Sensory Physiology
Chapter 10

Sensory Organs (Receptors)
- Monitor the internal and external environment
- Transmit peripheral signals to CNS for processing
- Critical for homeostasis

Types of Sensors
Structural Design
- Primary Sensors
  - Dendritic endings of sensory neurons
  - Stimulation directly evokes APs in neuron
- Secondary Sensors
  - Specialized sensory cell
  - Stimulation of sensor induces release of neurotransmitter to sensory neuron.

Types of Sensory Receptors
Functional Types
- Chemoreceptors
  - Respond to changes in chemical concentration
- Mechanoreceptors
  - Respond to mechanical energy (touch, pressure, vibration)
- Photoreceptors
  - Respond to light
- Thermoreceptors
  - Respond to temperature changes
- Nociceptors
  - Respond to tissue damage (pain)

Sensory Adaptation
- Response of sensors to constant stimulation
- Phasic receptors
  - Exhibit sensory adaptation
  - Firing rate of receptor (θ AP’s) decreases with constant stimulus
- Tonic receptors
  - Exhibit little adaptation
  - Maintain constant firing rate as long as stimulus is applied

Four Steps to Sensation
1. Stimulation
   - Application of stimulus
   - Must be strong enough to induce AP in sensory neuron
   - Sensors most sensitive to one particular stimulus modality (adequate stimulus)
2. Transduction
   - Induction of an action potential
   - Stimulation of sensor induces graded potentials in sensors
     - Generates potentials, or receptor potentials
     - If strong enough depolarization, AP results
     - ↑ stimulus strength above threshold
       → ↑ AP firing rate
Four Steps to Sensation

3. Conduction
   - relay of information through a sensory pathway to specific region of CNS
   - Usually three neurons in sensory pathway
     - 1st order neuron
       - from stimulation point to CNS
     - 2nd order neuron
       - e.g., from entry into CNS to thalamus
     - 3rd order neuron
       - e.g., from thalamus to perception site
4. Perception
   - Detection of environmental change by CNS
   - Evaluation of nature of change and magnitude

Acuity

- Acuity = ability to discriminate size, shape of an object in the environment
- Determined by size of receptive field
  - area of the body that, if stimulated, will cause a response from a sensory neuron
- ↑ receptor density, ↓ receptive field size, ↑ acuity
  - easier to define borders of an object

Classification of Sensory Input

- Somatesthetic senses
  - sensors located over wide areas of the body
  - Information usually conducted to the spinal cord first (then possibly the brain)
- Special Senses
  - Changes detected only by specialized sense organs in the head
  - Information conducted directly to the brain

Somatesthetic Senses

- Touch and Pressure
- Heat and Cold
- Limb movements
- Pain

Somatosensory Information Conduction

- Two possible destinations for sensory information upon entering the spinal cord:
  - Part of spinal reflex arc
  - Relayed up ascending to somatosensory cortex

Somatesthetic Senses: Sensor Structure

- Free nerve endings
  - heat, cold, pain
- Expanded dendritic endings
  - Ruffini endings and Merkel's disks (touch)
- Encapsulated endings
  - Meissner's corpuscles, Krause's corpuscles, Pacinian corpuscles (touch and pressure)
- Bundled receptors
  - Spindle fibers, Golgi tendon organs
Special Senses
- Taste
- Smell
- Hearing
- Equilibrium
- Vision

Taste (Gustation)
- Detection of chemical concentrations in the oral cavity
- Taste buds - chemoreceptors
  - contain microvilli that project to the external surface
  - When chemicals come into contact with these hairs, buds release NT to sensory neurons → APs
- Travel to the parietal lobe (inferior postcentral gyrus)

Taste (Gustation)
- Different tastes derived from activation of different signaling pathways within the cells
  - Salty (high [Na+])
  - Sour (high [H+])
  - Sweet (organic molecules)
  - Bitter (toxins)
  - Umami (glutamate)

Smell (Olfaction)
- Detection of chemicals in air
- Modified bipolar neurons (chemoreceptors)
  - Ciliated receptors located in nasal epithelium
  - respond to chemicals in air
- APs travel to olfactory bulb
  - Synapse with mitral cells (2nd order) in glomeruli
  - Each glomerulus receives signals from one type of receptor
- Info Relayed to olfactory cortex (temporal lobe) and medial limbic system

Smell (Olfaction)
- Defines much of food flavor
- ~1000 different genes for olfactory receptor proteins
  - Humans can distinguish among a great variety of odors (10,000)
  - Combinatory effect of odorants binding to different receptors

Hearing
- Neural perception of vibrations in the air
- Hair cells - mechanoreceptors
  - vibrations bend stereocilia
    - Opens/closes physically gated ion channels
    - alters release of NT to sensory neurons
Anatomy of the Ear

- Outer Ear - air-filled
- Middle Ear - air-filled
- Inner Ear - fluid-filled

Outer (External) Ear

- Pinna (Auricle)
  - collects and channels sound waves
- External Auditory Meatus
  - entrance into the skull
- Tympanic Membrane
  - vibrates when struck by sound waves

Middle Ear

- Air-filled chamber
- Eustachian tube
  - connects middle ear to pharynx
- Auditory ossicles
  act as sound amplifiers
    - malleus - against tympanic membrane
    - incus
    - stapes - linked to oval window

Inner Ear

- Fluid-Filled
- Two regions:
  - Vestibular apparatus
    - equilibrium
  - Cochlea
    - hearing

Cochlea

- Three snail-shaped tubes filled with fluid
  - Outer canals (continuous)
    - scala vestibuli – superior
      - Links to oval window
    - scala tympani – inferior
      - Links to round window
  - inner canal = Cochlear Duct
    - floor - organ of Corti

Organ of Corti

- Hair cells
  - embedded in supporting cells
- Basilar membrane
  - Flexible, vibratory
- Tectorial membrane
  - covers hair cells
  - stereocilia imbedded in membrane
Conduction of Sound

- Fluid pressure waves cause basilar membrane to vibrate
- Hair cells move against tectorial membrane
- Stimulates neurotransmitter release to sensory neurons
  - Auditory nerve
- Signals conducted to auditory cortex (temporal lobe)

Equilibrium

- Changes in position and motion of the head
  - Balance and coordination of body movement
- Hair cells - mechanoreceptors

Vestibular Apparatus

- Fluid-filled compartments in the inner ear
- Semi-circular canals
  - Rotation of the head
- Otolith organs
  - Linear movement of head and orientation relative to gravity
- Sensory information relayed via the vestibular nerve to the cerebellum and medulla

Semicircular Canals

- Fluid-filled circular tubes oriented in three planes
- Bell-shaped ampulla at one end of each canal
  - Contains hair cells covered with gel-like cupula
- Rotation of head in one direction generates inertial pressure in fluid
  - Bends cupula
  - Stimulates hair cells
  - Stimulates vestibular neurons

Otolith Organs

- Two fluid-filled chambers (utricle and saccule)
- Macula – mound of hair cells covered with otolithic membrane
  - Jelly-like membrane
  - Otoliths (CaCO₃ crystals)
- Linear movement or tilting of head causes otolithic membrane to sag
  - Bends hair cells
  - Stimulates vestibular neurons

Vision

- Perception of electromagnetic radiation
  - Narrow portion of the EM spectrum
- Photoreceptors
  - Stimulated by photons of light
  - Contain photopigments
    - Undergo chemical changes in response to light
    - Induces metabolic changes in photoreceptors leading to receptor potentials
Anatomy of the Eye

- Three distinctive layers of tissue
  - Sclera - outer layer
  - Choroid - middle layer
  - Retina - inner layer

Sclera

- “White” of the eye
- Tough connective tissue
  - Protects inner structures
  - Maintains eye shape
- Cornea (anterior portion)
  - transparent: lets light pass into the eye
  - fixed lens (bends light)
  - covers the anterior cavity
    - filled with aqueous humor

Choroid

- Contains blood vessels for the eye
- Specialized structures anteriorly:
  - Iris
  - Ciliary Muscle
  - Lens

Iris

- Thin ring of pigmented muscle in front of lens
  - pupil - opening in muscle
- Muscles alter pupil size, thus amount of light passing
  - Radial muscles - open pupil in dim light (sympathetic)
  - Circular muscles - close pupil in bright light (parasympathetic)

Ciliary Muscles and Lens

- Lens
  - solid but pliable transparent body
  - used to focus light on the retina
- Ciliary Muscle
  - ring-shaped smooth muscle
  - linked to lens by suspensory ligaments
  - adjusts shape of lens to focus light

Accommodation

- Changing lens shape to focus light from objects at different distances on the retina
- Far objects
  - light from narrow range of angles
  - ciliary muscles relax, lens stretched
  - less convex, less bending of light
- Near objects
  - light from wide range of angles
  - ciliary muscles contract, lens recoils
  - more convex, more bending of light
Refraction of Light

- Light bends when passing between mediums with different densities
- Four different refractive mediums in the eye:
  - cornea
  - aqueous humor
  - lens
  - vitreous humor (btw lens and retina)
- Bending of light leads to projection on the retina
  - Lens is responsible for focusing the image

Retina

- Inner layer of the eye
- Contains photoreceptors
  - rods and cones
- Fovea centralis
  - Point where light is focused
  - High density of cones
- Optic disk
  - Where optic nerve joins the eye
  - No photoreceptors - “blind spot”

Retina Cells

- Photoreceptors
  - Deepest layer
  - Rods and cones
- Bipolar cells
  - Modified neurons
  - Receive signals from cells
  - Transfer signals to ganglion cells
- Ganglion cells
  - Sensory neurons
  - Conduct signals to CNS via the optic nerve

Photoreceptors

- Rods - Light intensity
  - More numerous than cones
  - Highly sensitive to light
  - Low light levels detected
  - Low visual acuity
- Cones - Color
  - Less sensitive to light
  - Need high light levels to respond
  - High visual acuity

Phototransduction

- Each photoreceptor has two segments
- Inner segment
  - Metabolic machinery
  - Synaptic endings
- Outer segment
  - Contains layers of internal membranes containing photopigments
  - Rhodopsin - Rod cells
  - Photopsins - Cone cells
- Photoreceptors synapse with bipolar cells
- Bipolar cells synapse with ganglion cells
- In absence of light, photoreceptors release inhibitory NT
  - Hyperpolarize bipolar cells
  - Inhibit bipolar cells from releasing excitatory NT to ganglion cells
**Phototransduction**

- when stimulated with light, photoreceptors STOP releasing inhibitory NT
  - bipolar cells **depolarize**
  - release **excitatory NT** to ganglion cells
  - ganglion cells undergo APs

**Conduction of Light**

- Cornea and aqueous body
- Pupil - adjust light level
- Lens - focus light
- Vitreous body
- Retina (fovea centralis)

**Transduction of Light**

- Rods and Cones cease release of inhibitory NT
- bipolar cells depolarize
  - release excitatory NT
- Ganglion cells depolarize
  - AP in optic nerve
- Signal conducted to visual cortex in occipital lobe