Ch 10: Sensory Physiology

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.
2.
3.
4.
5.
Sensory Receptors - Overview

- are transducers → convert stimuli into graded potential (receptor potential)
- are of various complexity
- react to particular forms of stimuli
  - Chemoreceptors
  - __________________
  - __________________
  - __________________
  - __________________

Fig 10-1
Sensory Transduction

Converts Stimulus into graded potential = receptor potential.  *How is stimulus energy transduced?*

Receptor potential in neuron above threshold $\Rightarrow$ AP

Receptor potential in non-neural receptors changes $\Rightarrow$ influence on NT release
Receptive Fields

Each $1^\circ$ sensory neuron picks up information from a receptive field.

Often convergence onto $2^\circ$ sensory neuron $\Rightarrow$ summation of multiple stimuli.

Size of receptive field determines sensitivity to stimulus $\Rightarrow$ Two point discrimination test (see lab).
Sensory Pathway

Stimulus

\[ \downarrow \]

Sensory receptor (= transducer)

\[ \downarrow \]

________________________

\[ \downarrow \]

CNS

\[ \downarrow \]

Integration, perception
Sensory Info Pathways and CNS Integration

1. Olfactory pathways from the nose project to the olfactory cortex.

2. Most sensory pathways project to the thalamus. The thalamus modifies and relays information to cortical centers.

3. Equilibrium pathways project to the cerebellum.

Fig 10-4
CNS Distinguishes 4 Stimulus Properties

- Modality (nature) of stimulus
- Location (lateral inhibition & population coding)
- Intensity
- Duration

Fig 10-10 Somatosensory cortex
IntENSITY & Duration of Stimulus

- **Intensity** is encoded 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** do NOT adapt or adapt slowly
  - **Phasic receptors** adapt rapidly
Tonic Receptors vs. Phasic Receptors

- Slow or no adaptation
- Continuous signal transmission for duration of stimulus
- Monitoring of parameters that must be continually evaluated, e.g.: baroreceptors
  __________?
- Rapid adaptation
- Cease firing if strength of a continuous stimulus remains constant
- Allow body to ignore constant unimportant information, e.g.:
  __________?

Fig 10-8
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)

*Fig 10-9*
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

- 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
- Nociceptors
- Adaptation only between 20 and 40°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)

May activate 2 different pathways:
  - Reflexive protective – integrated in spinal cord
  - Ascending to cortex (pain or pruritus)

Fast (Aδ) vs. slow pain (C) (review axon diameter, myelination)
Pain in organs is poorly localized
May be displaced if
Multiple 1° sensory neurons converge on single ascending neuron
Chemoreception: 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
Gustation

- *Organ for taste = ?*

Taste buds
- located in papillae
- contain group of taste and support cells

See Fig 10-15
Taste Buds: Five taste sensations

5) _____________?

sour

Phasic receptors ⇒ ______ adaptation!
Each taste cell is sensitive to only one taste

Ca\(^{2+}\) signal releases NT
Sour and Salt Ligands

- **Sour ligand**: $H^+$
- **Salty ligand**: $Na^+$
- **Leak channel**: $Na^+$
- **Leak channel**: $K^+$

Cell depolarizes and opens $Ca^{2+}$ channels.

Triggers exocytosis of synaptic vesicles.
Special Senses: Hearing & Balance

- **Review Ear anatomy**
  - outer
  - middle
  - inner

Hearing: organ of corti
Balance: maculae and cristaee ampullaris
Sound transmission

Sound waves

Tympanic membrane vibrations

Ossicles transmit & amplify vibration

Via oval window to perilymph then endolymph
Vibrations in endolymph stimulate sets of receptor cells

NT release of receptor cell stimulates nearby sensory neuron

Impulse to auditory cortex of temporal lobe via________________ nerve
Hearing Transduction

= multi-step process:

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

At rest ~ 10% of ion channels open

More ion channels open: Excitation

All channels closed: Inhibition

Fig 10-21
Signal Transduction cont.

- At rest
- Excitation
- Inhibition

Membrane potential of hair cell:

- (a) Membrane potential at rest
- (b) Excitation
- (c) Inhibition

Excitatory force opens ion channels
Inhibitory force closes ion channels

Action potentials in primary sensory neuron:

- Release

mV
**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
- Tone = pure sound of 1 frequency (e.g. tuning fork)
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

→ Temporal aspects of frequency are transformed into spatial coding

→ Spatial coding is preserved in auditory cortex

Compare to Fig 10-22
Interpretation of Sound Waves: Loudness perception

Rate at which APs are fired $\uparrow \Rightarrow$ loudness $\uparrow$

Sound Intensity Measurement:

Decibel Scale (dB) starts at 0 and is logarithmic

- 130 dB pain threshold
- $> 80$ dB frequently or prolonged $\Rightarrow$ ?

Examples:
- noisy restaurant $\sim 70$ dB
- rock concert $\sim 120$ dB


2 (3) types of Hearing Loss

**Conduction deafness**
- External or middle ear
- Many possible etiologies
  - Otitis media, otosclerosis etc....

**Sensorineural deafness (+ central)**
- Damage to neural structures (from receptors to cortical cells)
- Most common: gradual loss of receptor cells
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

- Important besides inner ear: 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 stereo cilia

Fig 10-25
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 & crista 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?
Vision

Review eye anatomy especially:

*Path of light through eyeball*
*Cellular layers of retina*
*Intrinsic eye muscles*
*Blind spot and fovea centralis*
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. Electrical signals sent along neuronal pathways are processed in visual cortex.
Light Modification Pre-Retina

• Amount of light is changed by altering pupil aperture from \( \sim 1.5 - 8 \text{ mm} \)

• Pupillary constriction due to ?

• Dilation ?

• Pupillary reflex is consensual
The Lens

Light is focused by changing lens shape

Refraction: Due to different densities, light waves are bent, or refracted when passing from one medium into another.
Accommodation: Light is focused (to keep objects in focus) by changing lens shape

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

Ciliary muscle contracts

Lens bulges up

See also Fig 10-32
Vision Problems

- Presbyopia (loss of accommodation)
- Myopia (near-sightedness)
- Hyperopia (far-sightedness)
- Astigmatism (asymmetry of cornea and/or lens)

Test of visual acuity in lab
Normal vision occurs when light is focused directly on the retina rather than in front or behind it.

Nearsightedness: visual image is focused in front of the retina.

Farsightedness: visual image is focused behind the retina.
Sensory Transduction Converts Stimuli into Graded Potentials

Stimulus energy is transduced into a membrane potential change.

How can you create an excitatory or inhibitory signal?
Phototransduction at Retina

Anatomy review:
Neurons organized into layers
Light = Electromagnetic Energy

Wavelength for visible light: $\lambda =$?

Some animals can see UV and IR waves
Photo-Receptors

Rods
- Monochromatic night time vision
- 1 pigment (Rhodopsin)
- Most numerous except in fovea

Cones
- High acuity vision & daytime color vision
- 3 pigments
Phototransduction for Rhodopsin

Retinal absorbs 1 photon

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

= “bleaching”

How does this produce AP?

Retinal = Vit. A derivative
Opsin = protein
No Light:
Rhodopsin inactive

Cells have membrane potential of \( \sim -40 \text{ mV} \) (what does that mean, what is it due to?)

Continuous (= tonic) NT release to adjacent bipolar cells
Light:
Rhodopsin splits
Activation of transducin (= __ - protein)
2nd messenger cascade decreases cGMP levels
Na\(^+\) channels close \(\Rightarrow\) ?
NT release decreases
- 120 Mio rods
- 6 Mio cones
- only 1.2 Mio axons enter optic nerve \(\Rightarrow\) mechanism?

**Visual processing in visual cortex**

**Optic nerves enter brain at optic chiasma:** some fibers cross sides \(\Rightarrow\) right side visual field to left side brain
Visual Field and Binocular Vision

3 vs. 2 dimensional view

Fig 10-41
the end