Neuro 80 Lecture 15

October 28, 2019

Receptive Field for visual

- spatial (center-surround)
- orientation
- motion
- color

Rapidly adapting receptors will be useful to signal

Why are some somatosensory signals transmitted more rapidly than others?

- myelin (functionally)
- reflexes

Somatotopic organization analogous to retinotopic organization

Olfactory transduction in mammalian odor receptor cell involves

GPCRs

↑ concentration of odors will:

- activate a given odor receptor neuron more strongly
- Activate additional odor receptor neurons

MCB/Neuro 80 - Neurobiology of Behavior

Today's Topic:

Other Senses

Lecture 15

Optional reading: Purves et al., Neuroscience 6th pages 193-200, 206-208, 214,217, 323-325,330-342

Lecture notes, review questions, office hour times available at:

https://canvas.harvard.edu/courses/59120


Climbing Mt. Potential
(in practice)
Response
Sensory/motor diseases
Upper Motor
Spinal Circuits
Neuronal processing
Cognition
Structural changes and aging
Long term synaptic plasticity
Memory systems
Stimulus (sensing information)
Information Coding
Other Senses
Visual system:
• Sensory transduction
• Visual circuits
• Cortical visual processing

What are the different senses?

Vision

Audition — any mechanical compression wave

Smell

Taste

Somatosensation (including visceral sense)

Unusual senses

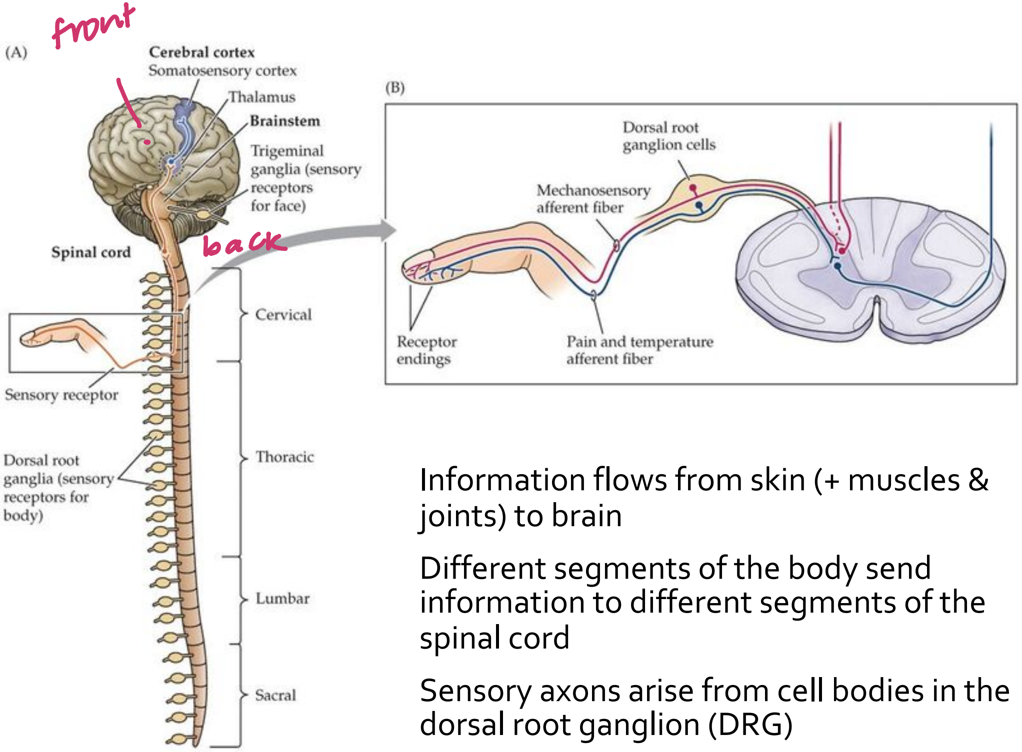
Magnetic sense, e.g. bees (controversial)

Electric sense – e.g. sharks

Echolocation – e.g. bats

Infrared (heat) – e.g. pit vipers

Somatosensation



NEUROSCIENCE 6e, Figure 9.1

Information flows from skin (+ muscles & joints) to brain

Different segments of the body send information to different segments of the spinal cord

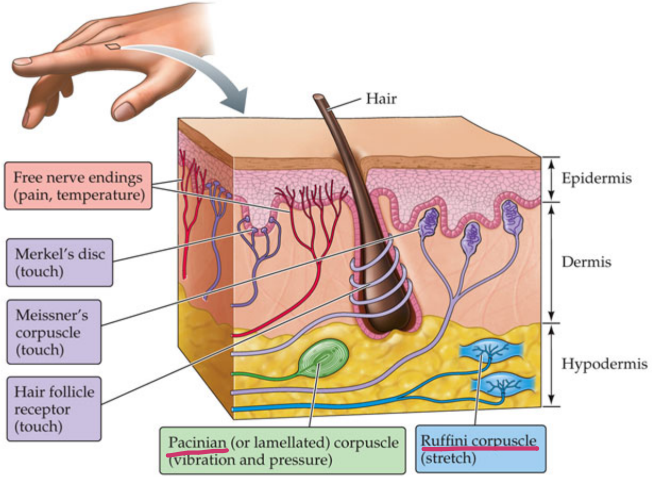
Sensory axons arise from cell bodies in the dorsal root ganglion (DRG)

Touch sensation

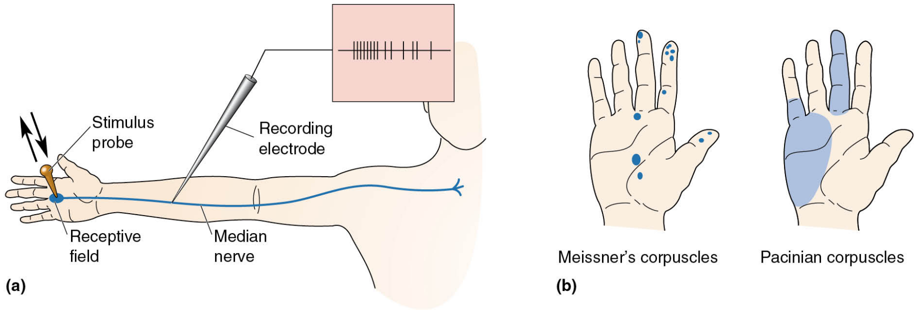
- Layers of skin
  - Epidermis (outer)
  - Dermis (inner)

- Functions of skin
  - Protects
  - Prevents evaporation of body fluids
  - Provides direct contact with the world

- Mechanoreceptors
  - Most somatosensory receptors are mechanoreceptors.

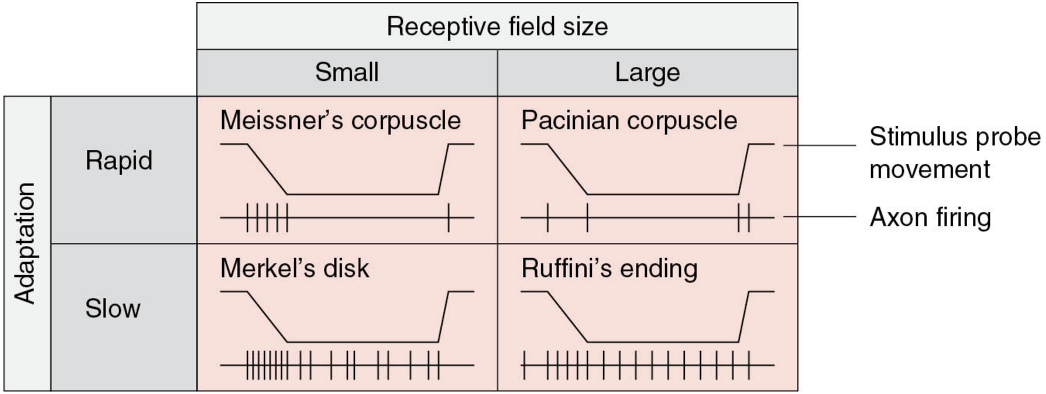


Receptive fields and adaptation



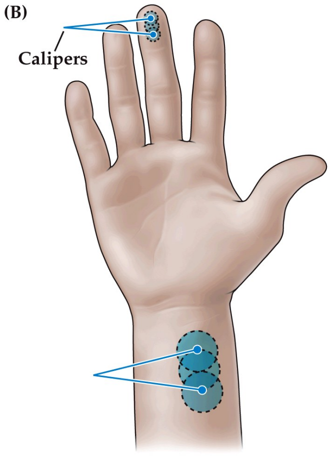
- Stimulate skin (touch, stroke, apply pressure etc)
- Record spikes (action potentials) from sensory nerve
- See how the spikes change in relation to where you stimulate
- Meissner's corpuscles have small "receptive fields"– i.e., a single Meissner's corpuscle respond to stimulus in a very specific region
- Pacinian corpuscles respond to stimuli in a broad region

Receptive fields and adaptation



- Responses to steady stimulation are not always steady over time – they adapt
- Merkel's disk and Ruffini's ending adapt slowly
- Meissner's and Pacinian corpuscles adapt rapidly

Different receptors signal differently



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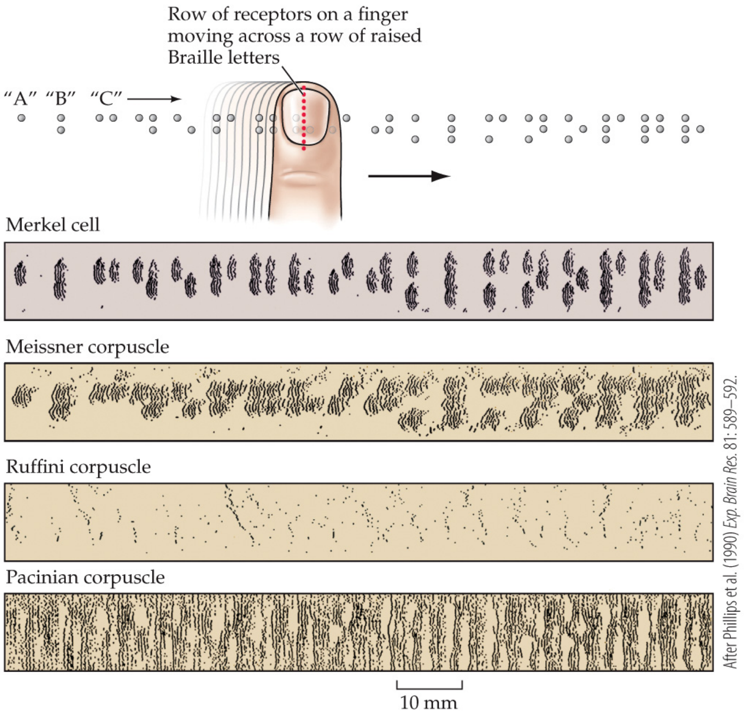

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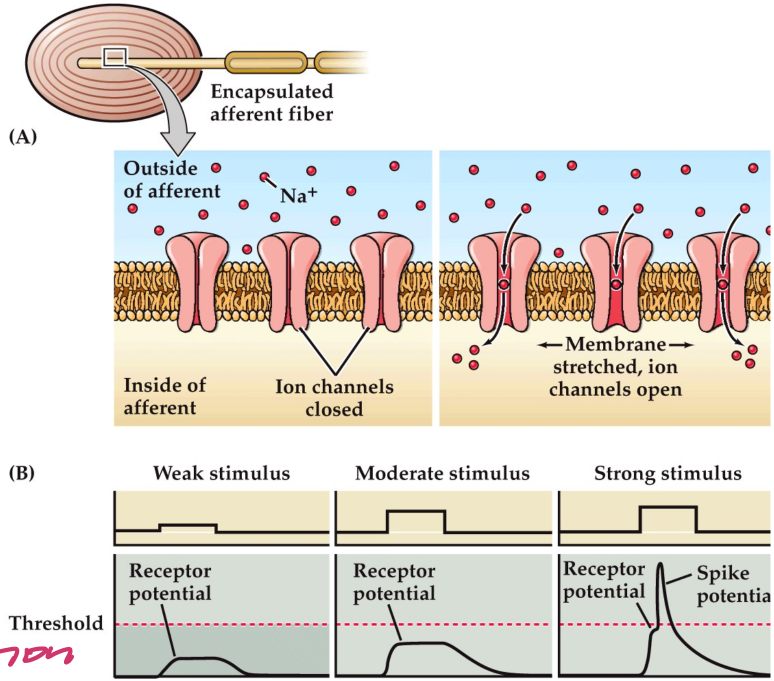
- Only Merkel disks transmit high-fidelity signals about Braille patterns

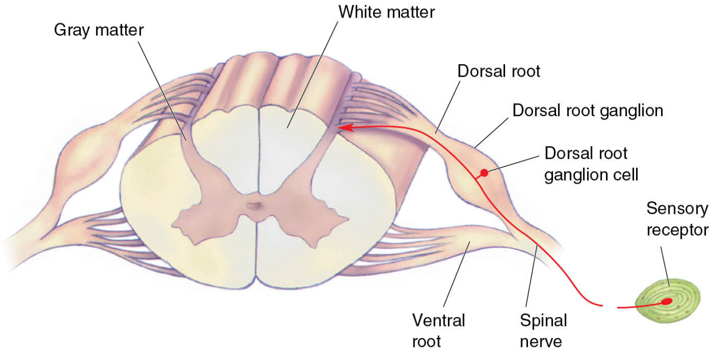
Mechanosensory signal transduction

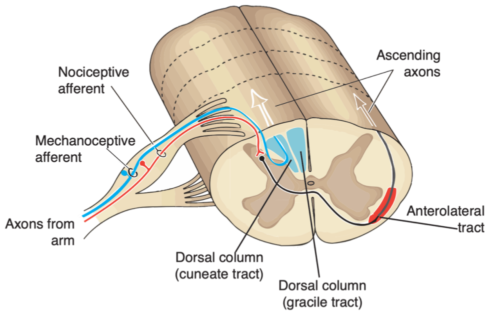
- Mechanical stimuli (touch, pressure etc) are transduced by nerve endings (afferent fiber)
- Stretch sensitive cation channels open to cause depolarization (receptor potential)
- If stimulus is strong enough to create a large receptor potential, spikes are generated
- Stronger the stimulus, the greater the number of spikes



20-30 mV of depolarization necessary

Primary afferent axons

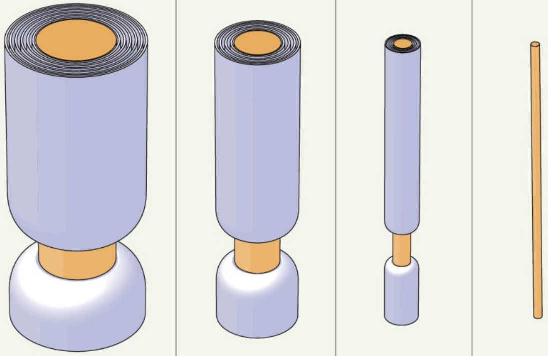




- Different types of receptors have different types of axons: Aα, Aβ, Aδ, C axons
- C fibers mediate pain, temperature, and itch. These synapse on neurons in the spinal cord, which cross to the other side and go up to the brain
- Aβ mediates touch sensations. These go up the spinal cord ipsilaterally (on the same side)
- Aα axons arise from muscle proprioceptors (recall the stretch reflex!)

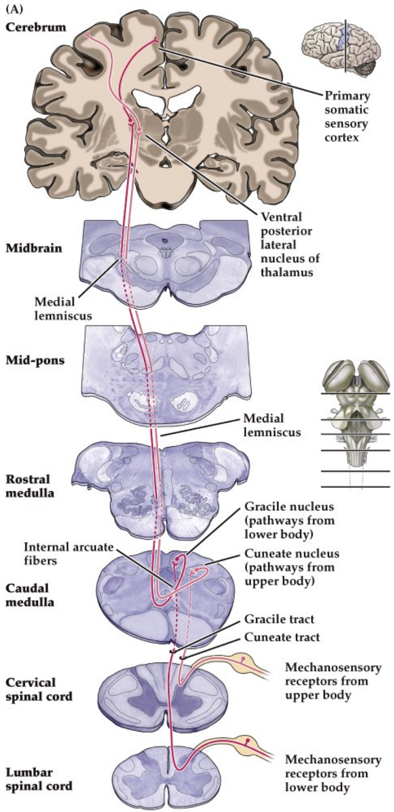
Size of primary afferent axons varies widely

Axons from skin	Aα	Aβ	Aδ	C
Axons from muscles	Group I	II	III	IV
Diameter (μm)	13–20	6–12	1–5	0.2–1.5
Speed (m/sec)	80–120	35–75	5–30	0.5–2
Sensory receptors	Proprioceptors of skeletal muscle	Mechanoreceptors of skin	Pain, temperature	Temperature, pain, itch



Main mechanosensitive pathway to the brain

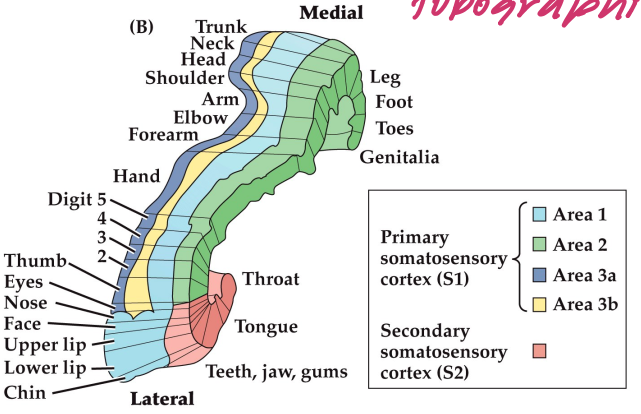
- Touch and proprioception



Somatosensory areas of cortex

- S1 = area 3b
- Adjacent areas
  - Postcentral gyrus: 3a, 1, 2,
  - Posterior parietal cortex: areas 5, 7

somatosensory topographic map



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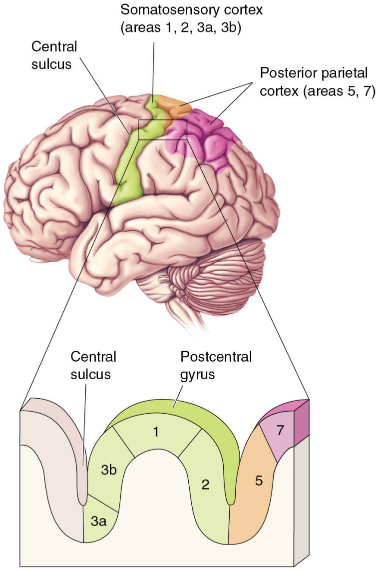
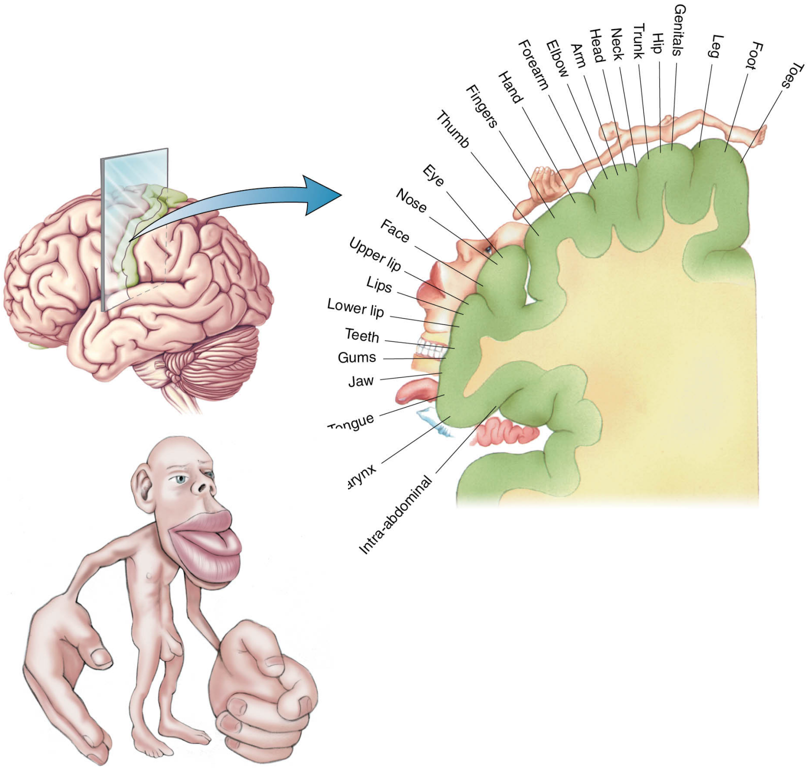


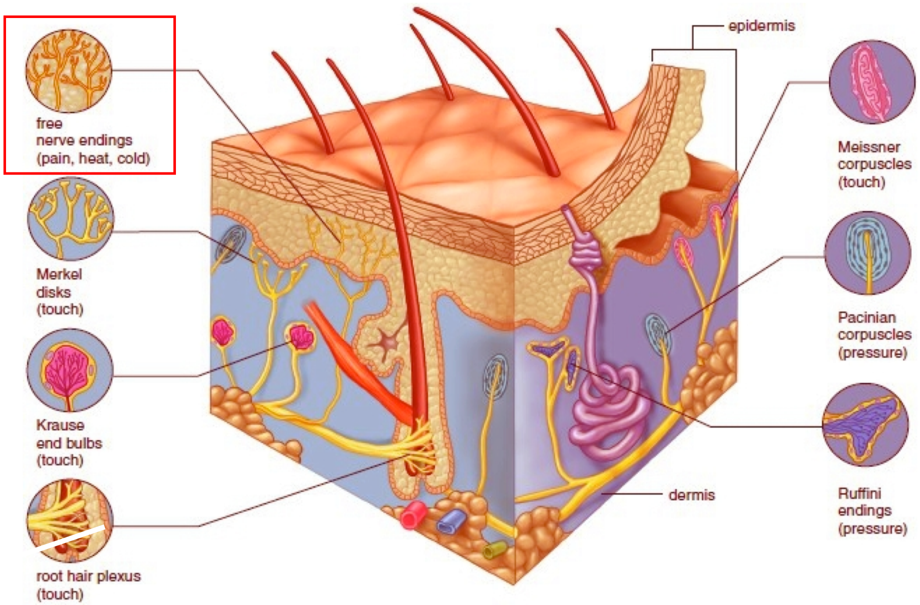
Somatotopic organization in human: homunculus



- There is a smooth progression in the cortex of the receptive fields of neurons – that is, neurons that respond to touch of neighboring regions are next to each other
- Neuronal territory dedicated to different parts of the body varies smoothly - this is called a topographic organization
- Compare this with the visual system

Pain & temperature are sensed by free nerve endings

- Free nerve endings in the epidermis
- Sense pain, heat and cold



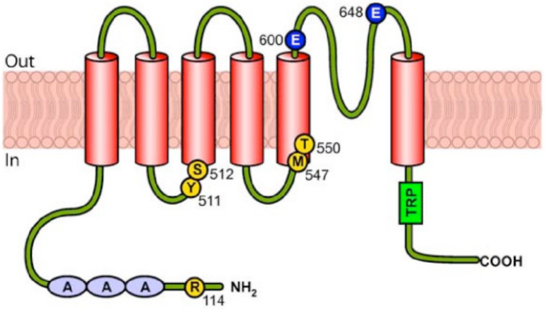
Pain

- Nociceptors

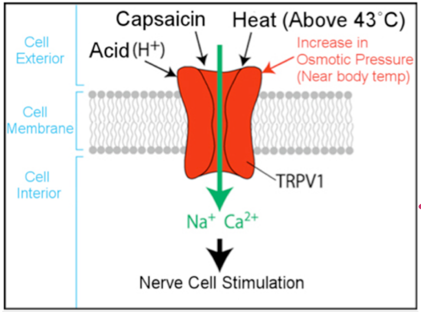
- Pain and nociception
  - Pain—feeling of sore, aching, throbbing sensations
  - Nociception—sensory process, provides signals that trigger pain

- Nociceptors: transduction of pain
  - Ion channels opened by:
    - Strong mechanical stimulation, temperature extremes, oxygen deprivation, chemicals
    - Substances released by damaged cells
      - Proteases (-> bradykinin), ATP, K^+ ion channels
      - Histamine

Noxious temperature sensation through Trpv1 channels

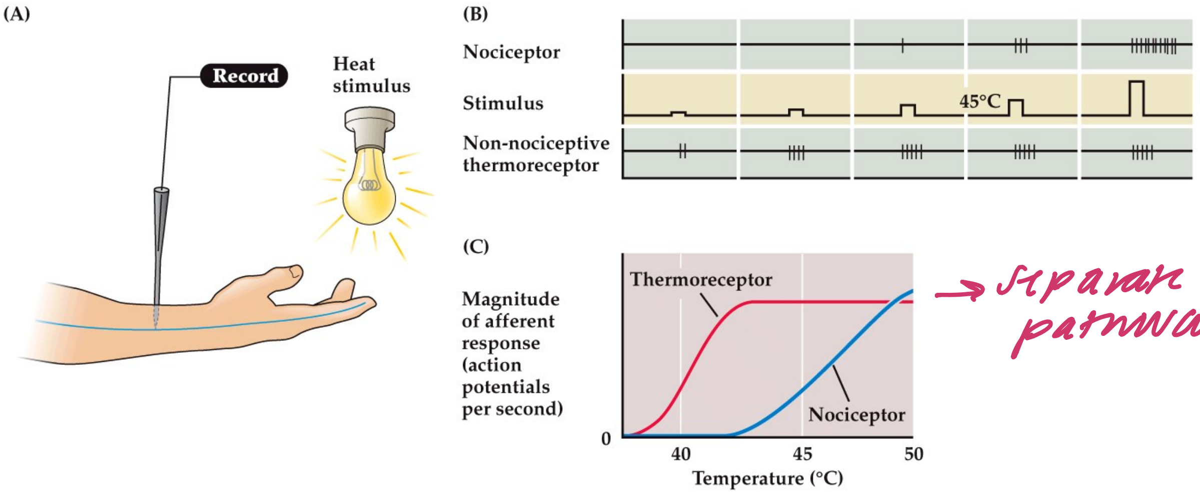


- Trp channels make up a big family of proteins and are involved in many aspects of signaling
- TrpV1 sense heat, acidity (pH) and capsaicin
- The amount of current through the channels increases with increasing temperature, H+ ions or presence of capsaicin



menthol closes this channel

Pain & temperature transmission involve dedicated neurons



→ separate pathways

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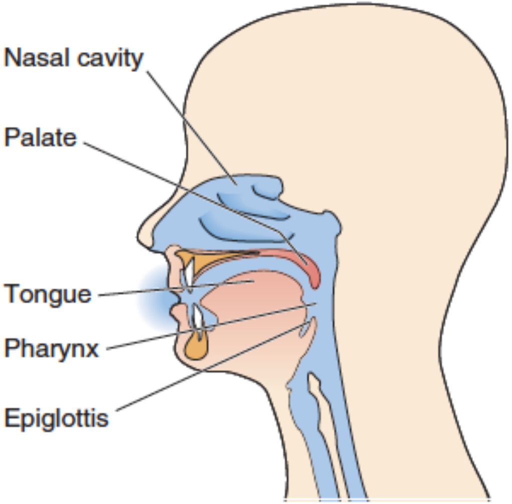
Smell and Taste

Chemical sensing in your nose and mouth



- Chemicals in the air are sensed by the nose, when you breathe in
- Chemicals in food are sensed by your tongue
- Chemicals in food you chew are also sensed by the nose through the "retronasal" path

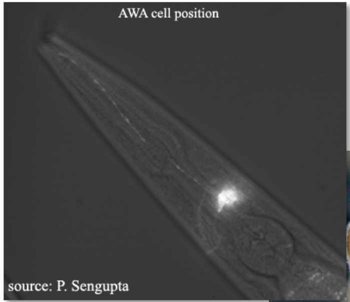
Chemical senses are important

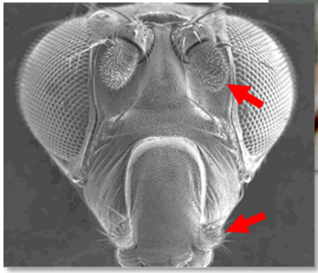
- Animals depend on the chemical senses to identify food, poison, predators, or potential mate.

- Chemical sensation is evolutionarily ancient & common

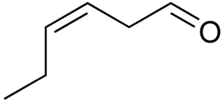
- Chemical senses
  - Olfaction
  - [Pheromone sensation]
  - Gustation

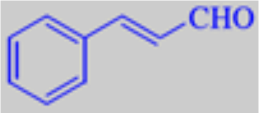
Sensory transduction begins in the “nose”

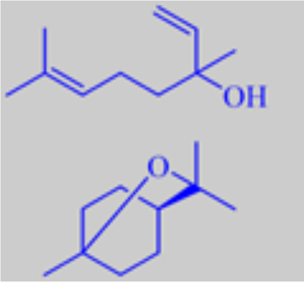


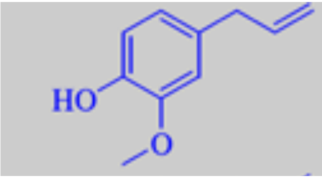


Smells and chemicals



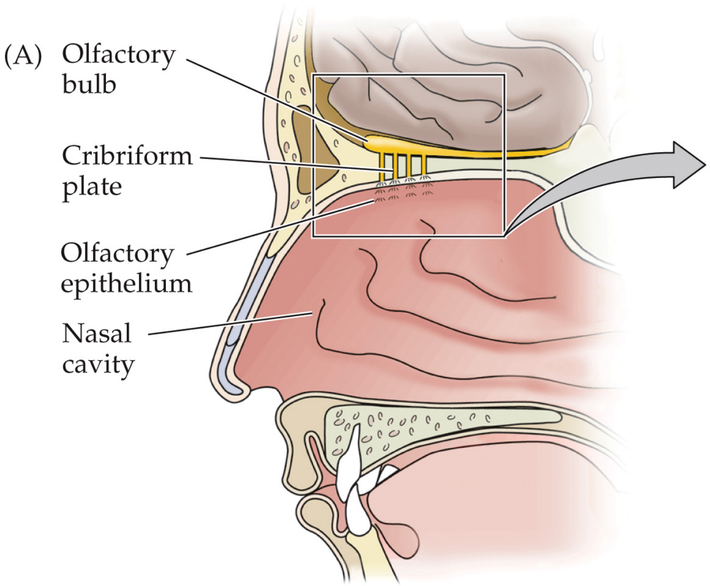






http://www.bojensen.net

The organs of smell



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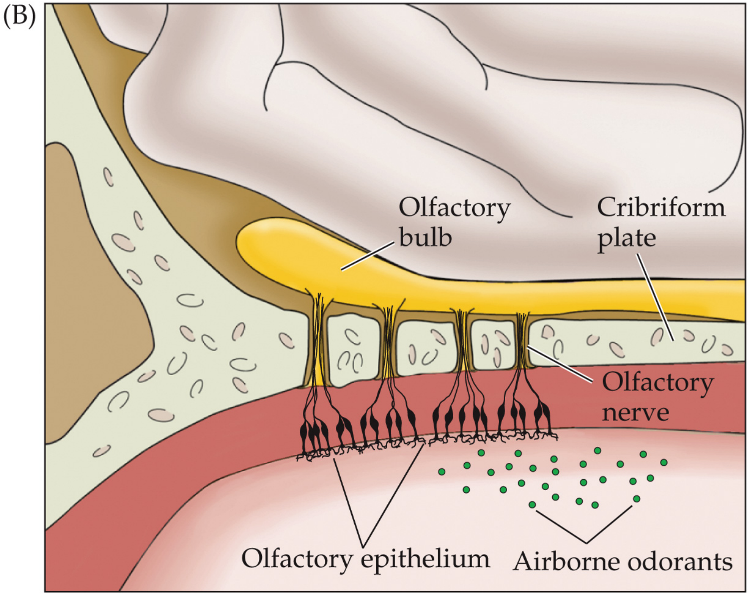
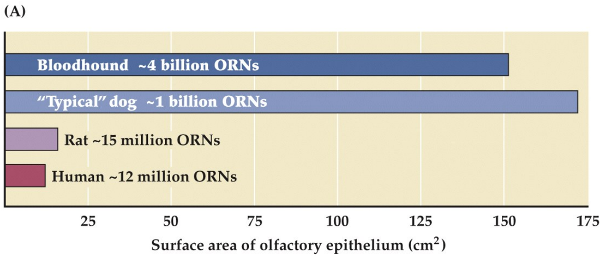


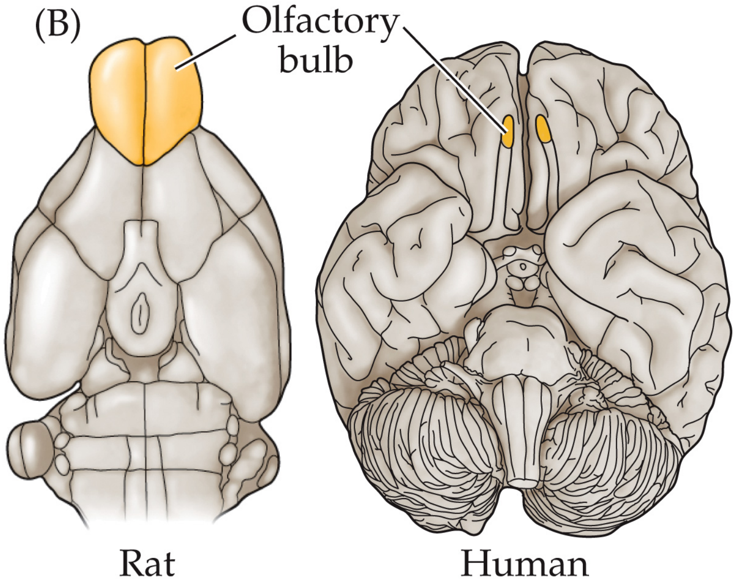
NEUROSCIENCE 6e, Figure 15.1 (Part 2)

The organs of smell – different relative sizes!

- The relative size of the olfactory system varies in animals – less fractional territory devoted to olfaction in humans

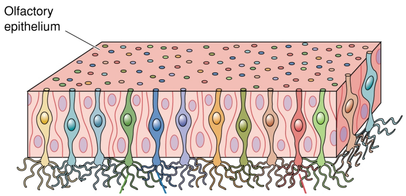
- The number of olfactory receptor neurons (ORNs) varies





NEUROSCIENCE 6e, Figure 15.2 (Part 2)

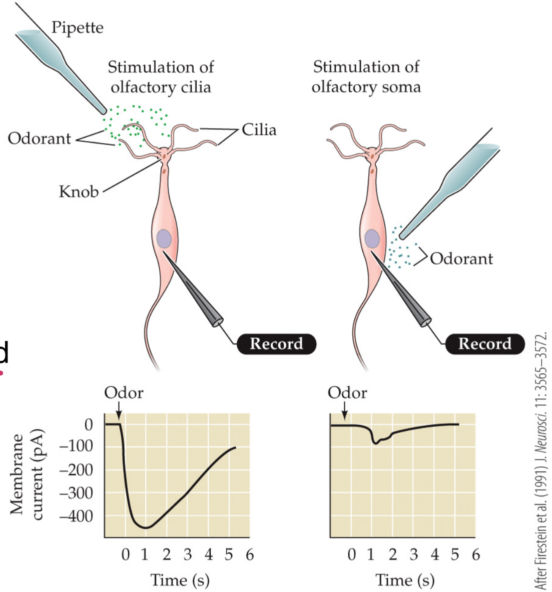
Olfactory receptor neurons are activated by odors



Odors (chemicals) activate ORNs

Odorant receptors are concentrated in the cilia

Vertebrate odorant receptors are mainly GPCRs



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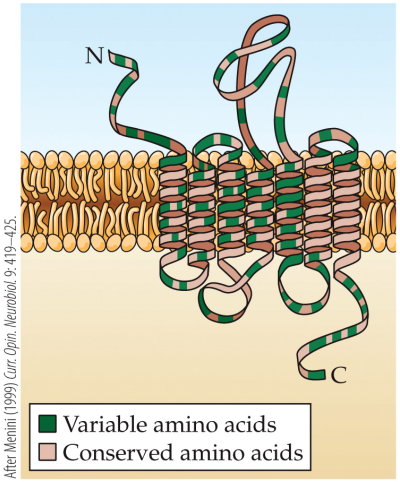
Odorant receptors are in the cilia



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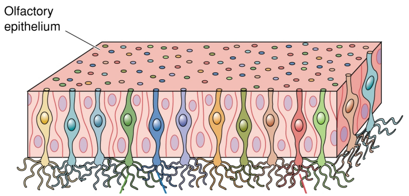
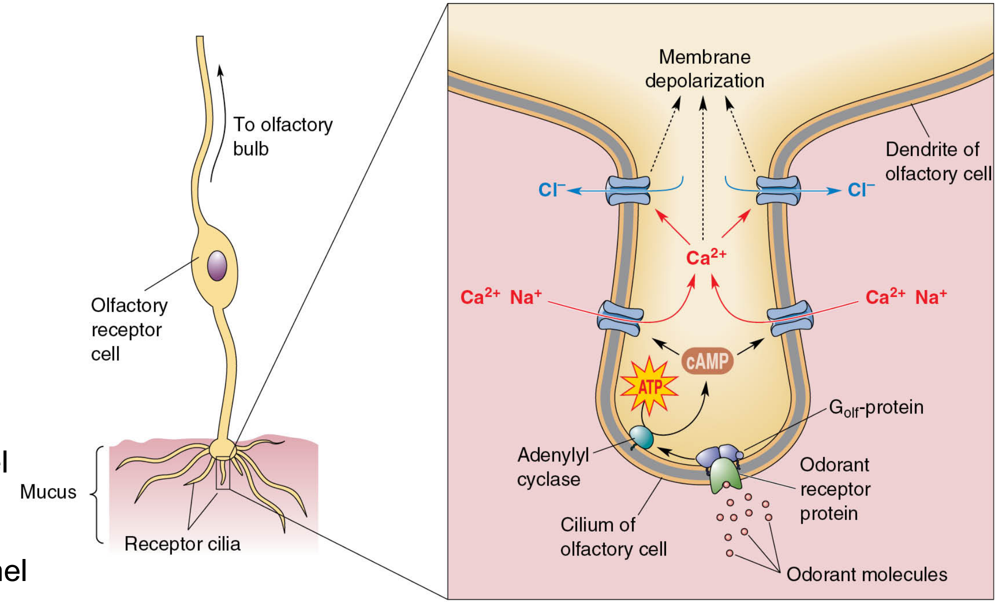
Transduction mechanism of vertebrate olfactory receptor cells



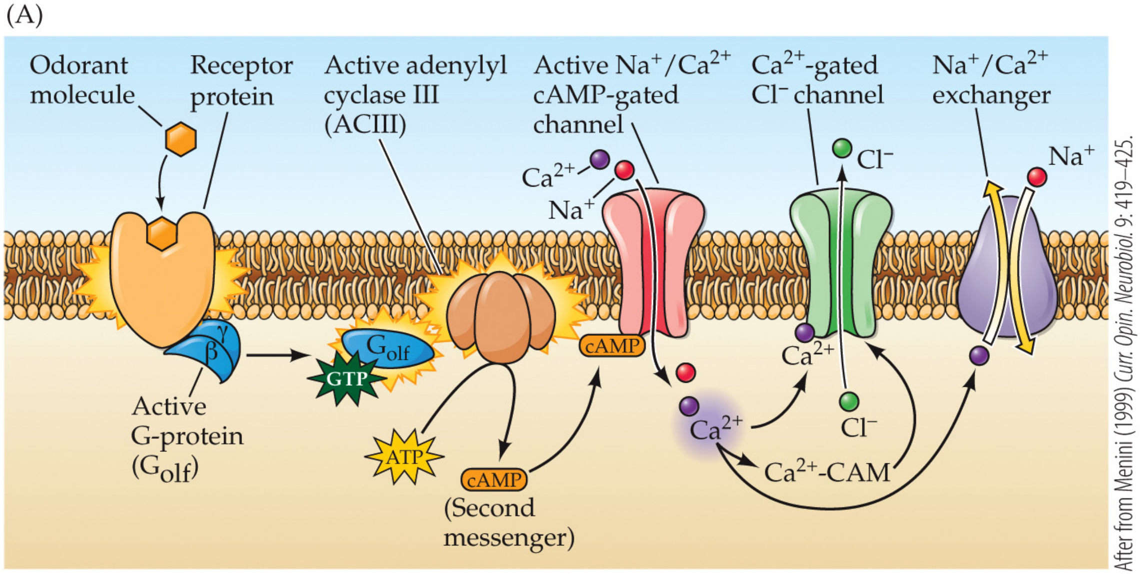
Transduction pathway:

GPCR binds to ligand
G-protein activated
Adenylyl cyclase activated
cAMP produced
cAMP opens cation channel
Membrane depolarizes

Ca entry activates Cl channel
Further depolarization



Transduction mechanism of vertebrate olfactory receptor cells



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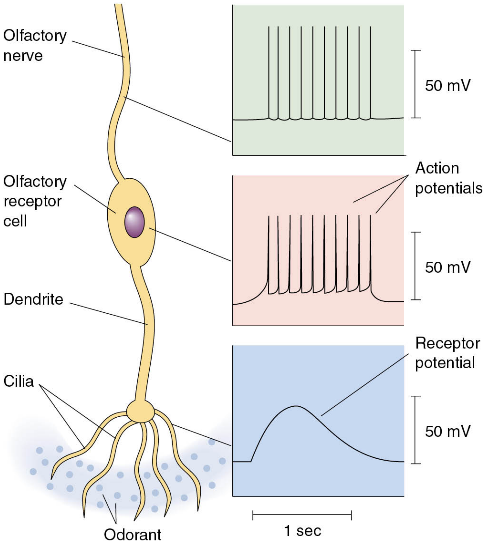
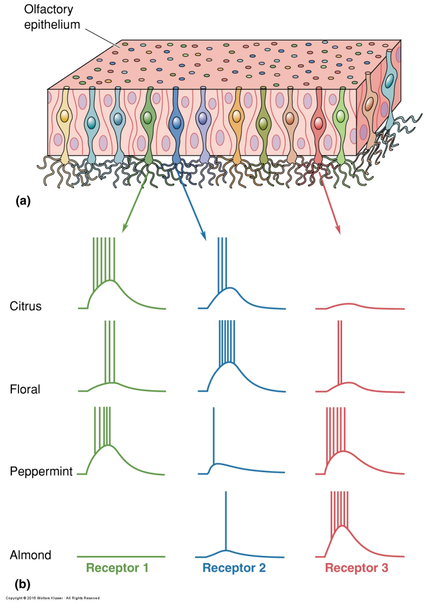
Olfactory receptor neurons are activated by different odors

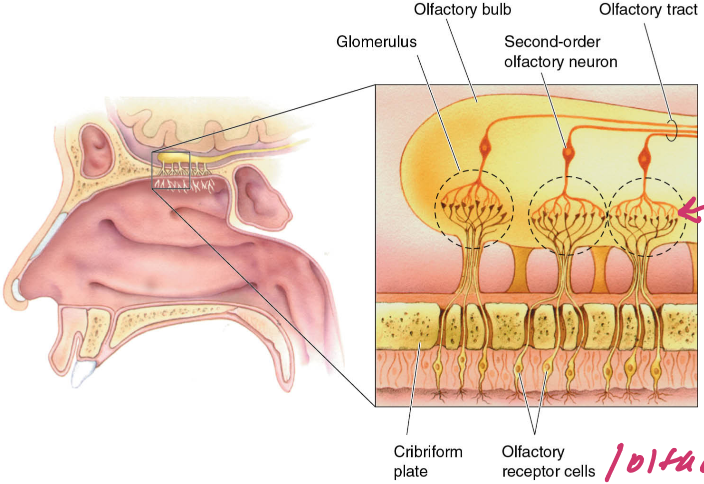


Odor Receptors have varying degrees of selectivity – many broadly tuned

Odors are encoded by the combined activity of multiple ORNs



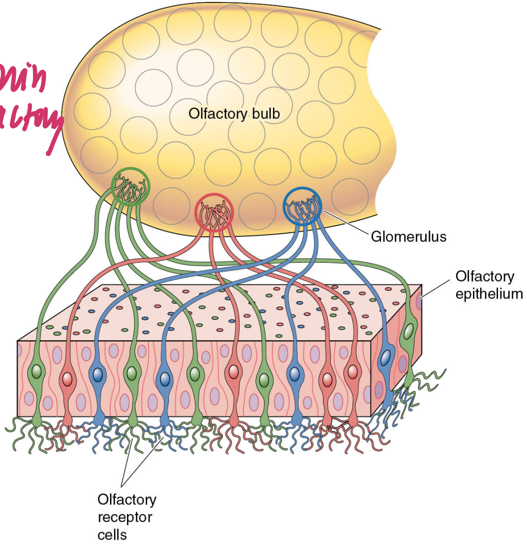
Location and structure of olfactory bulb



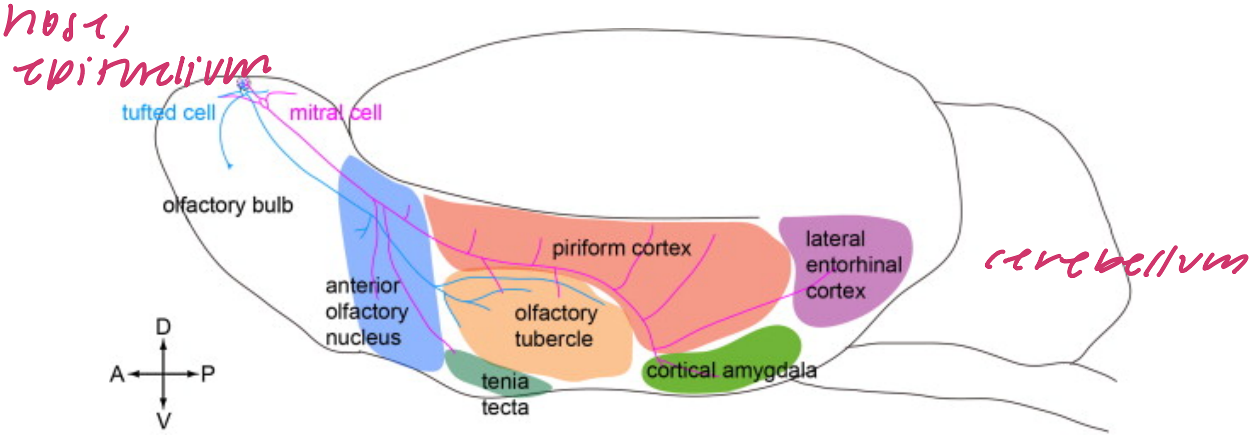
mitral/tufted cells

within olfactory bulb

/olfactory sensory neurons



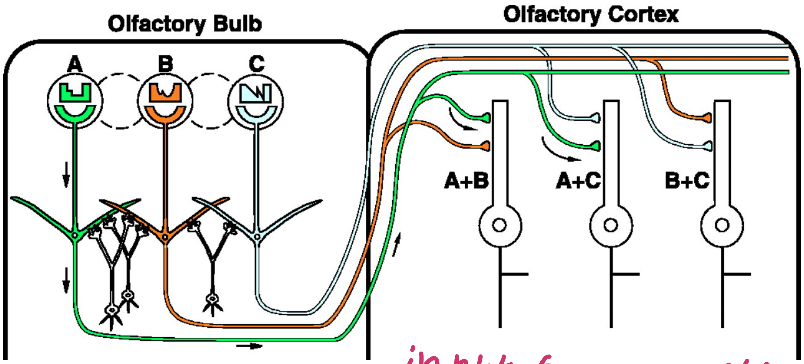
Direct projections from olfactory bulb to cortex



skips thalamic relay

- Olfactory bulb projects to many brain regions, without an intervening thalamic station (unlike other sensory modalities)
- Output from mitral (and tufted) cells from a single glomerulus spreads widely in higher brain regions
- No known "topography" – that is, point to point projections and neighborhood relations (very scattered)

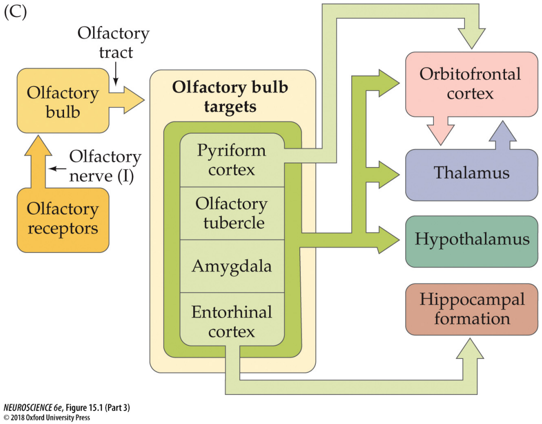
Information integration in olfactory cortex

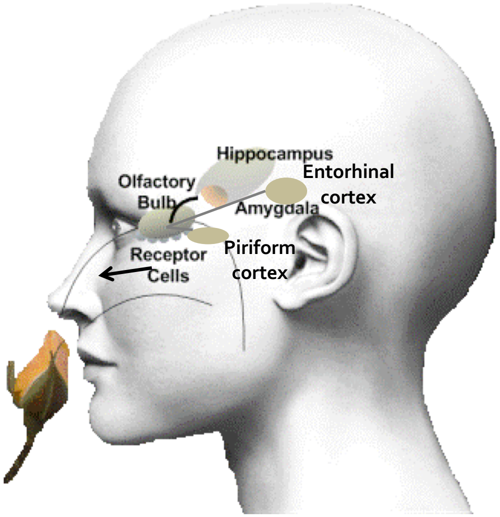


input from multiple glomeruli

- Output from mitral cells from a single glomerulus spreads widely in cortex
- Each cortical pyramidal cells integrates information from many glomeruli
- Odor information is, therefore, integrated in the olfactory cortex

Olfaction processing has relatively few relay stations





Olfactory pathways reach cortex and higher brain areas without a thalamic relay

(No need to memorize all these brain areas)

Learning Objectives

- Describe the somatosensory system and the types of stimuli it is responsive to.
- Explain the difference between rapidly adapting and slowly receptors and what type of information would best be transmitted by each.
- Compare somatotopy to retinotopy in the primary sensory cortices, including any distortion in the maps.
- Understand steps in olfactory transduction.
- Diagram the olfactory system from sensory cells to the brain.
- Identify the type of receptors that are found on olfactory sensory cells and describe the signal cascade that sends information to the olfactory bulb.
- Olfactory cortex has distributed representation, but lacks a topographic map.

Lecture 15 – Other Senses

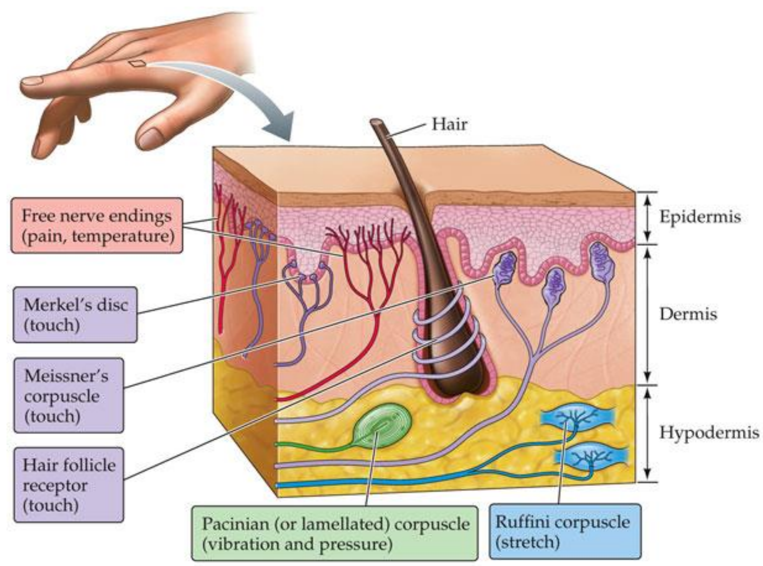
Pre-class notes for October 28, 2019

Reading: *Neuroscience ed. 6* by Purves et al., pages 193-200, 206-208, 214, 217, 323-325, 330-342

5 major senses (with some additional unusual ones in some animals)**:** vision, hearing, somatosensation, smell and taste. We will look into somatosensation and smell.

Somatosensory system - the collected parts of the nervous system that provide bodily sensation: touch, proprioception (the sense of body position and movement), thermosensation (the detection of temperature), pain, etc. and thus responds to a diverse set of stimuli.

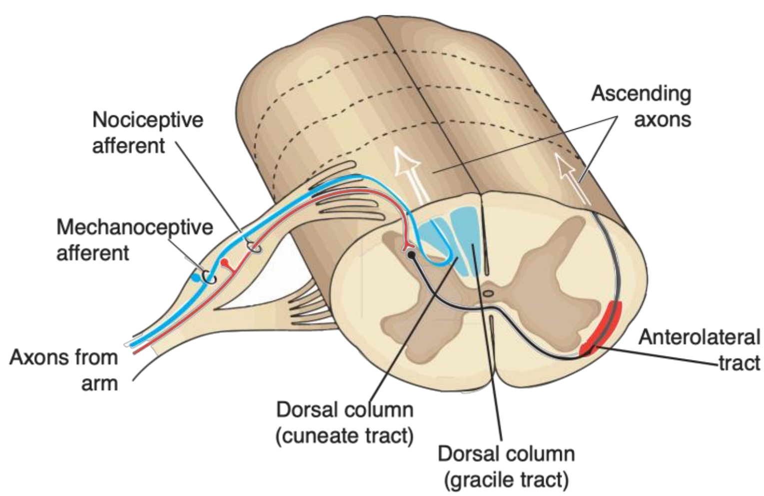
Dorsal root ganglion cell - cell bodies of all somatic sensory neurons are located in the dorsal root ganglion (DRG) (except for the cell bodies of sensory neurons for the face which are loaded in the trigeminal ganglia near the brain stem). Each dorsal root ganglion cell has two processes: the sensory axon that collects information from the skin or muscle fibers and a central axon that transmits the information to the spinal cord and brain stem.



Somatosensory receptive fields - the area of the skin surface over which stimulation results in a significant change in the rate of action potentials. Depends on type and density of receptors.

Mechanoreceptors - receptors that transduce mechanical forces into electrical signals. Responsible for proprioception, touch and a subset of pain sensations.

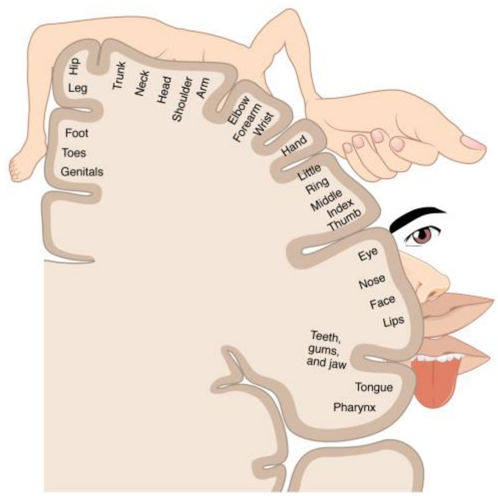
Ascending somatosensory pathway - after the main axons of the dorsal root ganglion cells enter the spinal cord they must travel up to the brain along the white matter tracts in the spinal cord. Mechanoreceptive and proprioceptive fibers enter the spinal cord and travel up in the ipsilateral dorsal column, until the medulla of the brain stem where the axon synapses with another neuron, which sends its axon across to the contralateral thalamus (and then another neuron connects to primary somatosensory cortex). Within the dorsal column, the axons from the



lower limb are located in the medial portion (gracile tract) while axons from the upper limb are found in the cuneate tract.

Parallel pain pathway - like the mechanosensitive and proprioceptive fibers, nociceptive and thermoreceptive fiber must also send their information up the spinal cord to the brain. However, instead of traveling up the ipsilateral dorsal column, pain/temperature afferents synapse immediately and then cross the midline once they enter the spinal cord before running up the spinal cord on the contralateral anterolateral spinal tract.

Primary somatosensory cortex (S1) - area of the cerebral cortex located just caudal to the central sulcus that receives somatosensory information from the the thalmus. Consistent with other sensory areas, layer 4 receives direct synaptic input from the thalamus (ventral posterior complex, the somatosensory area). Additionally, neurons within S1 are organized into a map where adjacent areas of the body are represented in adjacent areas of cortex, which is termed ***somatotopy***.



Homunculus - somatotopic maps do not represent the proportions of the body accurately, rather more cortical space is dedicated to the hands and face in humans. In rodents, extra cortical space is dedicated to each individual whisker in an area known as *barrel cortex*.

Olfaction:

Odorants - molecules that elicit olfactory perception, usually airborne and volatile.

Nasal epithelium - lining of the nasal passage that contains the olfactory sensory neuron cell bodies and cilia. Nasal epithelium is coated with mucosa which not only helps warm the air entering the lungs, but also aids in binding of odorants to receptors.

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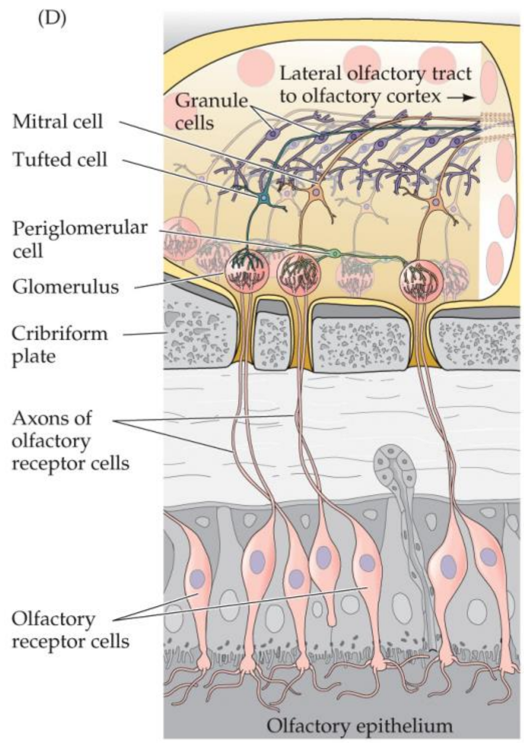

NEUROSCIENCE 6e, Figure 15.13 (Part 4)
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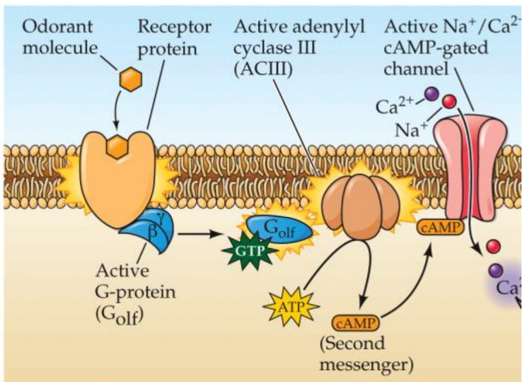
Olfactory sensory neuron - bipolar neurons with cilia that extend into the nasal passage where the *olfactory receptors* located on the cilia can interact with odorants in the nasal passage. Olfactory sensory neurons send their axons through a portion of the skull (the *Cribriform plate)* and onto the olfactory bulb. Each olfactory sensory neuron expresses only one type of olfactory receptor.

Olfactory receptor - member of a family of G-protein coupled receptors that is activated by odorants. There are many different genes for olfactory receptors (~1400 in rodents, ~800 in humans). Each type of olfactory receptor is activated by a subset of odorants. Some receptor only respond to a couple of identified odorants (narrowly tuned), others are activated by more odorants (broadly tuned).

Olfactory transduction pathway - binding of an odorant molecule to a olfactory receptor activates a G-protein (G_{olf}) that in turn activates adenylate cyclase. Adenylate cyclase increases the concentration of cAMP which in turn activates a cAMP-gated cation channel and depolarizes the neuron.

Olfactory nerve - bundle of unmyelinated axons of olfactory receptor neurons that sends olfactory information (action potentials) from the nasal epithelium, through the cribriform plate, to the olfactory bulb.



Olfactory bulb - target of the olfactory sensory neuron axons and since there is no olfactory thalamic region, it is the first processing center of the vertebrate brain.

Glomerulus - ball like structure in the olfactory bulb where olfactory sensory neurons synapse with the target cells. Each glomerulus receives axons from olfactory sensory neurons that express the same, single olfactory receptor.

Mitral/tufted cell - excitatory output neurons of the olfactory bulb. Each mitral or tufted cell send their apical dendrite to a single glomerulus.

Population coding of odorants - despite there being ~1000 different olfactory receptor genes, there are more possible odorants in the environment. Odorants are represented by combinatorial activation of olfactory receptor neurons/glomeruli, in a manner that is similar to color vision, but using hundreds of parallel channels.

Piriform cortex - area of cortex that responds to olfaction information and a target of mitral and tufted cell axons.

Learning Objectives: (By the end of Lecture 15 you should be able answer the following)

1. Describe the somatosensory system and the types of stimuli it is responsive to.
2. Explain the difference between rapidly adapting and slowly receptors and what type of information would best be transmitted by each.
3. Compare somatotopy to retinotopy in the primary sensory cortices, including any distortion in the maps.
4. Understand steps in olfactory transduction.
5. Diagram the olfactory system from sensory cells to the brain.
6. Identify the type of receptors that are found on olfactory sensory cells and describe the signal cascade that sends information to the olfactory bulb.
7. Olfactory cortex has distributed representation, but lacks a topographic map.