste

2 of the five special senses

Very old (bacteria use to sense environment)

Olfaction

- Olfactory epithelium has > 1,000 different odorant receptors
- Bipolar neurons continuously divide!
- G-protein – cAMP mediated
- Brain uses "**population coding**" to discriminate 1,000s of odors

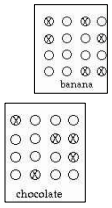


Fig 10-14

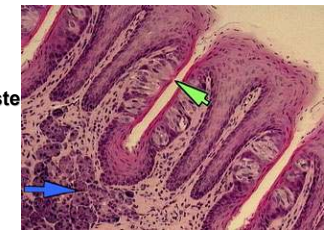
Special Senses: Gustation

- ***Organ for taste = ?***

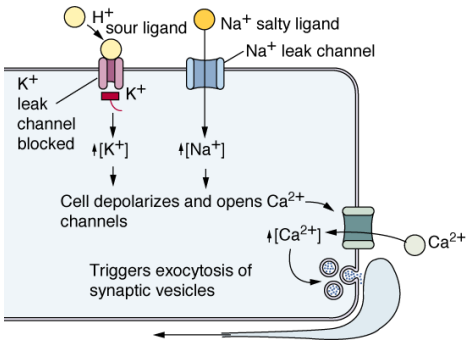
See Fig 10-15

Taste buds

- **located in papillae**
- **contain group of taste and support cells**

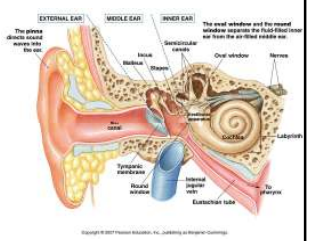


Sour and Salt Ligands

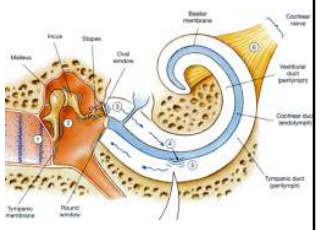


Special Senses: Hearing & Balance

- **Review Ear anatomy**
  (fig 10-17)
  - Outer
    - Pinna or auricle
  - Middle
    - Incus, malleus, stapes
  - Inner
    - Cochlea
      - **Organ of Corti**
    - Semicircular Canals
      - **Macula and crista ampullaris**



Special Senses: Sound Transmission and Transduction



Sound waves

↓

Tympanic membrane vibrations

↓

Ossicles transmit & amplify vibration

↓

Via oval window to perilymph then endolymph

Interpretation of Sound Waves: Pitch Perception

- Sound wave frequency expressed in Hertz (Hz) = wavelength / sec
- Human can hear between 20 and 20,000 Hz
- High pitch = high frequency
- Low pitch = low frequency
- Loudness = amplitude
  - Relative to the rate of AP released
  - Decibels (Db) is a logarithmic scale, i.e., each 10 Db increase is a 10X increase in intensity
    - noisy restaurant ~ 70 dB
    - rock concert ~ 120 dB
- Tone = pure sound of 1 frequency (e.g. tuning fork)

Sound Transmission *cont.*

Vibrations in perilymph are transferred across the basilar membrane to the cochlear duct

⇩

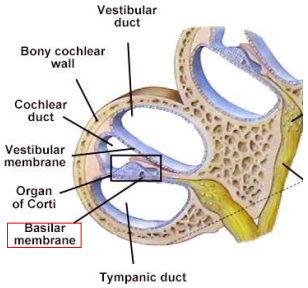
Vibrations in endolymph stimulate sets of receptor cells

⇩

Receptor (hair) cells release NT which stimulates nearby sensory neuron

⇩

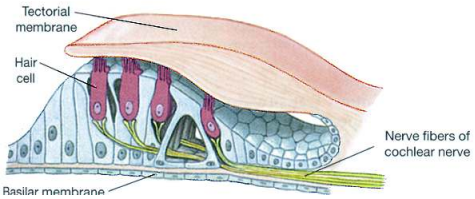
Impulse to auditory cortex of temporal lobe via Cochlear nerve to Vestibulocochlear N. (VIII)



Movement of Tectorial Membrane

Fig 10-20

The movement of the tectorial membrane with sound waves moves the cilia on the hair cells and affects neurotransmitter release by the hair cells.



Hearing Transduction

= *multi-step process*:

air waves → mechanical vibrations → fluid waves → chemical signals → APs

At rest ~ 10% of ion channels open

More voltage-gated Ca^{2+} ion channels open: Excitation

All channels closed: Inhibition

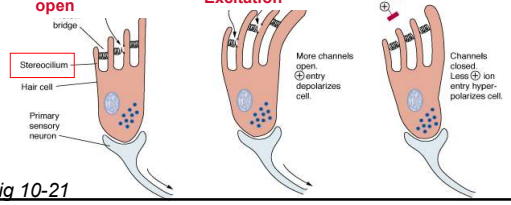
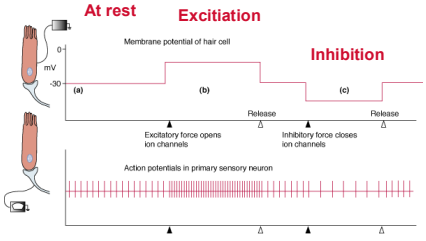


Fig 10-21

Signal Transduction cont.



Basilar Membrane

Pitch perception is function of basilar membrane

BM stiff near oval window

BM more flexible near distal end

Brain translates location on membrane into pitch of sound

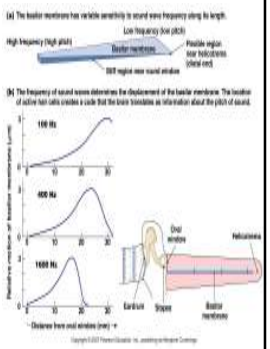
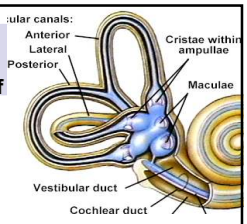


Fig 10-22

2 (3) types of Hearing Loss

1. **Conduction deafness**
   1. External or middle ear
   2. Many possible etiologies
      1. Cerumen, Otitis media, otosclerosis etc.…
2. **Sensorineural deafness**
   1. Damage to neural structures (from receptors, i.e., hair cells, to cortical cells)
   2. Most common: gradual loss of receptor cells
   3. Need for hearing aids and cochlear implants
3. **Central**
   1. Damage to neural pathways
   2. Not common

Special Senses: Equilibrium State of Balance



- Utricle and saccule (otolith organs) with maculae (sensory receptors) for linear acceleration and head position
- Semicircular canals and ampullae with cristae ampullaris (sensory receptors) for rotational acceleration
- Equilibrium also interpreted with input from vision & stretch receptors in muscle

Otolith Organs of Maculae

- **Maculae and Crista ampullaris** receptors similar to organ of corti receptors
- However: gravity & acceleration provide force to move stereocil

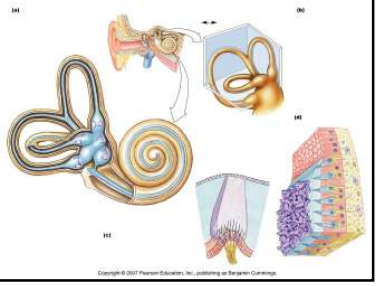


Fig 10-25

Not in book

Motion Sickness

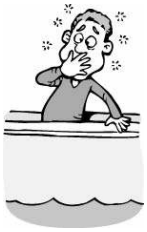
= Equilibrium disorder

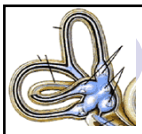
Due to sensory input mismatch

Example?

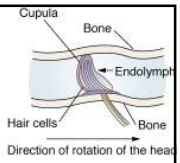
Antimotion drugs (e.g.: Dramamine):

Depression of vestibular inputs





Vestibular Nystagmus



- **= Reflex movement via input from semicircular canals & cristae ampullaris**
- ***As you rotate***
  - eyes slowly drift in opposite direction (due to backflow of endolymph)
  - then rapid eye movement in direction of rotation to establish new fixation point
- **Continues until endolymph comes to rest**
- ***Sudden stop ?***

Special Senses: Vision

Chapter 10, cont'd

Review eye anatomy, especially:

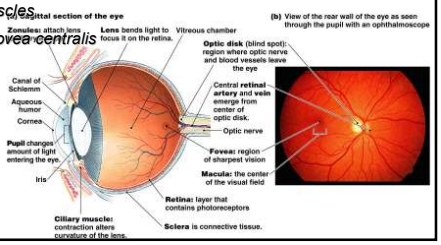
Path of light through eyeball

Cellular layers of retina

Intrinsic eye muscles

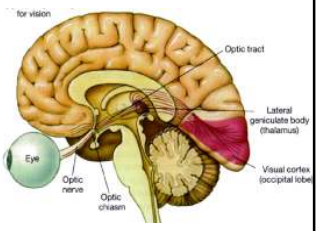
Blind spot and fovea centralis

Fig 10-28



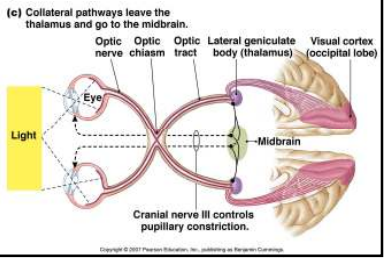
Vision Process can be Divided into Three Steps

1. Light enters eye, is focused by lens onto retina
2. Photoreceptors transduce light energy into electrical signal
3. Processing via optic N. (II), lateral geniculate body to Visual Cortex



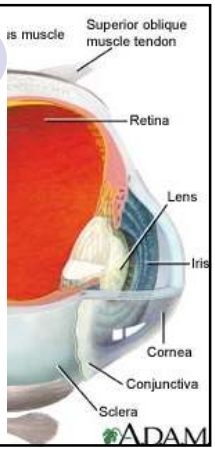
Pupillary light Reflex

- Amount of light is changed by altering pupil aperture from ~1.5 – 8 mm
- Pupillary constriction due to the ciliary muscle via CN III (oculomotor)
- Pupillary reflex is consensual



The Cornea and Lens

- Light is bent (refracted) when it passes from one medium to another
- Two thirds of refraction is by the cornea
- Focusing is done by the lens, which can alter its shape.
  - Called accomodation
  - Ciliary muscle



Accommodation: Light is focused (to keep objects in focus) by changing lens shape

Lens attached to ciliary muscle via suspensory ligament (= zonulas)

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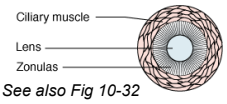
Ciliary muscle contracts



See also Fig 10-32

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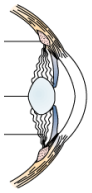
Lens bulges up



Accommodation

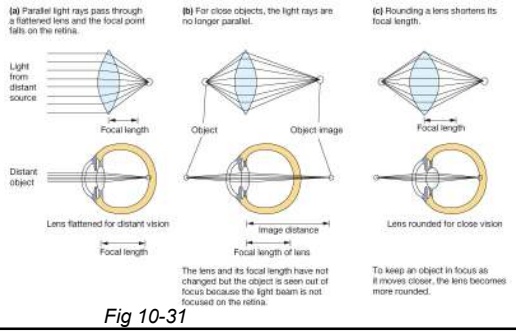
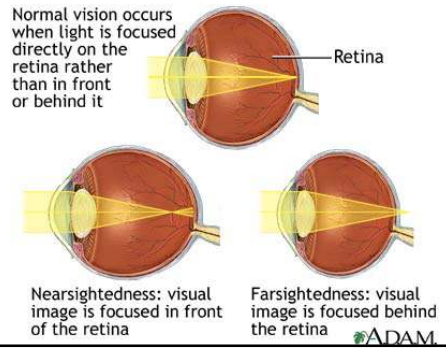


Fig 10-31

Compare to Fig 10-33

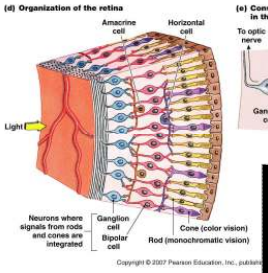


Vision Problems

- Emmetropia = Normal vision
- Presbyopia (loss of accommodation; need reading glasses)
- Myopia (near-sightedness; retina too far away)
- Hyperopia (far-sightedness; retina too close)
- Astigmatism (asymmetry of cornea and/or lens)

Test of visual acuity in lab

Retina Review



- Fovea = area of maximum acuity
  - The neurons and blood vessels are pushed off to the side
- The macula surrounds the fovea
- Optic Disk

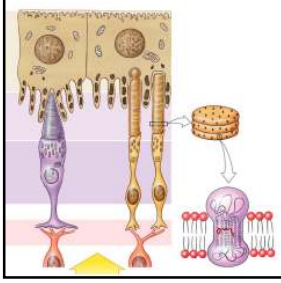
Important concept from 1st part of chapter:

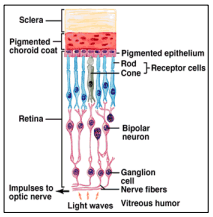
Sensory Transduction at the photoreceptor converts visible light into Graded Potentials

Stimulus energy is transduced into a membrane potential change.

Phototransduction at Retina

Neurons organized into layers





Light = Electromagnetic Energy

Wavelength for visible light: λ =?

Some animals can see UV and IR waves

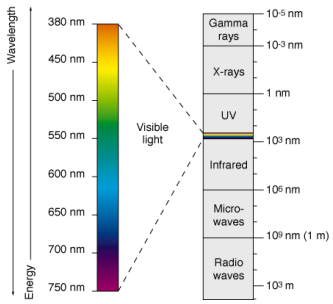


Photo-Receptors

Rods

- Monochromatic night time vision
- 1 pigment (Rhodopsin)
- Most numerous except in fovea
- 20X more rods than cones

Cones

- High acuity vision & daytime color vision
  - Highest density in fovea
- 3 pigments (similar to rhodopsin)

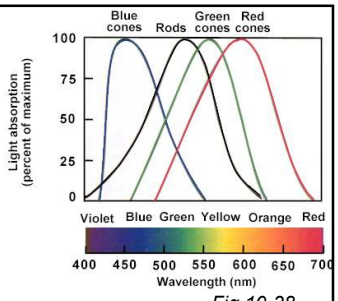
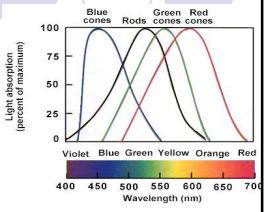


Fig 10-38

Colorblindness

- "Color deficiency" more accurate term
- ~ 10% of men, sex-linked trait
- L-, M- and S Cones detect the colors
- Most common is L-Cone deficiency (red-green)
- Very small differences in AA sequence of photochromic pigments in cones



Not in Book

Phototransduction for Rhodopsin

(similar for cone pigments)

Retinal absorbs 1 photon

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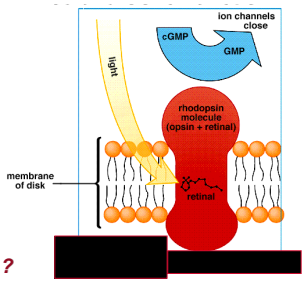
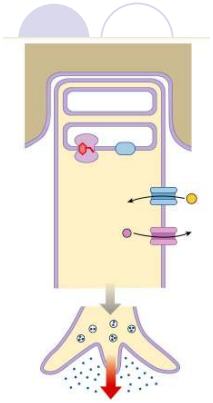
Rhodopsin splits: Retinal is released from opsin due to conformational change

⇩

= "bleaching"



How does this produce AP ?



No Light:

Rhodopsin inactive

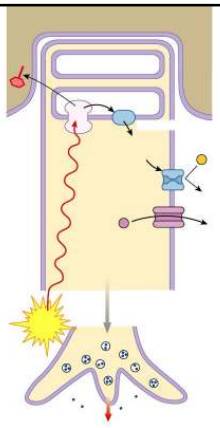
Cells have membrane potential of ~ - 40 mV *(what does that mean, what is it due to ?)*

Continuous (= tonic) NT release to adjacent bipolar cells

Fig 10-39

Light:

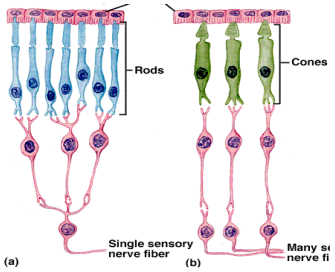
1. **Rhodopsin splits**
2. **Activation of transducin**
3. **2nd messenger cascade decreases cGMP levels**
4. **Na^+ channels close ⇒ NT release decreases**
   1. **NT is glutamate**
5. **Bipolar neurons receive NT**
   1. **May be excitatory or inhibitory**



- **120 x 10^6 Mio rods**
- **6 x 10^6 cones**
- **only 1.2 x 10^6 axons enter optic nerve ⇒ mechanism?**

Visual processing in visual cortex

Optic nerves enter brain at optic chiasma: some fibers cross sides ⇒ right side visual field to left side brain



Visual Field and Binocular Vision

Fig 10-41

3 vs. 2 dimensional view