Sensory Systems

Vision

I. Background

A. Processes
1. Light energy is transduced into neural activity
2. Neural activity is processed by the brain

Note: By way of analogy, you can imagine taking a picture with a camera. The eye is the camera, the retina, which is a specialized part of the brain at the back of the eye, is the film, and the parts of the brain that process visual information is the photoshop.

B. Human visual systems permit light reflected off distant objects to be:
1. Localized relative to the individual within his or her environment
2. Identified based on size, shape, color, and past experience
3. Perceived to be moving (or not)
4. Detected in a wide variety of lighting conditions

C. Sequence of events
1. Light entering the eye is focused on the retina
2. Retina converts light energy into neuronal activity
3. Axons of the retinal neurons are bundled to form the optic nerves
4. Visual information is distributed to several brain structures that perform different functions

II. Anatomy of the Eye

A. Structural levels
1. Gross anatomy
2. Ophthalmoscopic appearance
3. Cross-section anatomy
B. Gross anatomy

1. External features of the eye
   a. Pupil--opening that allows light to reach the retina
   b. Iris--circular muscle that controls the diameter of the pupil
   c. Aqueous humor--fluid behind the cornea
   d. Sclera--outermost layer that forms the eyeball
   e. Extraocular muscles--attached to the eye and skull and allow movement
   f. Conjunctiva--membrane inside the eyelid attached to the sclera
   g. Optic nerve--axons of the retina leaving the eye
   h. Cornea--transparent surface covering the iris and pupil

2. Ophthalmoscopic appearance (Retina as seen through the pupil)

   Aside: in photographs, the red appearance of the eye is actually the retina photographed. Double flash camera causes the pupil to constrict.

   a. Optic disk (blind spot)--no vision is possible
      i. Blood vessels originate here. The vessels shadow the retina
      ii. Optic nerve fibers exit here
iii. No photoreceptors
b. Macula--area of the retina responsible for central vision (vs. peripheral)
c. Fovea--center of the retina (where most of the cones are)

3. Cross sectional anatomy
   a. Lens--transparent surface that contributes to the formation of images (w/i 9 meters)
   b. Ciliary muscles--change the shape of the lens and allow focusing
   c. Vitreous humor--more viscous than the aqueous humor
      i. Lies between the lens and the retina
      ii. Provides spherical shape
   d. Retina
      i. Inner most layer of cells at the back of the eye
      ii. Transduces light energy into neural activity

III. Image Formation

A. Processes
1. Refraction by the cornea
2. Accommodation by the lens
3. Pupillary reflex

B. Refraction by cornea
1. Distant objects
   a. Light rays run in parallel
2. Light rays slow
   a. Cornea
   b. Aqueous humor
3. Light rays bend
   a. Perpendicular to the angle (radius of the cornea) between the curve of the cornea and the plane they are traveling on
4. Focal distance
   a. Distance between the refractive surface and where the light rays converge
   b. Depends on the curvature of the cornea
i. 2.4 cm
ii. Distance between the cornea and the retina

C. Accommodation by the lens

1. Objects within 9 meters
   a. Light rays do not travel in parallel
      i. Some diverge

2. Lens adds refractive power
   a. Provided by changing the shape of the lens

3. Contraction of ciliary muscles
   a. Tension on the suspensory ligaments is released
   b. Lens becomes rounded
   c. Greater the curvature provides greater the refraction

D. Pupillary reflex
1. Pupil contribute to optical qualities of the eye
   a. Adjusts for different light levels
   b. Contributes to simultaneous focusing on near and distant objects

2. Accommodation alters light rays that would otherwise run in parallel
   a. Light rays are no longer focused on the retina by the cornea

3. Closing the aperture of the pupil
   a. Only light rays that are primarily in the center of the cornea and lens are allowed in
   b. These are generally not focused
   c. Permits seeing things in the foreground and background in focus

E. Additional terms and concepts
1. Visual field
   a. Total space that can be viewed by the retina
      i. 150 degrees
      ii. 90 on temporal side
iii. 60 on the nasal side

2. Image formed on the back of the retina is reversed and inverted
(A) Emmetropia (normal)

(B) Myopia (nearsighted)

(C) Hyperopia (farsighted)

3. Emmetropia (normal vision)
   a. Parallel light rays are focused on the retina without accommodation

4. Hyperopia (farsightedness)
   a. Eye ball is too short
   b. Image is focused at a point behind the retina
   c. Lens can accommodate for distant objects but not for near
   d. Condition can be corrected with a convex lens (e.g., increase refractive power)

5. Myopia (nearsightedness)
   a. Eye ball is too long
   b. Light rays converge in front of the retina
   c. Lens can accommodate for near objects but not distant
   d. Condition can be corrected with a concave lens
III. Microscopic Anatomy of the Retina
A. Specialized cells of the retina convert light energy into neural activity
B. Cellular architecture of the retina
   Section of retina
1. Cell types
   a. Photoreceptors—the only light sensitive cells in the retina
      i. Transduce light energy into neural signals
   b. Bipolar cells—connect photoreceptors to ganglion cells
   c. Ganglion cells—fire action potential and send axons to the brain
   d. Horizontal cells—receive inputs from photoreceptors and project laterally to bipolar cells
   e. Amacrine cells—receive inputs from bipolar cells and project laterally to ganglion cells

2. Layers (3 primary, but there are subdivisions)
   a. Ganglion cell layer—cell bodies of the ganglion cells
   b. Inner nuclear layer—cell bodies of the bipolar cells
   c. Outer nuclear layer—cell bodies of the photoreceptors

3. Characteristics:
   a. Photoreceptors are the only cells that respond to light
   b. Ganglion cells are the only output cells
   c. Light travels through the other cell layers to reach the photoreceptors
d. At the back of the eye is a pigmented epithelium that absorbs any light not absorbed by the photoreceptors

Side point: Inside many mammalian eyes, there is an additional layer of cells between the photoreceptors and the epithelial layer that reflects the light back out again. The photoreceptors have two opportunities to be exposed--greatly enhances night vision.

C. Photoreceptors--two kinds based on appearance and function

1. Rods--long, cylindrical, many disks
   a. Photopigment is in the disk
   b. Rods have a much higher pigment concentration
   c. 1000x more sensitive to light than cones
   d. Function in scotopic conditions
      i. Nighttime lighting
   e. All rods have the same pigment
i. Rhodopsin

2. Cones—shorter, tapering outer segment, relatively few disks
   a. Photopic conditions
      i. Daytime lighting
      ii. Primarily cones
   b. 3 different types of cones based on type of photopigment
      i. Pigments are differentially sensitive to wavelength of light

3. Retina is therefore a duplex
   a. Scotopic retina using only rods
   b. Photopic retina using primarily cones

4. Distribution of rods and cones
   a. Rods and cones are distributed regionally
   b. Center of the eye (i.e., the fovea)
i. Only cones

5. Connectivity
   a. Central retina
      i. 1:1 (approximately) correspondence between photoreceptor and ganglion
   b. Peripheral retina
      i. Many photoreceptors (rods) converge on a single output ganglion cell
      c. Peripheral retina is more sensitive to light

IV. Phototransduction

A. Photoreceptors transduce (change) light energy into changes in membrane potential
   1. Analogous to transduction of chemical signals into electrical signals that occurs during synaptic transmission at G-protein coupled receptors
   2. Events at G-protein coupled receptors
      a. Binding of NT activates G-proteins
      b. G-protein activation stimulates various effector enzymes
      c. Enzymes alter the intracellular concentration of cytoplasmic second messengers
      d. 2nd messengers either directly or indirectly alter membrane ion channels which alter membrane potential
   3. Events during phototransduction
      a. Light stimulation of photopigment activates G-proteins
      b. G-proteins activate various effector enzymes
      c. Enzymes decrease intracellular concentrations of 2nd messengers (cGMP)
      d. Change in 2nd messenger concentration closes a Na+ channel
B. Functional considerations
1. In complete darkness there is a steady influx of Na+ which depolarizes the photoreceptor membrane
   a. Movement of + charge across the membrane is called the dark current
2. Na+ channels responsible for this current are gated by cGMP (cyclic guanosine monophosphate)
   a. cGMP is produced continually in photoreceptors
      i. Na+ channels stay open in the dark
3. In the light
   a. cGMP is converted to GMP (phosphodiesterase hydrolyxes cGMP)
   b. Membrane hyperpolarizes in response to light
      i. Na+ channels close
4. Rhodopsin
   a. Photopigment
   b. Located in stacked disks in the outer segment of the rods
   c. Comprised of retinal and opsin
i. Opsin absorbs light

5. Bleaching
   a. Photoreceptors no longer respond at particular light intensities
   b. Activation of rods by light bleaches the photopigment
      i. Changes the wavelengths absorbed by rhodopsin

6. Cones also contain opsins
   a. Three different opsins
      i. Each maximally activated by different wavelengths of light
         ii. Blue--430 nm
         iii. Green--530 nm
         iv. Red--560 nm
   b. All colors are created by mixing the proper ratio of red, green and blue
   c. Colors are assigned by the brain based on a comparison of the readout of the three cone types
      i. White results from equal activation of all three

C. Dark and light adaptation

Note: Most of have had the following experiences. Get up at night and turn on the bathroom light; leave a brightly lit room to go down the basement when there are no lights on. Remember there are two different visual systems--one for daytime that utilizes all cones and one for nighttime that utilizes all rods. There is a time course necessary for the photoreceptors to "come on line".

1. Changes associated with adaptation
   a. Pupil diameter changes
   b. Regeneration (or generation) of unbleached (bleached) rhodopsin
   c. Change the functional circuits to allow 1:1 rod to ganglion or reverse that to allow 1:1000
V. Neural Circuitry

A. Pathway

1. Retina to LGN (lateral geniculate nucleus of the thalamus)
2. LGN to the primary visual cortex
3. Primary visual cortex to other cortical areas

B. Connection between eyes and brain
1. Optic nerve, optic chiasm, optic tract
2. Functional considerations
   a. Information from the right visual field crosses to the left side of the brain
      i. Decussation
   b. Information from the left crosses to the right
   c. Not all information crosses
      i. Partial decussation

C. General considerations
1. Left and right visual worlds are processed contralaterally
   a. Information about the left visual field is processed by the right side of the brain
   b. Information about the left that is seen by the right eye does not cross over
2. Right and left eyes perceive parts of both visual worlds
3. Image is inverted and reversed
Exercise
Look straight ahead. Imagine a vertical line dividing the right and left side.
1. Objects appearing to the left are in the left visual hemifield.
2. Objects appearing to the right are in the right visual hemifield.

Close your left eye. Your right eye sees part of the left visual hemifield.
Remember that images as seen on the retinal are reversed. Objects in the temporal part of the left hemifield are focused onto the nasal retina of the left eye. Objects in the nasal part of the right hemifield are focused on the temporal retina of the left eye. The temporal retinal output does not cross over.

D. Formation of image on the retina
Audition

I. Background

A. Audition
1. Sense of hearing
2. Mechanisms within the ear and brain that translate sound in our environment into meaningful neural signals

B. Sound

1. Audible variations in air pressure (compressions)
2. Molecules are displaced forward leaving a corresponding area of lower pressure
3. Sound waves vary in two ways:
   a. Amplitude--intensity; peak to trough; perceived as differences in loudness
   b. Frequency--# of compressions per second; pitch; unit: hertz (1 cycle/second)
II. Structure of the Auditory System
A. Three divisions of the ear

1. Outer
2. Middle
3. Inner

B. Outer ear
1. Pinna
   a. Funnel shaped outer ear made of skin and cartilage
2. Auditory canal
   a. Channel leading from the pinna to the tympanic membrane
C. Middle ear

1. Tympanic membrane (eardrum)
   a. Moves in response to variations in air pressure

2. Ossicles
   a. Series of bones in a small air filled chamber
   b. Transfer the movement of the tympanic membrane into the movement of a second membrane covering a hole in the bone of the skull
      i. Oval window
   c. Bones of middle ear
      i. Malleus (hammer)
      ii. Incus (anvil)
      iii. Stapes (stirrup)
3. Functional considerations:
   a. Cochlea is filled with an incompressible fluid
   b. More force is required to displace fluid than air
   c. Bones in the middle ear amplify the pressure
      i. Pivot points that act as fulcrums
      ii. Malleus is displaced in response to the movement of the tympanic membrane--bottom moves towards the inner ear and the top moves towards the outer ear
      iii. This pulls the top of the incus towards the outer ear and pushes the bottom towards the inner ear
      iv. Stapes is consequently pushed forward against the oval window which is compressed inward
   d. Oval window is smaller and the same pressure across a smaller area results in a greater force (like a spiked high heel)

4. Eustachian tube
   a. Tube that connects the air-filled middle ear to the mouth
   b. Contains a valve

Note:
Why do you need to ‘pop’ your ears when you go up in an airplane? On the ground your middle ear is as the same pressure as the outside environment. As you ascend, air pressure is lower at high altitudes. The tympanic membrane will bulge out because the pressure in the middle ear is greater than the outside environment. When you yawn or swallow, the valve in the tube is opened and the pressure is relieved.

D. Inner ear

1. Converts the physical movement of the oval window into neural signal
2. Takes place in the cochlea
3. Elements
   a. Cochlea
b. Vestibular apparatus
   i. Not part of the auditory system
   ii. Involved in balance

III. Basic Auditory Pathway

A. Processes
1. Sound waves move the tympanic membrane.
2. Tympanic membrane moves the ossicles.
3. Ossicles move the membrane at the oval window.
4. Motion at the oval window moves the fluid in the cochlea.
5. Movement of the fluid in the cochlea causes a response in sensory neurons.
6. Signal is transferred and processed by a series of nuclei in the brain stem.
7. Information is sent to a relay in the thalamus (medial geniculate nucleus--MGN).
8. MGN projects to the primary auditory cortex in the temporal lobe.

IV. Cochlea

A. Background
1. Cochlea transduces the mechanical displacement of the oval window into a neural signal

B. Anatomy
1. Cross section
2. Chambers of the cochlea
   a. Scala vestibuli
   b. Scala tympani
   c. Scala media
3. Organ of corti
a. Contains auditory receptor cells
b. Located in the scala media (see below)

3. Basilar membrane
   a. Separates scala media and scala tympani
   b. Properties are very important for audition (see below)

4. Fluid is continuous between scala vestibuli and scala tympani
   a. Physical connection is known as the helicotrema

V. Physiology of the Cochlea

A. Process
1. Mechanical force pushes on the oval window
2. Fluid within the cochlea is incompressible
3. Fluid pushes forward
   a. Conserves the wave properties of the sound (i.e. the movement of the fluid has frequency and amplitude)
   b. Causes the round window to bulge out
4. Structures within the cochlea are not rigid
   a. Basilar membrane is flexible and bends in response to sound
5. Structural properties of the basilar membrane determine the way it responds to sound

   a. Membrane is wider at apex than base (5:1)
   b. Stiffness of the membrane decreases from base to apex (like a diving board)
   c. High frequency sounds have higher energy and can displace the stiffer part of the basilar membrane (near the base)
   d. Lower frequency sounds have lower energy and displace the apex end
   e. Base responds to high frequency and the apex responds to low frequency
6. Basilar membrane establishes a place code in which different locations are maximally deformed in response to different frequency sounds
VI. Transduction of Mechanical Displacement
A. Organ of Corti

1. Structure
   a. Outer hair cells
   b. Inner hair cells
   c. Tectorial membrane
   d. Reticular membrane
   e. Basilar membrane
   f. Stereocilia
   g. Spiral ganglion

B. Auditory receptors
   1. Hair cells
      a. Stereocilia
C. Transduction

1. Bending of these cilia is the critical event in the transduction of sound into neural signal
2. Hairs extend above the reticular membrane and come in contact with the tectorial membrane
3. When the basilar membrane moves in response to the motion of the stapes
a. Whole complex moves as a unit either towards or away from the tectorial membrane
b. Lateral motion of the reticular membrane bends the stereocilia

4. Depending on the direction that the hairs bend, the inside of the hair cells will either:

- Hyperpolarization
- Depolarization

- a. Depolarize
b. Hyperpolarize
5. Changes in cell potential result from the opening of K+ channels on the tips of the stereocilia
   a. Channels are mechanically gated
   b. Flaps that are connected to the neighboring cilia by a special protein molecule
6. Depending on the direction that the hairs bend, the channel will either be opened or closed
   a. Opening the channel allows K+ to enter and depolarize the hair cell
   b. Closing the channel stops the flow of K+
7. In response to depolarization resulting from influx of K+
   a. Ca++ channel is activated
   b. Influx of Ca++ causes the release of synaptic vesicles from the end of the hair cell
D. Sequence overview:
1. Physical displacement of the basilar membrane bends the stereocilia

![Sound-induced vibration](image)

2. Bending of the cilia either opens or closes a K+ channel
3. When K+ enters, the hair cell depolarizes
4. Depolarization activates a Ca++ channel
5. Ca++ influx causes NT release

VII. Generation of Action Potential
A. Action potential occurs at the level of the output ganglion
B. Organization
1. Multiple outer hair cells make synaptic contact with a single ganglion cell.
2. Ganglion make synaptic contact with a single inner hair cell (although many ganglion cells can contact the same inner hair cell)
3. 75% of all hair cells are outer hair cells
   a. Outer alter the stiffness of the tectorial membrane
4. Only 5% of the fibers in the auditory nerve are from outer hair cells
VIII. Localization of Sound
A. Mechanisms for detecting interaural time differences

1. Two ears separated by about 20 cm
   i. Diameter of your head
2. Detect differences as small as 10 msec

B. Circuit
1. Medial superior olive (MSO) has cells that receive coincident innervation from the right and left anteroventral cochlear nucleus
   a. Cells within the MSO are organized such that the distance from the respective cochlear nuclei varies systematically
      i. Length of the axonal connections determine which MSO cell receives coincident activation by action potential

C. Limitations
1. System works well for sounds that have frequencies below 3 kHz
D. Localization of sounds above 3 kHz
1. Sound does not bend around the head
2. Directed to one side or the other and an intensity difference results
3. Circuit
   a. Anteroventral cochlear nucleus projects directly to the ipsalateral lateral superior olive (LSO)
      i. Indirectly to the contralateral lateral superior olive via an inhibitory neuron originating in the medial nucleus of the trapezoid body (MNTB)
4. Mechanism
   a. Anteroventral cochlear nuclear firing rate is greater for sound with higher intensities
      i. Sound arising directly lateral to the listener, LSO firing will be highest on that side
      ii. Excitation from the ipsalateral anteroventral cochlear nucleus will be maximal
      iii. Inhibition from the contralateral MNTB will be minimal

IX. Coding of Intensity and Frequency

A. Intensity
1. Firing rate of individual hair cells
2. Activation of multiple hair cells.
3. Wave of higher amplitude has more width and activates more hair cells in a given area
B. Frequency
1. Consequence of the mechanics of the basilar membrane
2. Different portions of the basilar membrane are maximally deformed by sound of different frequencies
3. Hair cells that are selectively activated project to cochlear nuclei (brain stem) with tonographic specificity
   a. Specificity is conserved all the way to the cortex

X. Cortical Responses

A. Neuronal organization
1. Isofrequency bands
   a. Temporal lobe
2. Neurons within these bands respond to fairly similar characteristic frequencies
Chemical Senses: Gustation

I. Background

A. Chemical senses
1. Mechanism by which we can detect chemicals in both the internal and external environment
2. Taste and olfaction are the most familiar chemical senses
3. Many types of chemically sensitive cells
   a. Chemoreceptors
      i. Distributed throughout the body
      ii. Report subconsciously and consciously about our internal state

B. Types
1. Chemoreceptors in skin and mucus membranes warn us about irritating chemicals.
2. Nerve endings in the digestive organs detect many types of ingested substances
   a. Viral agents may release chemicals into the GI tract that cause discomfort, activate vomiting reflexes, etc.
3. Chemical receptors in the arteries in the neck measure CO2 and O2 levels in the blood.
4. Sensory endings in the muscles respond to acidity
   a. Burning sensation experienced during anaerobic exercise results from lactic acid formation

C. Taste (Gustation) and Olfaction have similar tasks
1. Detection of environmental chemicals
2. Both are required to perceive flavor
3. Both have strong and direct connections to our most basic needs
   a. Thirst, hunger, emotion, sex, and certain forms of memory
4. Systems are separate and different and only merge at higher levels of cortical function
   a. Have different chemoreceptors
   b. Use different transduction pathways
   c. Have separate connections to the brain
   d. Have different effects on behavior

II. Gustation
A. Basic categories
1. Salty
2. Sour
3. Sweet
4. Bitter

B. Complex flavors
1. Each food activates a different combination of basic tastes
2. Most foods have a distinctive flavor as a result of their taste and smell occurring simultaneously
3. Other sensory modalities may contribute to a unique food-tasting experience
   a. Texture, temperature, pain sensitivity (some hot and spicy flavors are actually a pain response)
C. Organs of taste

1. Tongue

2. Pharynx, palate and epiglottis have some sensitivity

3. Nasal passages are located so that odors can enter through the nose or pharynx and contribute to the perception of flavor

D. Anatomy of the tongue

1. Basic tastes
   a. Bitter across the back
   b. Sour on side closest to the back
   c. Salty on side more rostral than sour
   d. Sweet across front

2. Taste distribution
   a. Most of the tongue is receptive to all basic tastes
      i. Regions are most sensitive to a given taste
3. Papillae

- Small projections
- Each papillae has one to several hundred taste buds

4. Taste buds
   - Each taste bud has 50-150 taste cells

5. Taste cells
   - Taste cells are only 1% of the tongue epithelium

E. Taste receptor cells
1. Not neurons
   - Form synapses with the endings of gustatory afferent axons near the bottom of the taste bud
III. Gustatory Transduction
A. Basic process
1. When taste receptor is activated by the appropriate chemical, its membrane potential changes
   a. Receptor potential
2. Depolarizing receptor potential cause Ca++ to enter the cytoplasm
   a. Triggers the release of NT
3. Taste stimuli may:
   a. Pass directly through an ion channel (salt and sour)
   b. Bind to and block ion channels (sour and bitter)
   c. Bind to and open ion channels (some sweet amino acids)
   d. Bind to membrane receptors that activate 2nd messenger systems that in turn open or close ion channels (sweet and bitter)
B. Salt

![Salt Diagram]

1. Na+ flows down a concentration gradient into the taste receptor cell (most salts are Na+ salts--NaCl)
2. Na+ increase within the cell depolarizes the membrane and opens a voltage dependent Ca++ channel
3. Ca++ increase causes the release of NT

C. Sour
1. Foods that are sour have high acidity (low pH)
   a. Acids (HCl) when dissolved in water generate H+ ions
2. H+ ions pass through the same channel that Na+ does (How do we discriminate between salt and sour then?)
3. H+ also blocks a K+ channel
4. Net movement of + into the cell depolarizes the taste cell
   a. Opens a Ca++ channel
   b. Causes NT release

D. Sweetness
1. Molecules that are sweet bind to specific receptor sites and activate a cascade of 2nd messengers in certain taste cells
2. Molecules bind receptor
3. G-protein activates an effector enzyme-adenylate cyclase (cAMP produced)
4. cAMP causes a K+ channel to be blocked
5. Cell depolarizes
6. Ca++ channel opens and Ca++ in
7. NT released

E. Bitter

Bitter

1. Chemicals in the environment that are deleterious often have a bitter flavor
   a. Senses have evolved primarily to protect and preserve
   b. Ability to detect bitter has two separate mechanisms
      i. May result from this evolutionary pressure

2. System I
   a. Bitter tastants can directly block a K+ channel (same transduction mechanisms as acids)
   b. Cell depolarizes
   c. Ca++ channel is opened and Ca++ in
   d. NT released

3. System II
   a. Bitter tastant binds bitter receptor
   b. G-protein activates an effector enzyme-phospholipase C
   c. Ca++ is released from intracellular storage
   d. Ca++ increase causes NT release

IV. Taste Neural Pathway
A. Circuit
1. NT release from taste cells causes an AP in the gustatory afferent axon
2. Three different cranial nerves (VII, IX and X) innervate the taste buds and carry taste information from the tongue, palate, epiglottis and esophagus
a. Efferent target of this information is gustatory nucleus in the medulla
3. Information is relayed to the thalamus (VPM--ventral posterior medial nucleus)
4. Information then goes to the primary gustatory cortex (parietal lobe)
Chemical Senses: Olfaction

I. Background

A. Olfaction--sense of smell
1. As many as 100,000 unique odors can be discriminated
   a. 80% of which are noxious
   b. Odors perceived to be noxious are often deleterious (rotting meat, etc.).

B. Organs of smell
1. Not the nose
2. Olfactory epithelium
   a. Thin sheet of cells high up in our nasal cavity
   b. Size of the olfactory epithelium is proportionate to olfactory acuity
      i. Man has 10 cm²
      ii. Dog has 170 cm²
      iii. Dogs also have 100x as many receptors per cm²
C. Olfactory receptors

1. Only receptor discussed thus far that are neurons
   a. Fire action potentials
   b. Only neurons in the nervous system that are replaced regularly throughout life
      i. Every 4-8 weeks
2. Olfactory receptors are neurons and continuous with the CNS
3. Ends of the olfactory receptors are a mucus (water soluble)
   a. This mucus contains cells of the immune system and is shed every ten minutes
i. Individual with an infection (cold, flu, etc.) one symptom is a runny nose
ii. Mucus is shed more frequently to protect the olfactory receptors from infection

4. 500-1000 different odor binding proteins
   a. Each olfactory receptor cell expresses only one type of binding protein

5. Receptor is G-protein-coupled
   a. Receptor binding activates an effector enzyme (either adenylate cyclase or phospholipase C, depending on the nature of the odorant)
   b. 2nd messenger (cAMP or IP3) opens a Ca++ channel
   c. Ca++ influx (unlike taste) does not cause NT release
      i. It opens a Cl- channel
   d. Cl- leaves the cell and the membrane is depolarized
   e. Sufficient depolarization causes an AP results
Somatic Sensory System

I. Background

A. Differences between somatic senses and other senses
   1. Receptors are distributed throughout the body as opposed to being concentrated at small, specialized locations
   2. Responds to many kinds of stimuli (usually mechanical)
   3. At least four senses (not one)
      a. Temperature
      b. Body position
      c. Touch
      d. Pain
   4. Place, pressure, sharpness, texture, and duration can be accurately gauged

B. Types of somatic sensation receptors
   1. Mechanoreceptors--sensitive to physical distortion
   2. Nociceptors--respond to damaging stimuli
   3. Thermoreceptors--sensitive to changes in temperature
   4. Proprioceptors--monitor body position
   5. Chemoreceptors--respond to certain chemicals

C. Classification
   1. Free nerve endings
      a. Nociceptors
      b. Thermoreceptors
   2. Encapsulated
      a. Most cutaneous receptors

D. Mechanism of function
   1. Stimuli applied to skin deform or change receptor
      a. Alters the ionic permeability of the receptor creating generator potentials
         i. Trigger action potentials

II. Mechanical Senses

A. Mechanical energy
   1. Easily differentiated
      a. Stimulus frequency
      b. Stimulus pressure
      c. Receptive field
B. Types of receptors
1. Mechanoreceptors
   a. Pacinian
      i. Sensitive to vibration (250-350 Hz)
      ii. Involved in the fine discrimination of texture or other moving stimuli that cause vibrations
   b. Meissner's corpuscle
      i. Most common receptor in glabrous skin (smooth, hairless)
      ii. Sensitive to vibration (low frequency, 30-50 Hz)
   c. Ruffini's ending-not well understood
   d. Mercel's disks
      i. Light pressure and tactile discrimination
   e. Hair follicle receptor

2. Nociceptors
   a. Free, unmyelinated nerve endings
   b. Signal that body tissue is being damaged
   c. In most tissues, not brain
   d. Types of damage detected
      i. Mechanical--strong pressure (sharp objects)
      ii. Thermal (different from temperature)--active when tissues begin to be destroyed
      iii. Chemical--environmental agents or those from tissues itself--pH, histamine, etc.
3. Thermoreceptors
   a. Brain temperature is tightly regulated
      i. Close to 37°C
      ii. Brain function changes above and below that temperature
   b. Specialized receptors in our skin that can perceive changes in temperature as small as 0.01°C.
   c. Two types:
      i. Warm--begin firing at 30°C up to 45°C (above causes damage and pain)
      ii. Cold--below 35°C to 10°C.

Note: Like other sensory receptors, temperature receptors adapt. They respond to sudden changes in temperature.

Experiment--three beakers of water: one cold, one hot, one lukewarm. One finger from one hand into hot; one finger from the other hand into cold. After some time period, immerse both simultaneously into the lukewarm. The finger from the hot senses the water to be cold and the finger from the cold senses the same water to be hot. Why? Adaptation--the hot and cold receptors adapted (stopped firing). When immersed in lukewarm, only the unadapted receptors were available. You need both to sense lukewarm, etc.

4. Proprioceptors
   a. Body position
      i. Where the body is
      ii. Direction of movement
      iii. Speed of movement
   b. Receptors in the skeletal muscles (more in movement lecture)
   c. Two different mechanosensitive proprioceptors:
      i. Muscle spindles-consist of specialized intrafusal muscle fibers distributed among ordinary (extrafusal) muscle fibers; detect changes in muscle length
ii. Golgi tendon organs-distributed among collagen fibers in tendons and detects changes in muscle tension

III. Organization of Somatic Sensory Information

A. Structure of spinal cord (see Neuroanatomy Lecture)

B. Spinal segments
1. 30 spinal segments consisting of paired dorsal and ventral roots
2. Spinal segments are divided into 4 groups: cervical, thoracic, lumbar, sacral
3. Each segment is named after the vertebra from which the nerves
   a. Cervical: C1 - C8
   b. Thoracic: T1 - T12
   c. Lumbar: L1 - L5
   d. Sacral: S1 - S5
1. Segmental organization of the spinal nerves and sensory innervation of skin are related.
2. Area of skin innervated by the dorsal roots of a single spinal segment is a dermatome.
3. Characteristics:
   a. Overlap between the dermatomes
   b. Cervical dermatomes
      i. Above the sternum
   c. Thoracic dermatomes
      i. Top of sternum to waist
   d. Lumbar dermatomes
      i. Front of legs and stomach
   e. Sacral dermatomes
      i. Back of legs and genitals
IV. Somatosensory Cortex

A. Anatomy
1. Parietal lobe
   a. Post-central gyrus
      i. Most complex processing occurs in the cortex

B. Somatotopy

1. Mapping of the body's surface sensations onto a brain structure
2. Features of the map:
   a. Not continuous
   b. Not scaled to the human body
   c. Relative size of the cortex devoted to each body part is correlated with the density of sensory input (i.e., lips versus the skin on your calf).
   d. Size is related to the importance of the sensory input (i.e., finger tip versus elbow)

C. Posterior parietal lobe
1. Primary somatosensory cortex receives simple segregated streams of sensory information
2. Integration takes place in the posterior parietal cortex
V. Pain and Its Control

A. Nociception
1. Sensory process that provides signals that trigger pain

B. Characteristics
1. Pain is influenced cognitively
2. Hyperalgesia
   a. Tissue already damaged is much more sensitive to pain
      i. Nociceptors are sensitized by various substances released by damaged tissue
         (prostaglandins, histamines, etc.)

C. Regulation of pain
1. Pain can be modified by non-painful sensory input (i.e., rub the skin around a bruise)
   a. Gate Theory of Pain-circuit in spinal cord dorsal root
2. Several brain regions can act to suppress pain
   a. PAG (periaqueductal gray matter) project to the raphe (serotonin) that sends axons to the spinal cord (5-HT is inhibitory, block synaptic activity)
3. Brain chemicals
   a. Endorphins
      i. Share many opioid properties and bind to opioid receptors in the brain
      ii. Opioid receptors are throughout the body, but especially in the brain and particularly in brain areas that process and modulate nociceptive information (PA, raphe, and spinal cord)