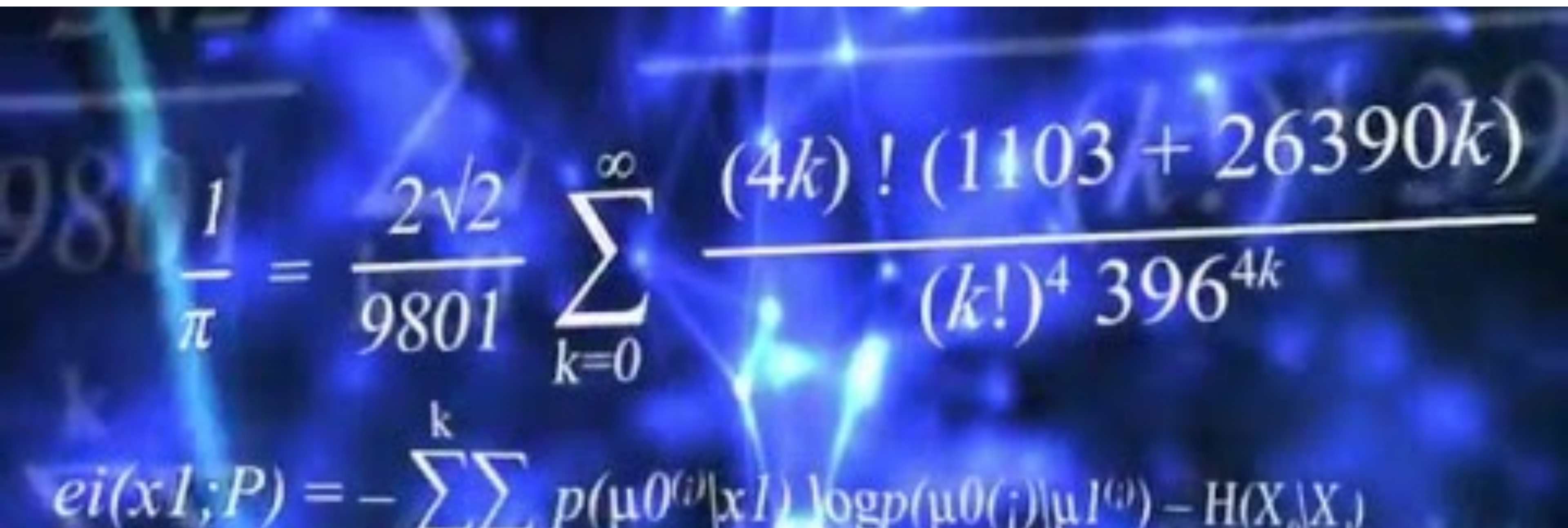
Applied Neuroscience

Columbia Science Honors Program
<u>Fall 2016</u>

Sensory Systems and Neural Circuits, Part Two

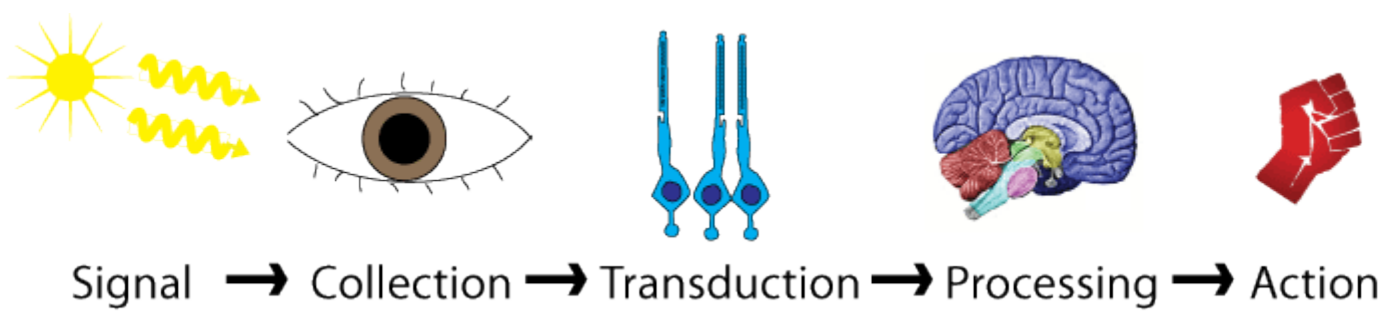


Last week's class

Sensory systems and neural circuits

1. Introduction to sensory systems
2. Visual system
3. Auditory system
4. Introduction to neural circuits

How do we take cues from our environment and make sense of the world around us?



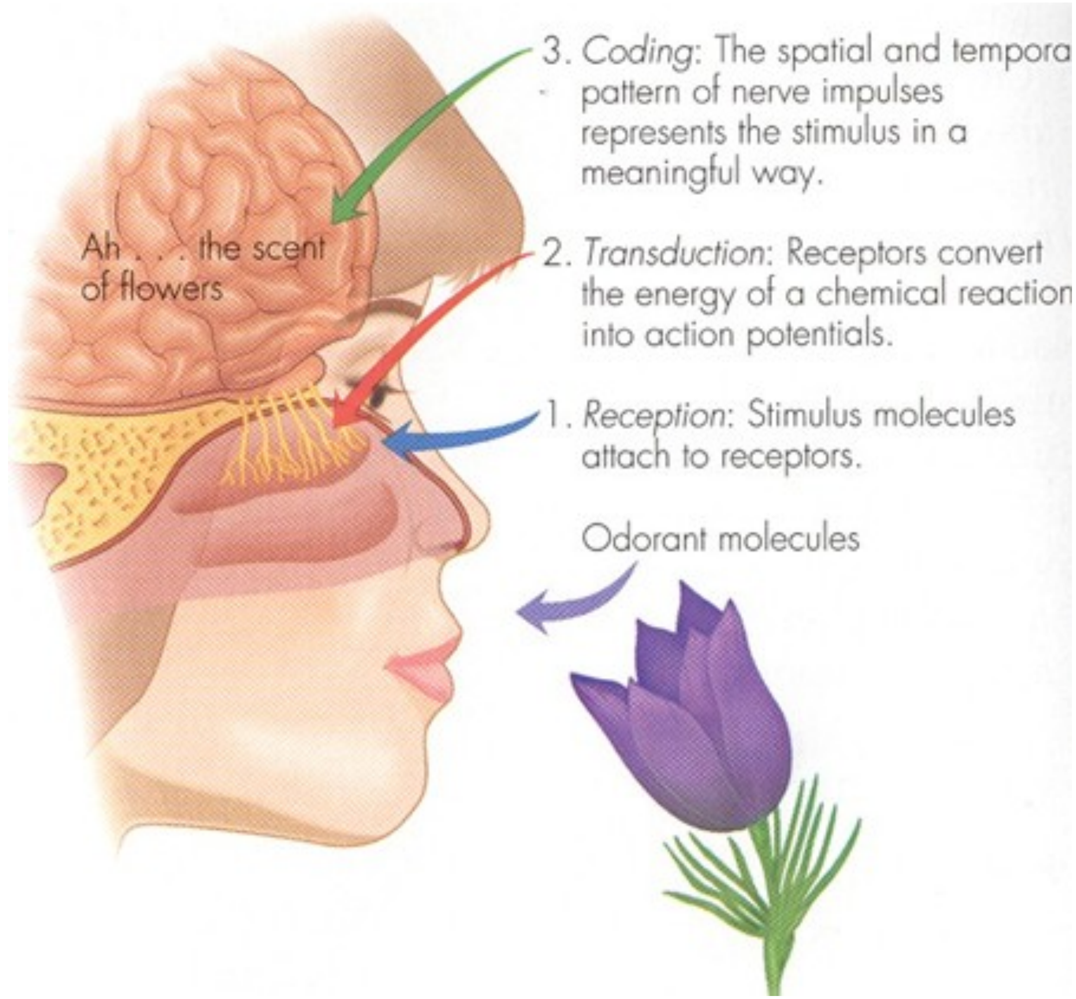
Sensory systems

How do sensory systems work?

Neurons in sensory regions of the brain respond to stimuli by firing action potentials after receiving a stimulus.

Each sensory system follows a specific plan:

1. Reception
2. Transduction
3. Coding



Today's class

Objective: Sensory Systems and Neural Circuits, Part Two

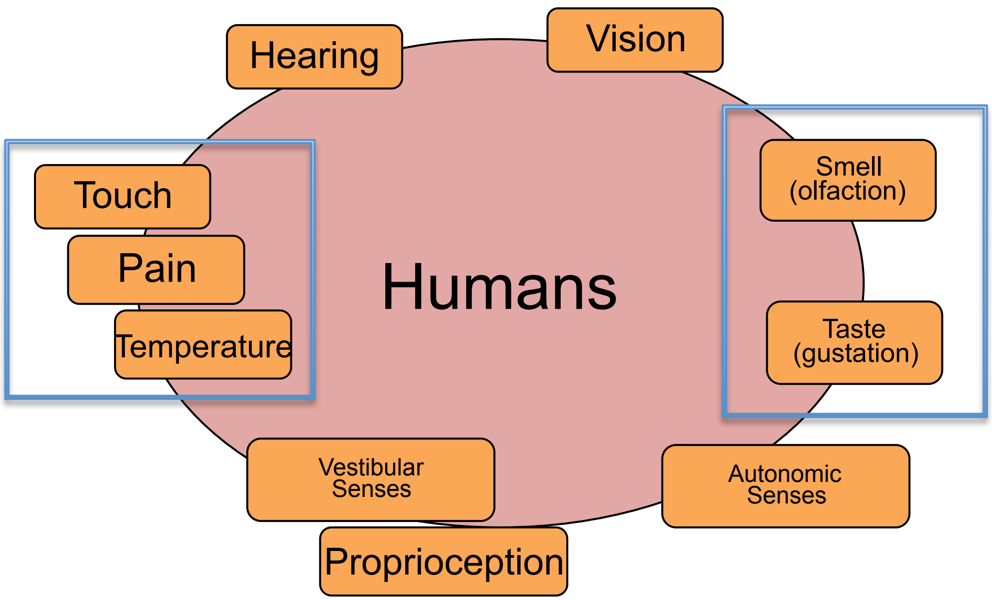
Agenda:

Sensory Systems

- Gustatory system (taste)
- Olfactory system (odor)
  - *Demo 1: Jellybean test*
- Somatosensory system (touch and pain)
- *Demo 2: Flavor tripping with 'Miracle Berries'*

Sensory systems

What are different types of senses?



Chemical senses

Sensory systems associated with the nose and mouth (olfaction and taste) detect chemicals in the environment.

Gustatory system: detects ingested, primarily water-soluble, molecules called tastants
Olfactory system: detects airborne molecules called odors

These systems rely on receptors in the nasal cavity, mouth or face that interact with the relevant molecules and generate action potentials.

Gustatory System

Objective: Understand how the gustatory system works

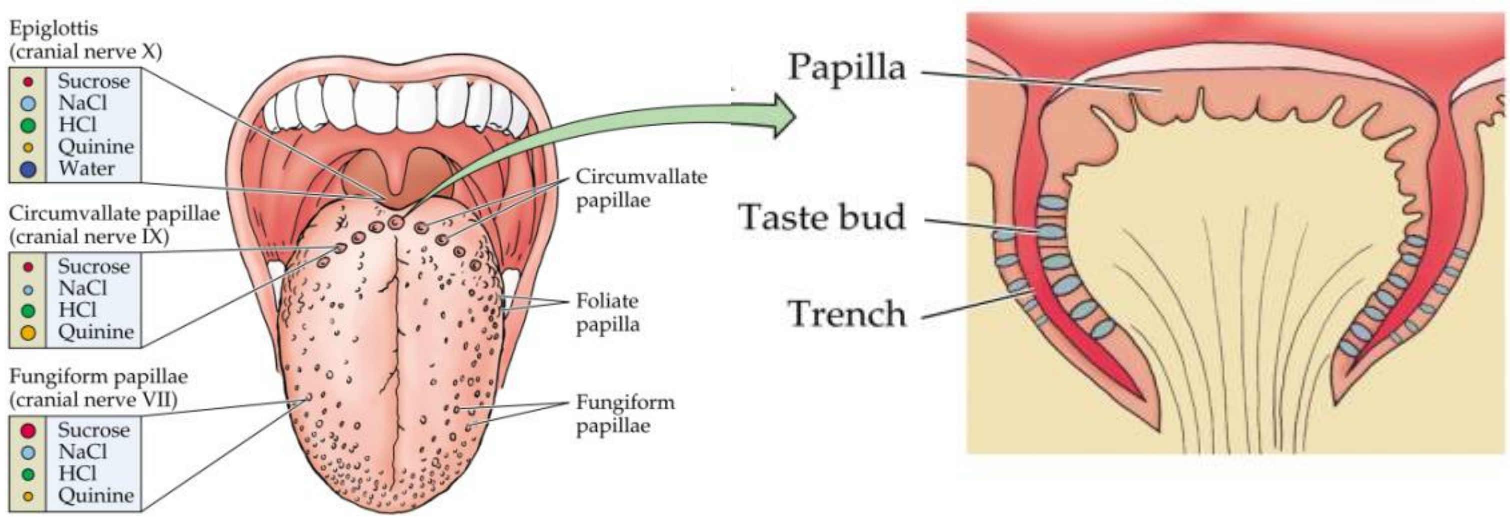
Agenda:

1. Morphology of cells
2. Gustatory pathway
   - ❖ Flavor tripping with 'Miracle Berries' (later in the class)

Gustatory System

Morphology of taste buds and cell types:

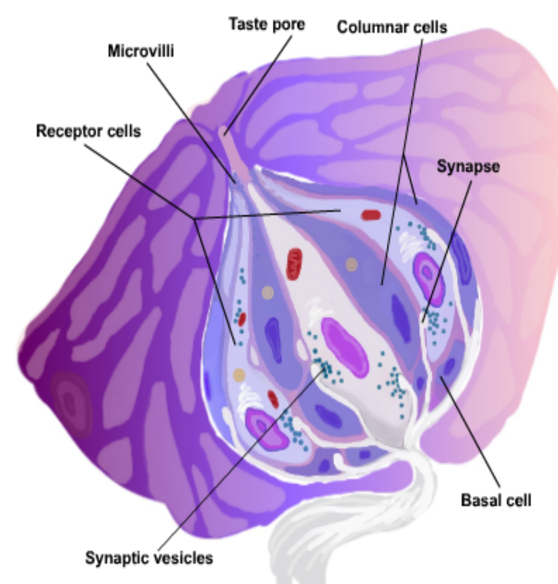
- Taste buds are located on papillae and are distributed across the tongue
- They are also found on the oral mucosa of the palate and epiglottis
- Taste buds contain 80 cells arranged around a central taste pore.



Gustatory System

Taste receptor cells:

- Spindle shaped cells that extend from the base to the apex of taste buds
- Taste solutes are transported to the taste pore and diffuse through the fluid layer to make contact with membrane receptor proteins on the microvilli and apical membrane
- Taste sensitivity is dependent on the concentration of taste molecules and their solubility in saliva



Gustatory System

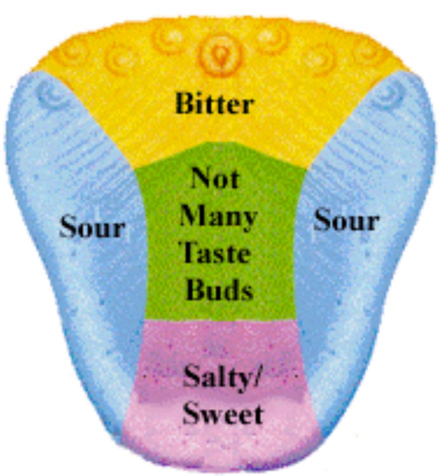
Sensory transduction:

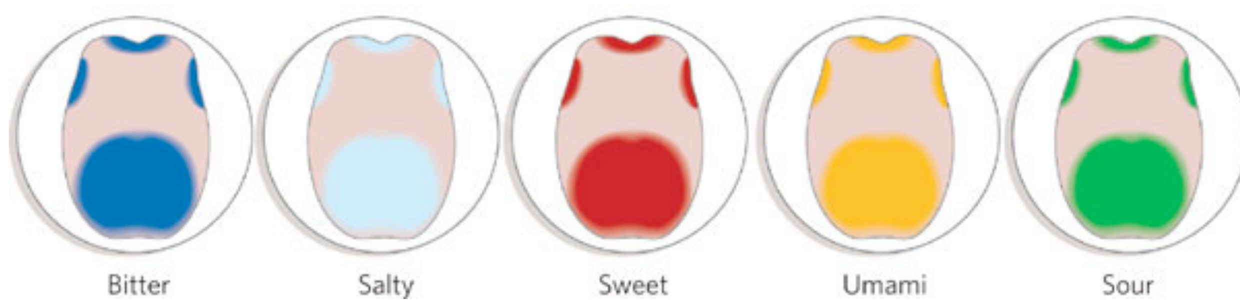
- Taste sensation can be caused by diverse tastants
- Action potentials in the taste receptor cells leads to an increase in Ca2+ influx through voltage-gated channels with a release of Ca2+ from intracellular stores
- In response to Ca2+, neurotransmitter is released, which causes synaptic potentials in the dendrites of the sensory nerves and action potentials in the afferent nerve fibers

Gustatory System

Taste distribution:

- **Most of the tongue is receptive to all basic tastes**
- There are certain regions that are most sensitive to a given taste
  - Bitter: across back of tongue
  - Sour: on side closest to the back
  - Salty: on side more rostral than sour
  - Sweet: across front of tongue

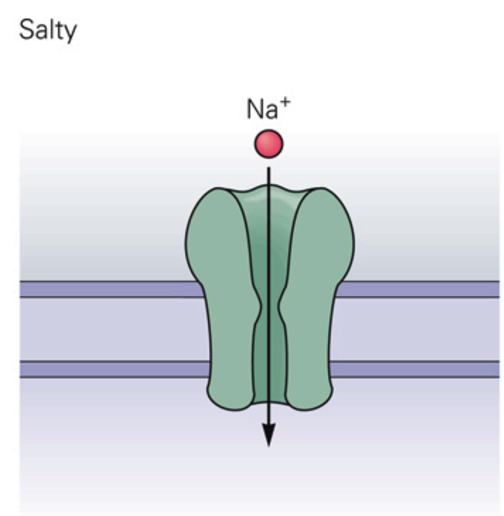




Gustatory System

How is <u>salt</u> processed?

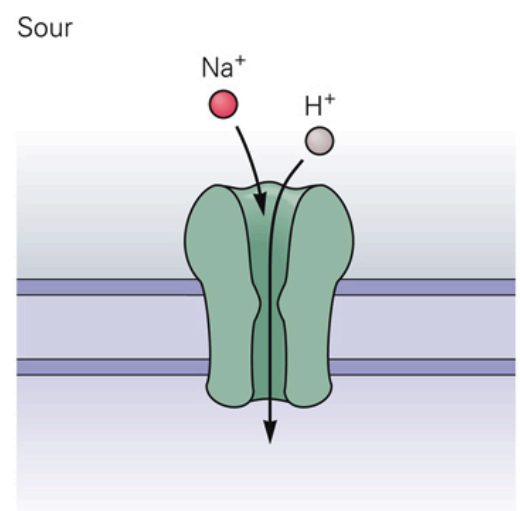
- Na+ flows down a concentration gradient into the taste receptor cell (most salts are Na+ salts, like table salt)
- Na+ increases within the cell, which depolarizes the membrane and opens a voltage dependent Ca2+ channel
- Ca2+ increase causes the release of neurotransmitters



Gustatory System

How are acids (<u>sour</u> tastants) processed?

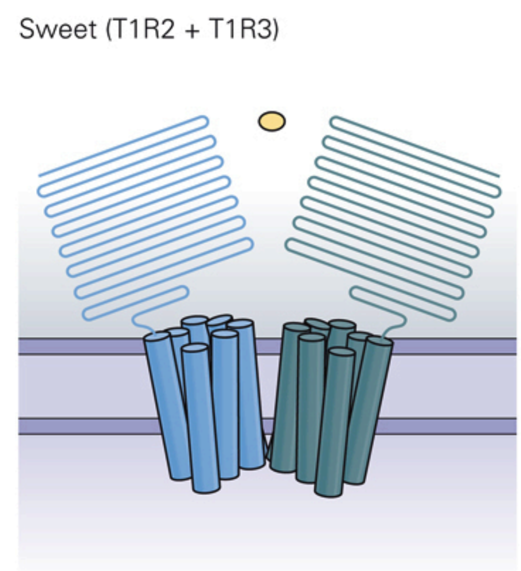
- Foods that are sour have high acidity (low pH)
  - When acids are dissolved in water, they generate H+ ions
- H+ ions pass through the same channel that Na+ does
- H+ blocks a K+ channel as well
- The net movement of cations into the cell depolarizes the taste cell
  - This opens a Ca2+ channel
  - It causes neurotransmitter release



Gustatory System

How is sweet processed?

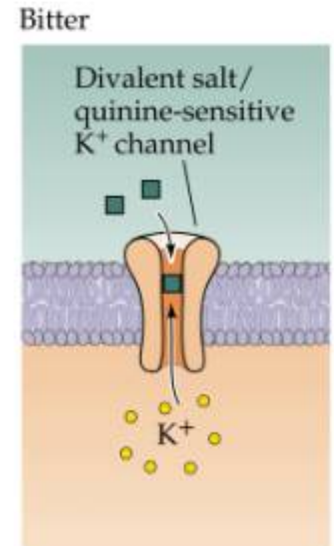
- Molecules that are sweet bind to specific receptor sites and activate a cascade of 2nd messengers in certain taste cells
- These molecules also bind to receptors
- G-protein activates an effector enzyme-adenylate cyclase and produces cAMP
- cAMP causes a K+ channel to be blocked
- The cell depolarizes
- Ca2+ channel opens and Ca2+ enters the cell
- Neurotransmitter is released



Gustatory System

How is <u>bitter</u> processed?

- Noxious chemicals in the environment are often bitter
  - Senses have evolved to protect and preserve
  - The ability to detect bitter has two separate mechanisms

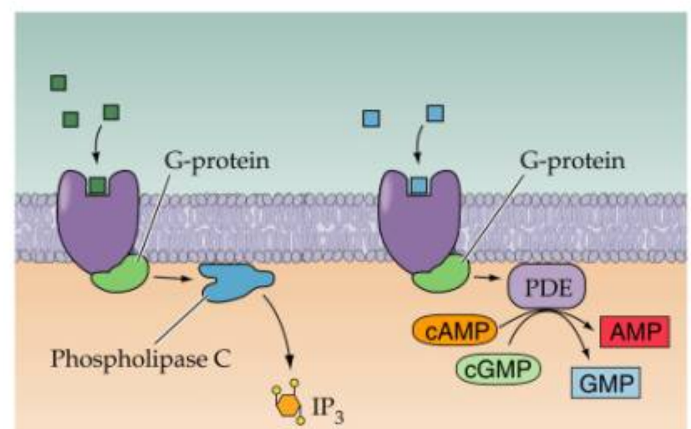


System 1:

- Bitter tastants can directly block a K+ channel
- Cell depolarizes
- Ca2+ channel opens and Ca2+ floods in
- Neurotransmitter is released

System 2:

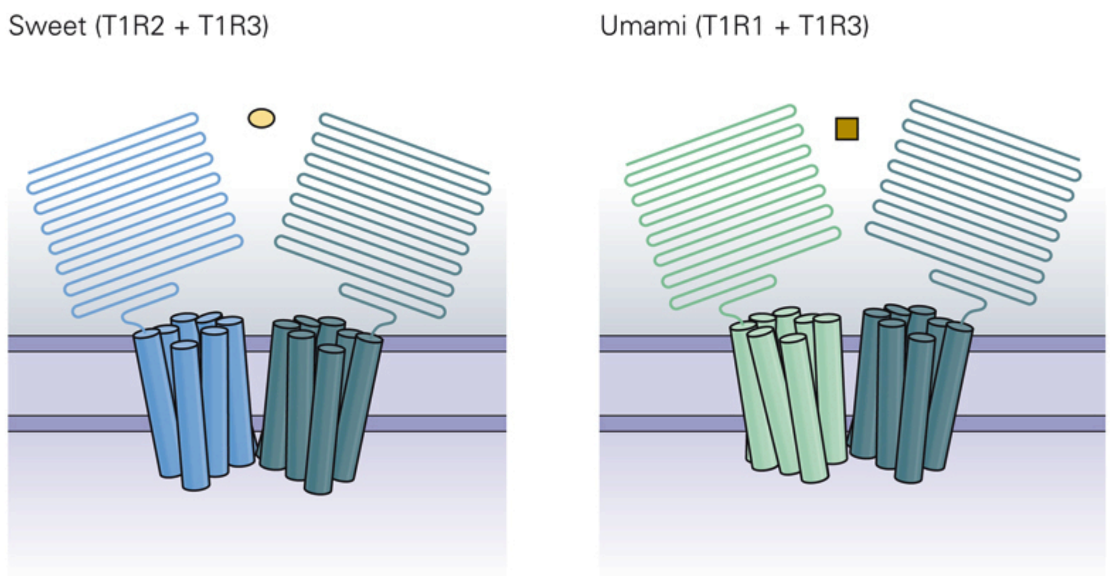
- Bitter tastants bind to bitter receptor
- G-protein activates an effector enzyme
- Ca2+ is released from extracellular storage
- Ca2+ increase causes neurotransmitter release



Gustatory System

How is <u>umami</u> processed?

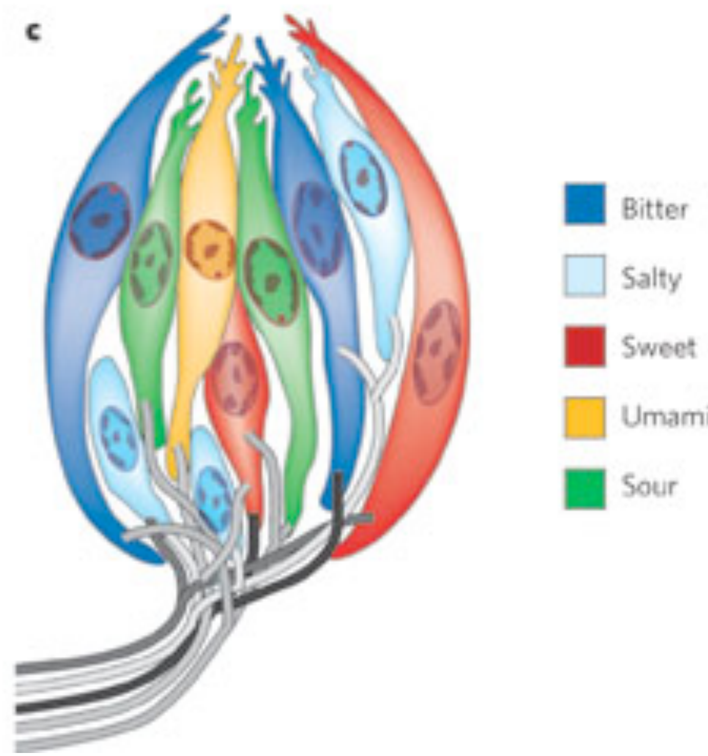
- Very similar to sweet, but slightly different downstream mechanism



Gustatory System

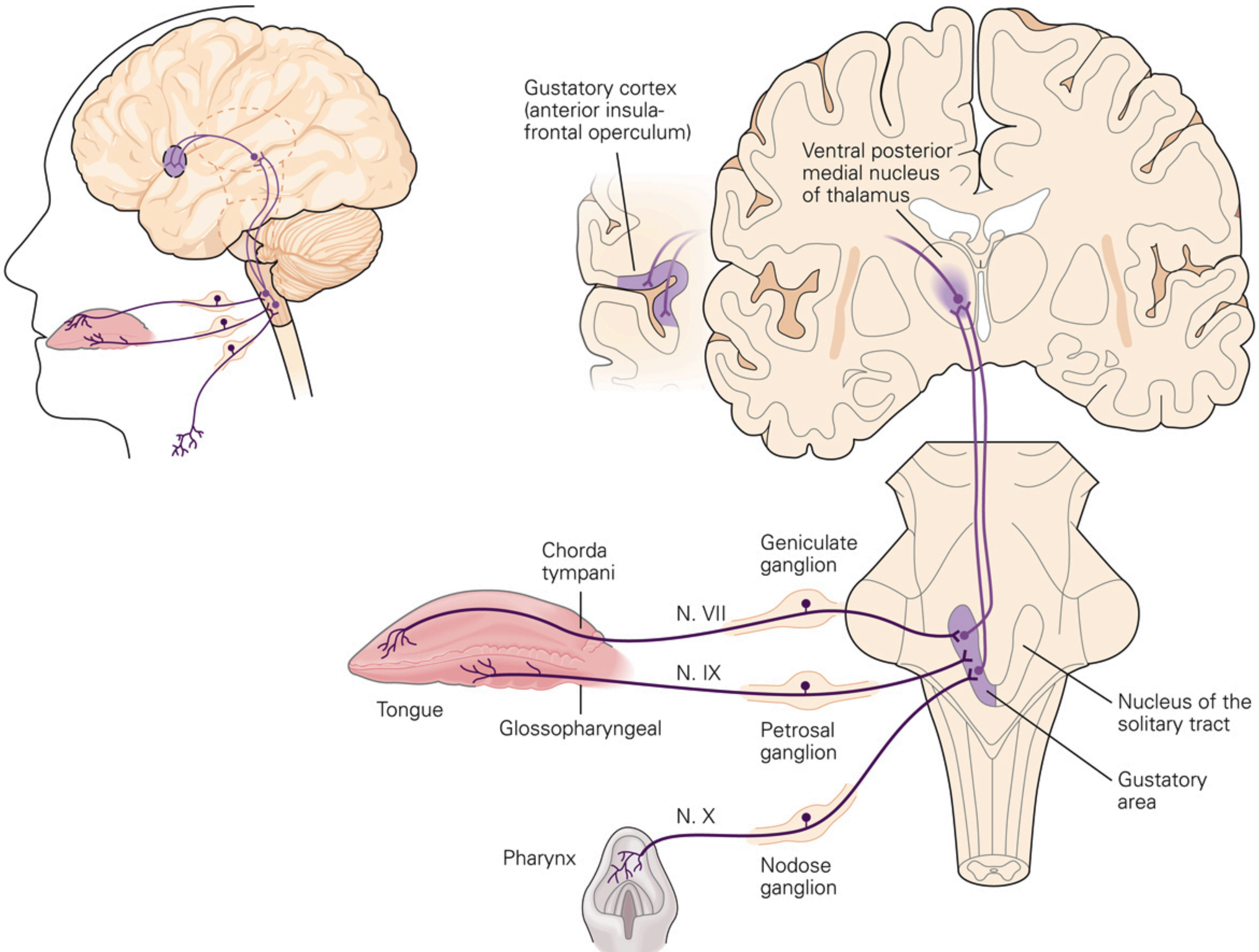
Taste neural circuitry

- There is no single fiber that conducts one taste quality (i.e. sweet, bitter), but some may respond best to one quality and less well to others
- Branches of nerve fibers innervate several cells within and in between different taste buds



Gustatory System

Propagation to the primary gustatory center



Olfactory System

Objective: Understand how the olfactory system works and its relation to other sensory systems

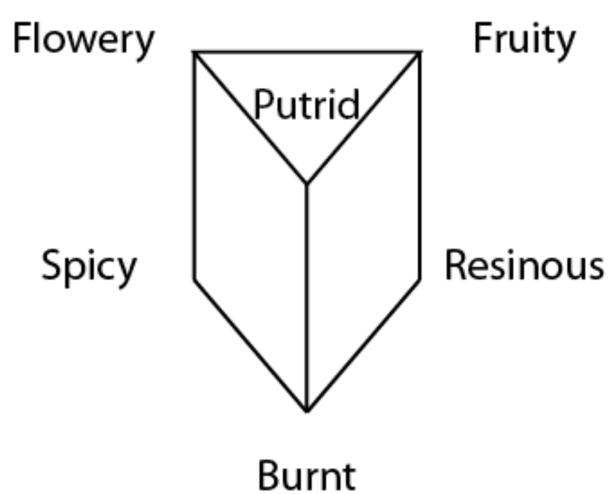
Agenda:

1. Morphology of cells
2. Neural pathway
   - Jellybean test

Olfactory System

What is the olfactory system?

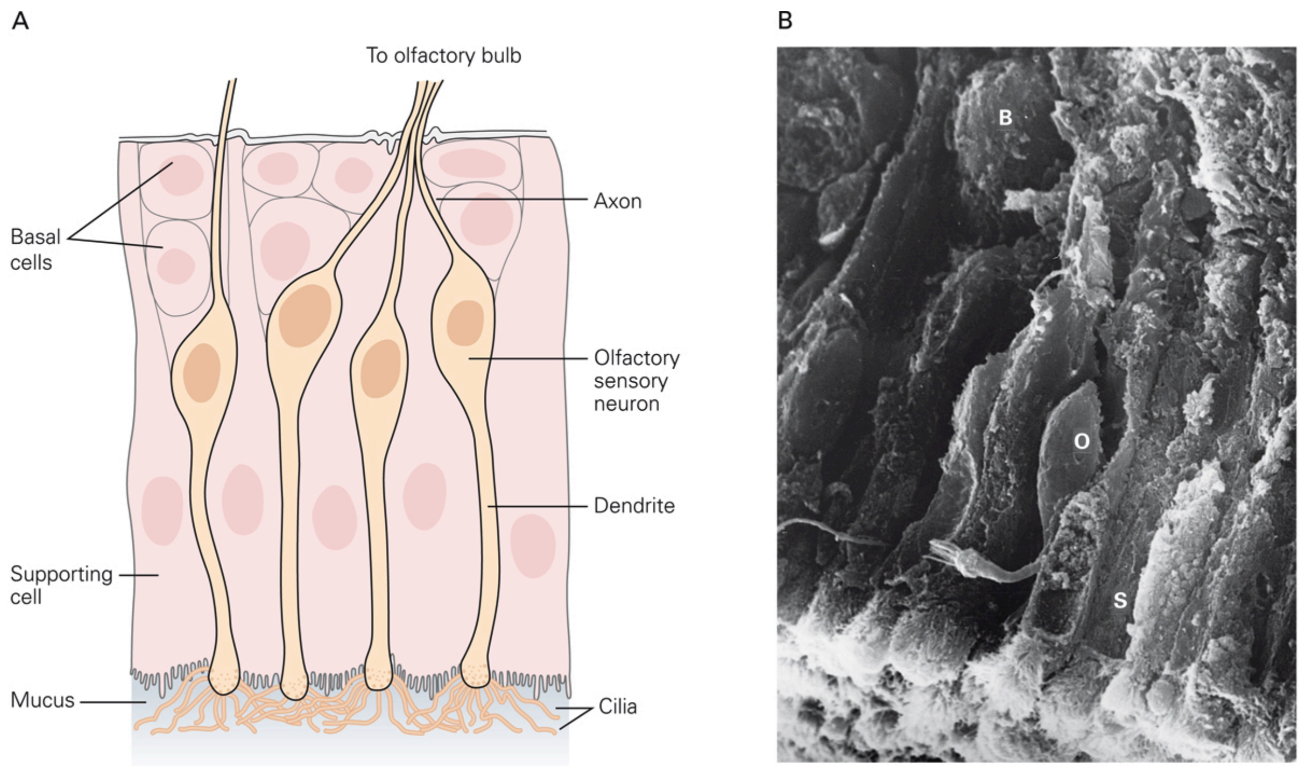
- Discriminative and sensitive chemosensory system
- Humans can detect between 1000-4000 odors
- All odors can be discriminated into six major groups: floral, fruit, spicy, resin, burnt and putrid
- Perception of odor begins with inhalation and transport of volatile odorants to the olfactory mucosa (located in the dorsal posterior region of the nasal cavity)



Olfactory System

Morphology of olfactory mucosa and cells:

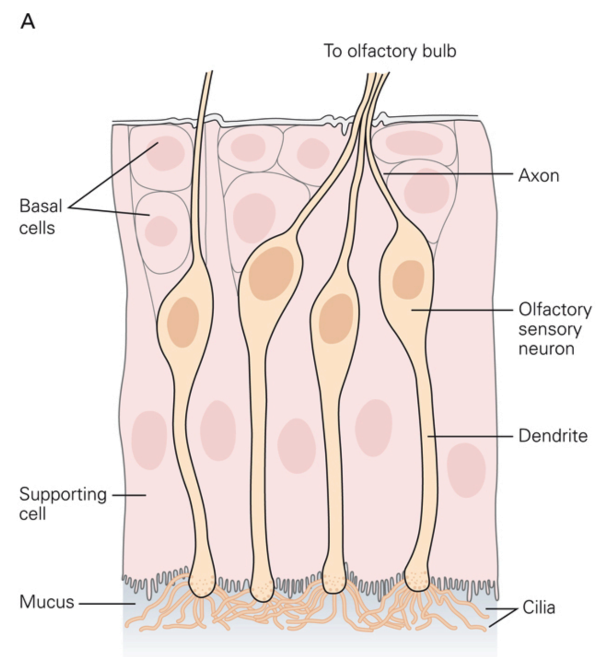
- The olfactory mucosa consists of a layer of columnar epithelium
- There are three major cells types: olfactory sensory neurons, supporting cells and basal stem cells



Olfactory System

Olfactory sensory neurons:

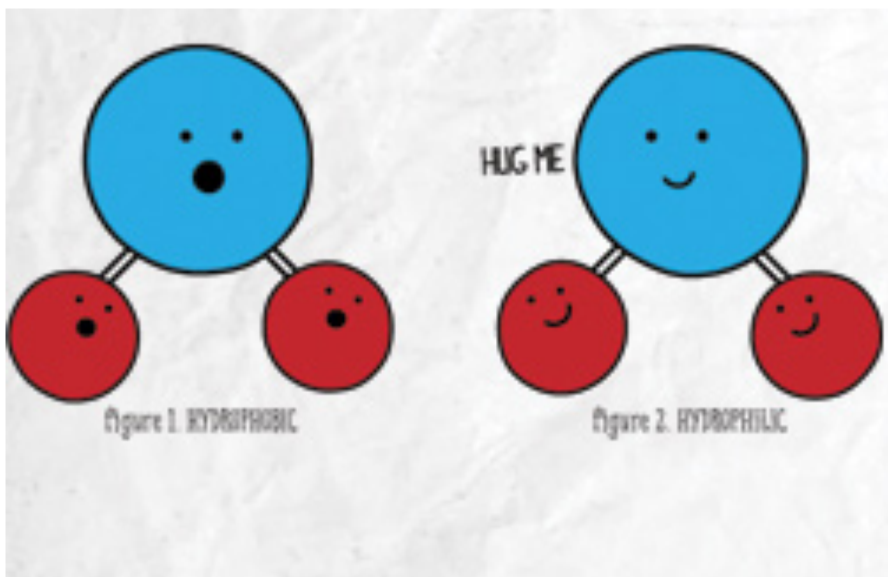
- Olfactory sensory neurons have a single dendrite that projects down to the mucus
- The terminal ending of dendrites have 5-25 cilia that are embedded in the mucus
- Each cilia has as many has 40 specific receptor membrane proteins for interaction with different odorant molecules
- The density of these receptors is very large in humans but much bigger in lower animals



Olfactory System

How do odorant molecules interact with sensory receptors?

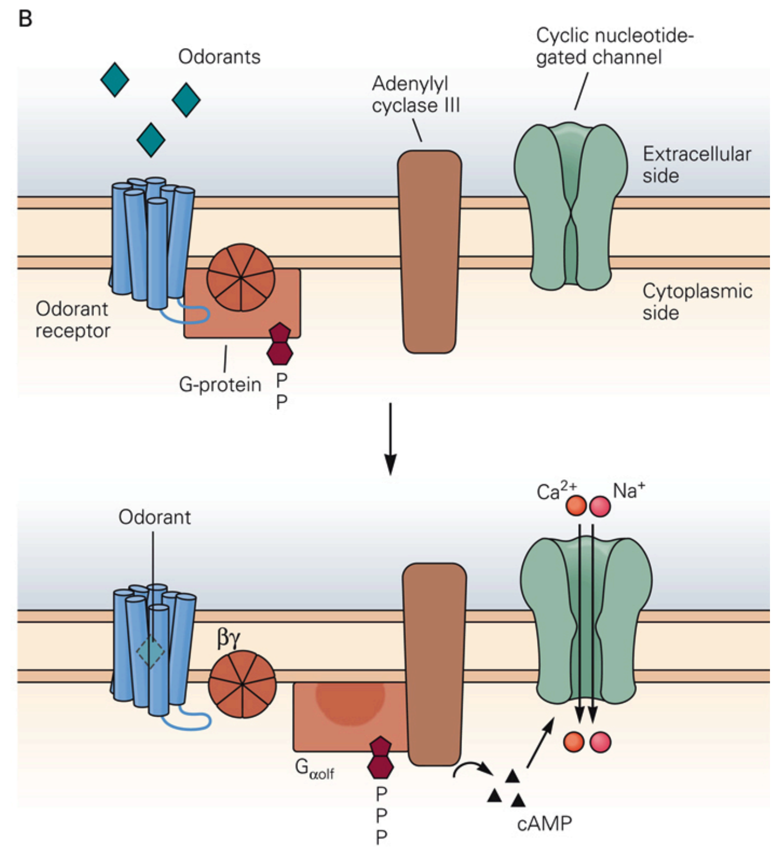
- Different for hydrophilic vs hydrophobic odors:
  - Hydrophilic (water loving): diffuse across mucus
  - Hydrophobic (water fearing): bound to specific odorant binding protein and transported to each cilium for interaction with specific receptors



Olfactory System

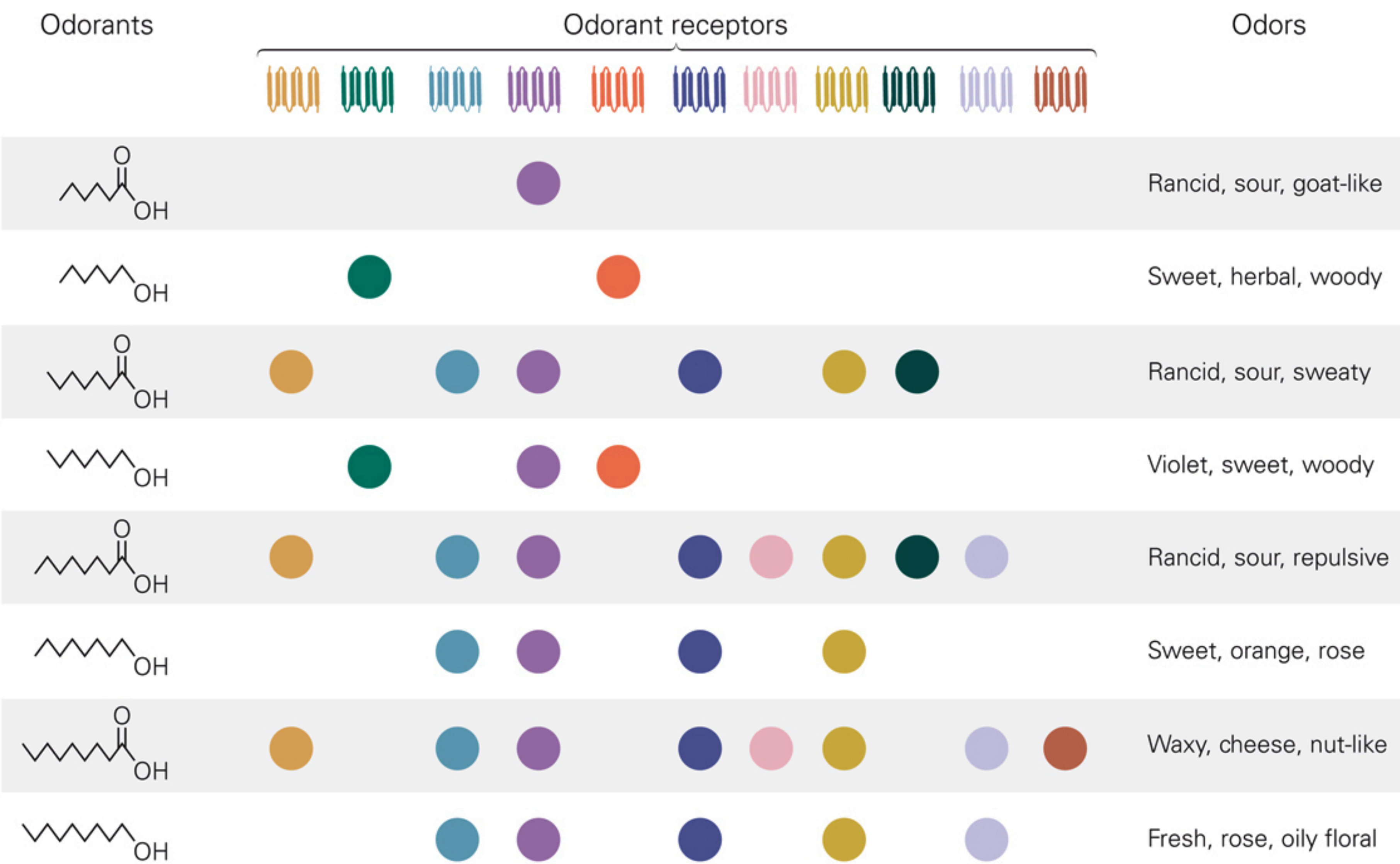
Transduction of olfactory stimuli

- Odorant molecules bind to the receptor which is coupled with G-proteins
- The activation of adenylyl cyclase leads to the formation of cAMP with the activation of Ca2+/Na+ cation channels
- The influx of these ions leads to depolarization
- The generated current is graded in response to the flow rate of the odorant molecules and their concentration



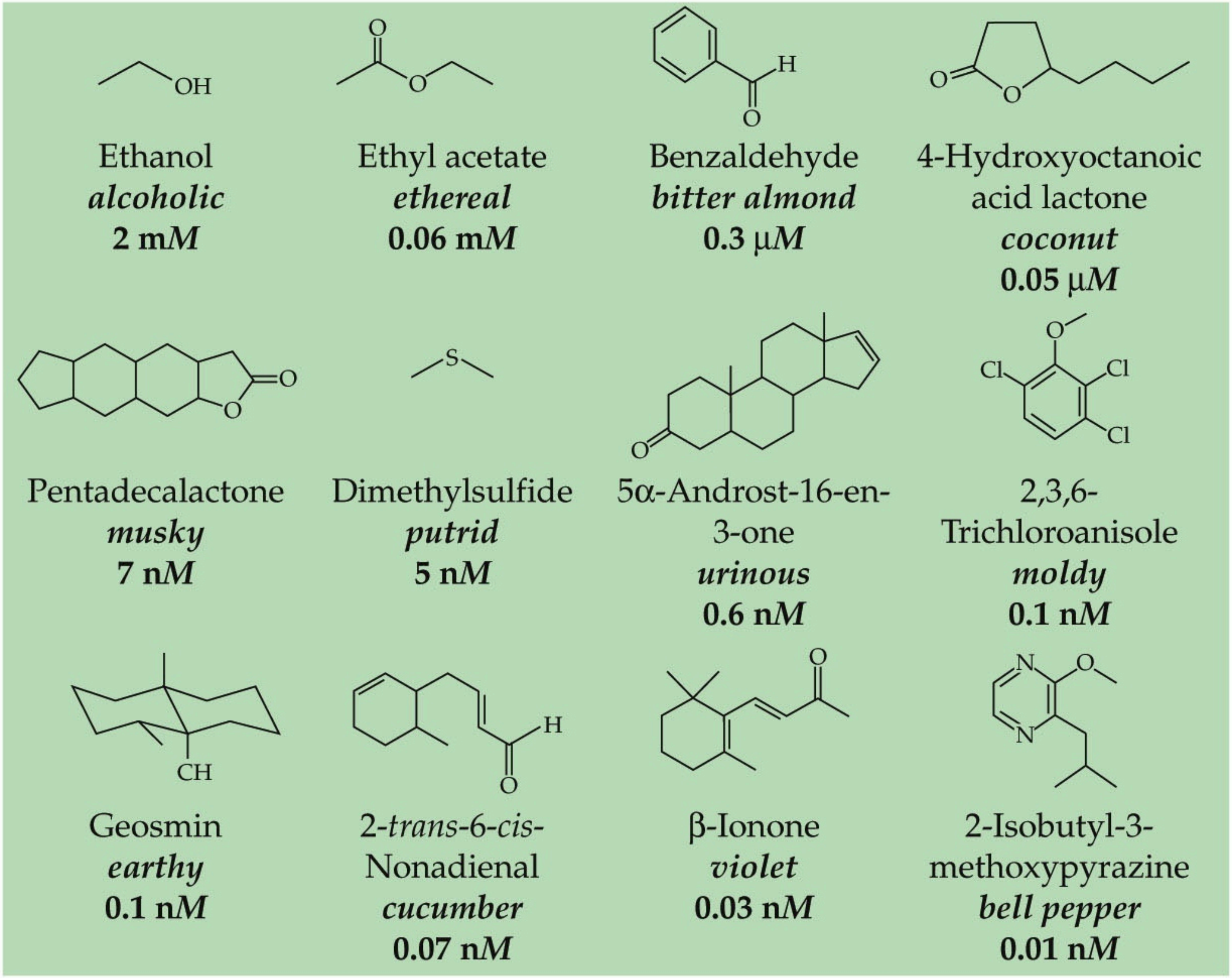
Olfactory System

Odorants are recognized by a unique combination of receptors



Olfactory System

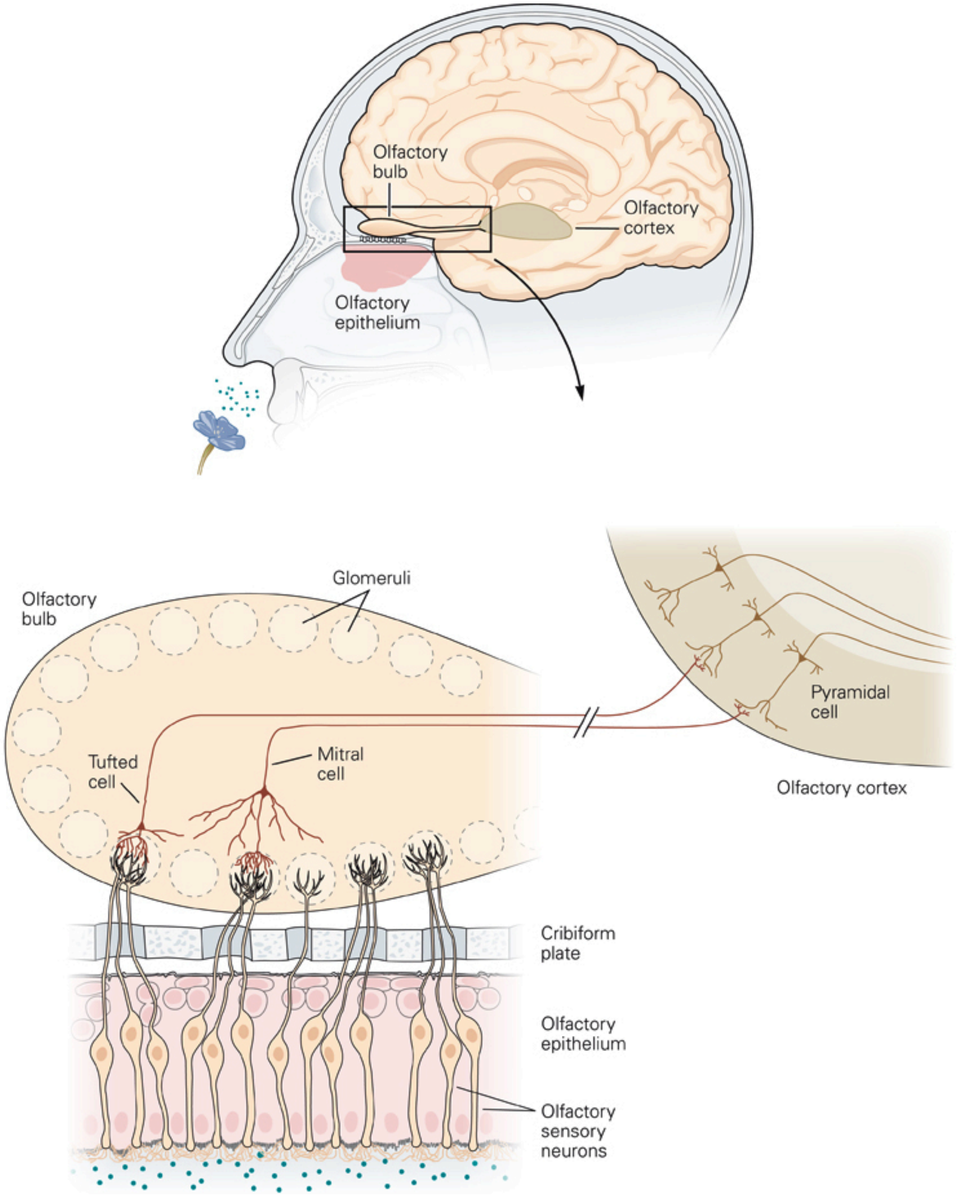
Human odor thresholds



Olfactory System

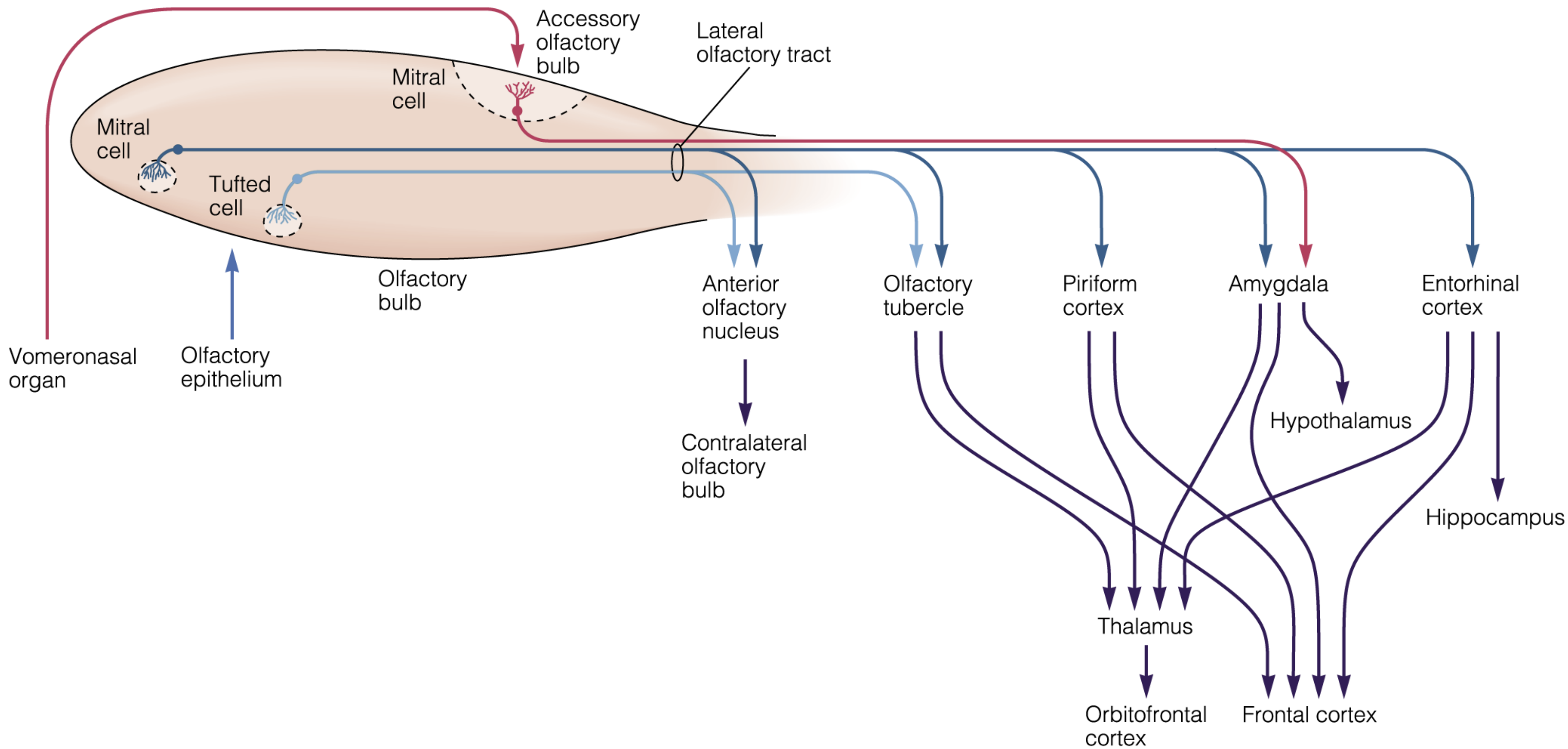
Neural pathway into the olfactory cortex

- Olfactory sensory neurons are located in the olfactory epithelium
- These neurons project axons into the olfactory bulb of the brain
- These projections innervate specialized regions of the olfactory bulb called glomeruli
- The terminations within the glomeruli are called mitral and tufted cells
- These relay neurons project to the olfactory cortex in the brain



Olfactory System

Higher order olfactory processing



Jellybean test demo

Jellybean test

Instructions

1. Partner up with a person sitting near you
2. Ask your partner to closer his/her eyes
3. Give your partner a jelly bean and ask them to chew it and guess its flavor
4. Repeat this two more times
5. Now tell your partner to close their eyes and pinch their nose
6. Give your partner a jelly bean and ask them to guess the flavor without letting go of their nose
7. Repeat this two more times
8. Switch roles

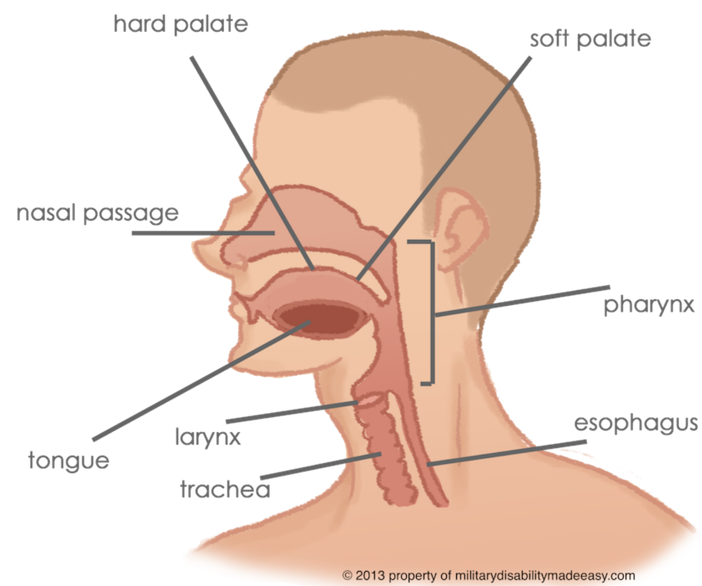
What's going on?

Jellybean test

What is going on?

1. Approximately 80-90% of what we perceive as taste is due to our sense of smell
2. You probably were not able to tell the specific flavor of the candy beyond a general sensation of sweetness
3. As you chew, you may have been able to identify the specific taste

This is because some scent molecules volatilize and travel up to your olfactory receptors
(through a passage at the back of your throat connected to your nose)



Somatosensory system

Objective: Understand different somatosensory senses (touch and pain) and their pathways

Agenda:

1. Morphology of receptors and cells
2. Neural pathway

Somatosensory System

What is the somatosensory system?

- Processes information about several modalities of somatic sensation

The Sensory Modalities Represented by the Somatosensory Systems		
Modality	**Sub Modality**	**Sub-Sub Modality**
Pain	sharp cutting pain	
	dull burning pain	
	deep aching pain	
Temperature	warm/hot	
	cool/cold	
Touch	itch/tickle & crude touch	
	discriminative touch	touch
		pressure
		flutter
		vibration
Proprioception	position (static forces)	muscle length
		muscle tension
		joint pressure
	movement (dynamic forces)	muscle length
		muscle tension
		joint pressure
		joint angle

Somatosensory System

Touch and pain

- Touch and pain are part of the somatosensory system
- Gives our brain information about our own body and the world around us
- **Interoception**: sensing information about our own body
- **Exteroception**: sensing information about the world around us

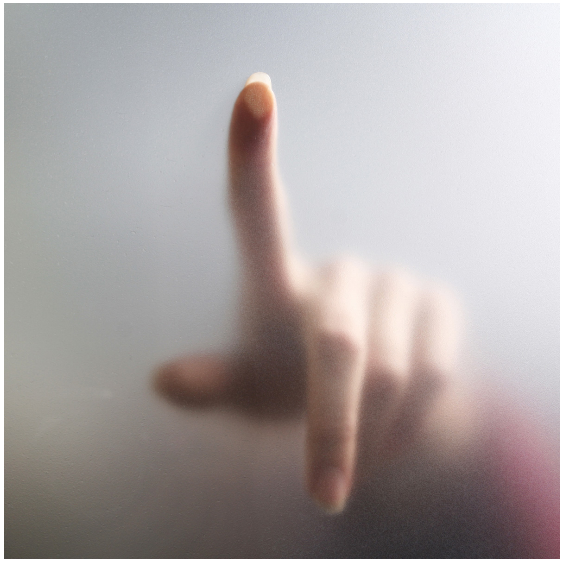
Somatosensory receptors are located all over the body, from the surface of our skin to deep in our joints.

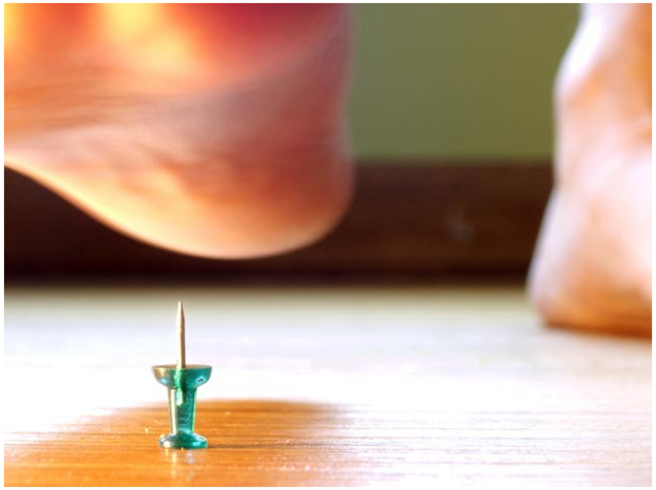
Somatosensory System

Different modalities

Cutaneous senses: senses of the skin
Proprioception: body position
Kinesthesis: body movement
Nociception: pain and discomfort

There might be a fifth modality: pleasant touch





Somatosensory System

Different receptor types are sensitive to specific stimuli (cutaneous senses)

- Different types of somatosensory information activate different receptors
- Activation of receptors lead to electrical nerve pulses (transduction)
- Three main groups of receptors in skin: mechanoreceptors, thermoreceptors, chemoreceptors
  - Mechanoreceptors: respond to mechanical stimuli (like stretching or vibration of skin)
  - Thermoreceptors: respond to hot or cold temperatures
  - Chemoreceptors: respond to certain types of chemicals either applied externally or released within the skin (i.e histamine from an inflammation)

Somatosensory System

Categories of low-threshold mechanoreceptors

Identity of receptor	Size of receptor*	Type of skin where found	Speed of adaptation*	Adequate stimulus*
Merkel's disks	Small, sharp borders	Glabrous*	Slow	Pressure
Meissner's corpusles	Small, sharp borders	Glabrous	Rapid	Indentation
Ruffini corpuscles	Large, diffuse borders	Hairy + glabrous	Slow	Stretching
Pacinian corpuscles	Large, diffuse borders	Hairy + glabrous	Rapid	Vibration

* **Adequate stimulus:** The type of stimulus that the receptor is specialized to receive and respond to.

* **Glabrous Skin:** The hairless skin found on our palms and the soles of our feet. This skin has a higher density of receptors of a more complex range, which reflects the fact that we use these areas of our body to actively explore our surroundings and to discriminate tactile properties of objects we're interacting with.

* **Low-threshold mechanoreceptors:** Mechanoreceptors that respond to stimulus that is so light it doesn't threaten to damage the tissue around it. High-threshold mechanoreceptors respond to stimulation of higher intensity, and are a type of nociceptor.

* **Receptive field:** The space of skin or tissue in which stimulation will elicit a response in the receptor. Smaller receptive fields make the receptor more sensitive to details.

* **Speed adaptation:** Slowly adapting mechanoreceptors continue to fire action potentials during sustained stimulation. Rapidly adapting mechanoreceptors fire action poentials in response to stimulus onset and offset (i.e. to stimuli chages), and help detect stimulus movement on the skin.

Somatosensory System

Different receptor types are sensitive to specific stimuli (nociception)

- Different types of somatosensory information activate different receptors
- Experience of pain usually starts with the activation of **nociceptors**
- These receptors fire specifically to tissue-damaging stimuli
- Most nociceptors are either chemoreceptors or mechanoreceptors
  - Chemoreceptors: when tissue is damaged or inflamed, certain chemicals are released from cells and activate these receptors
  - Mechanoreceptors: respond to intense mechanical stimulation

Somatosensory System

Action potentials in receptor cells travel at different speeds

Using stepping on a pin as an example

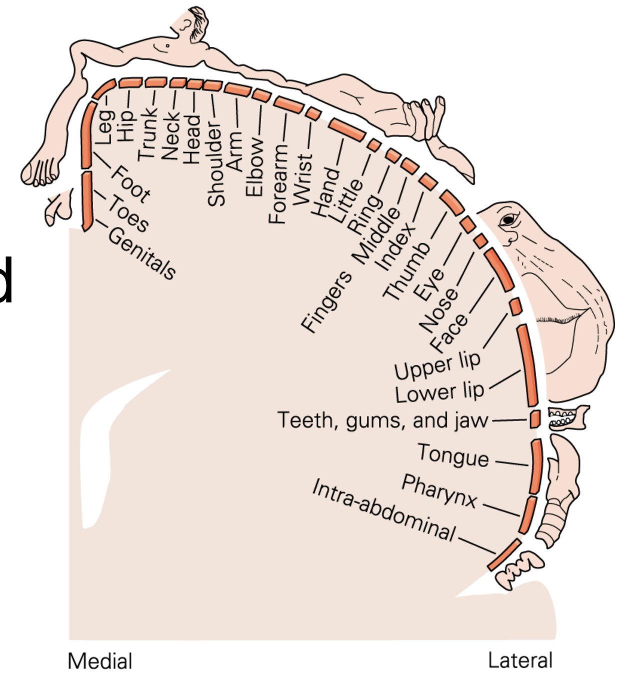
- When you step on a pin, you activate many mechanoreceptors (many of which are nociceptors)
- Sensation changes over time: probably feel a sharp stab at first and then a wave of aching pain
    - Sharp pain: signaled via fast-conducting A-fibers, which project to the somatosensory cortex
    - Aching pain: a separate, simultaneous signal sent from the nociceptors in feet via C-pain fibers to the insular cortex and other brain regions involved in emotion

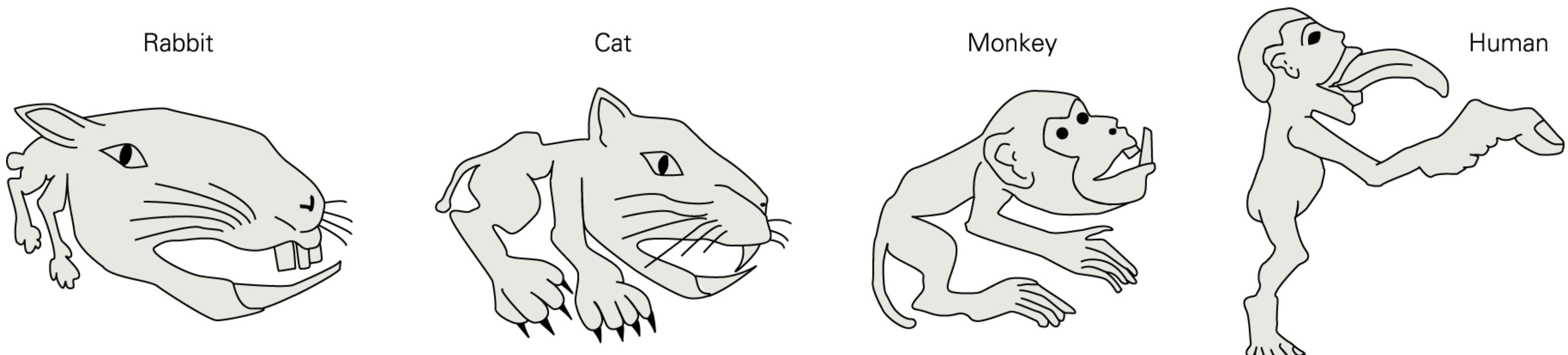
Stepping on a pin is made up of two separate signals: discriminatory (used to localize touch) and affective (tells us that stepping on a pin is bad)

Somatosensory System

Somatosensory cortex organization

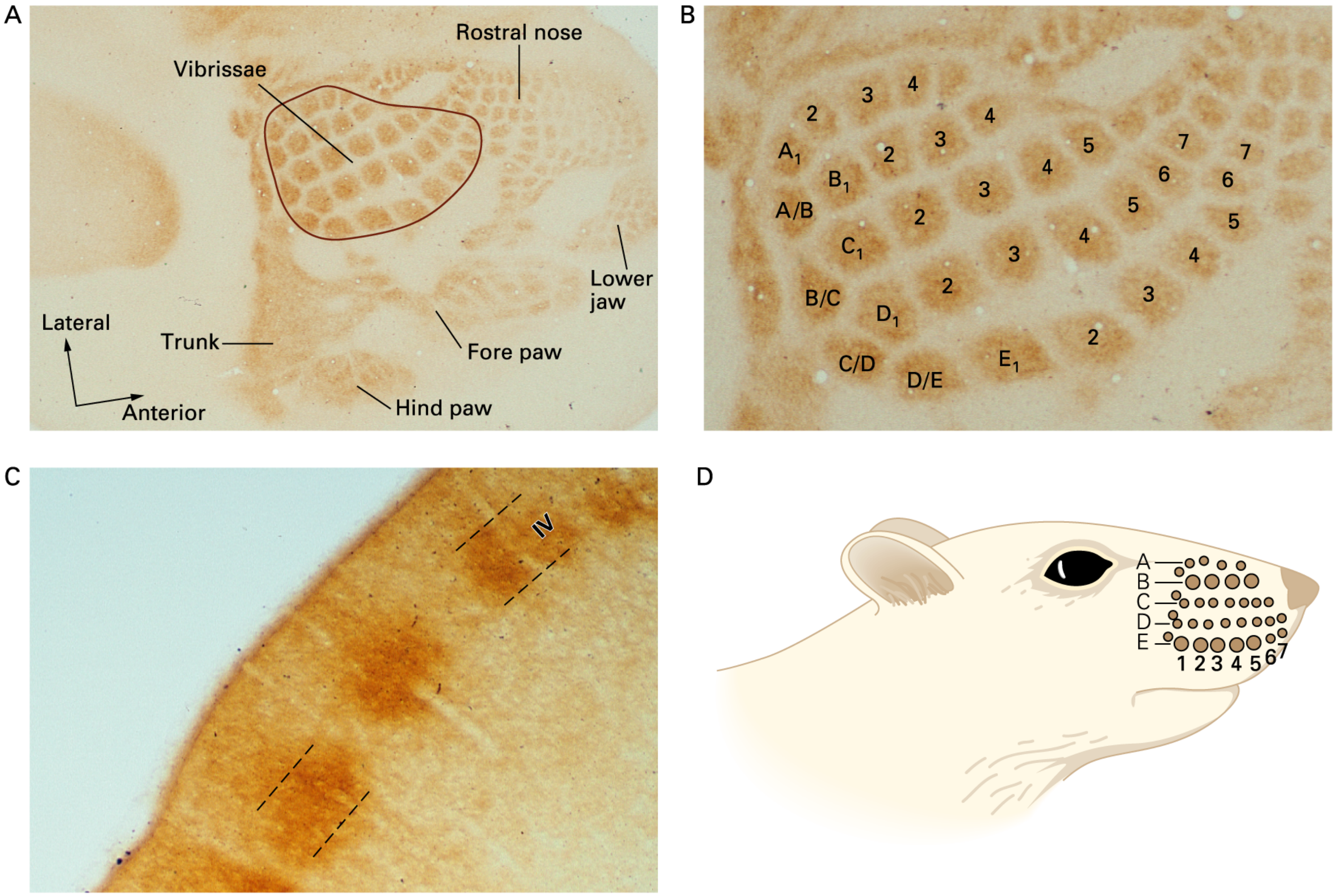
- The somatosensory cortex is somatotopically organized
  - The sensory signals are represented according from where in the body they come from
- Homonculus: model of bodies distorted to reflect the relative space that body parts occupy in the somatosensory cortex





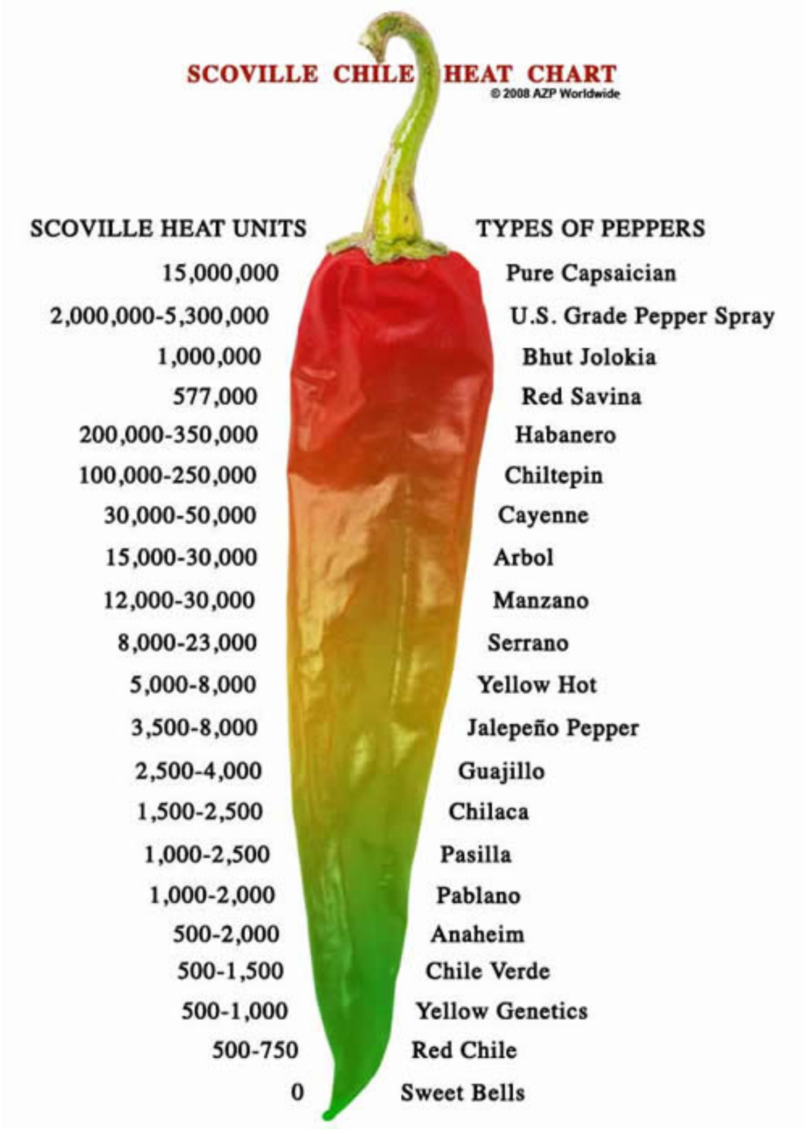
Somatosensory System

Case study: rodent barrel cortex



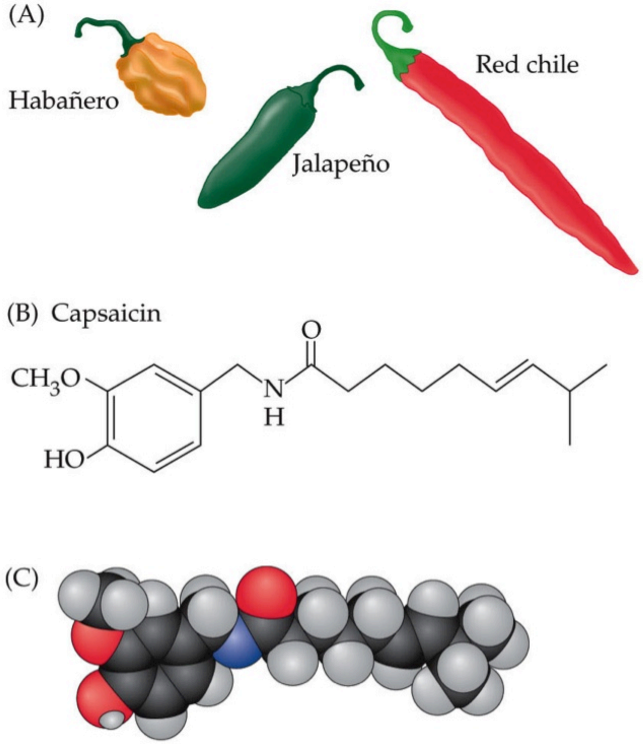
Integrating systems

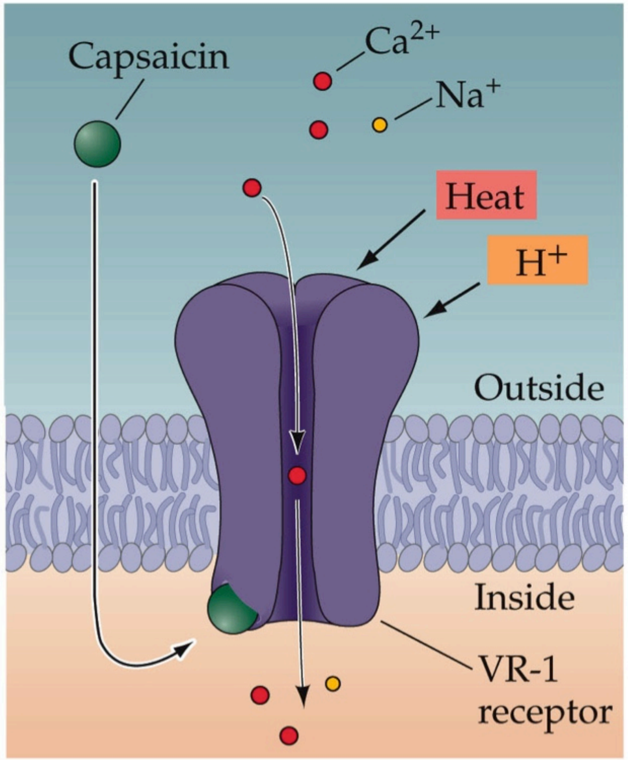
Understanding spiciness



Integrating systems

Understanding spiciness

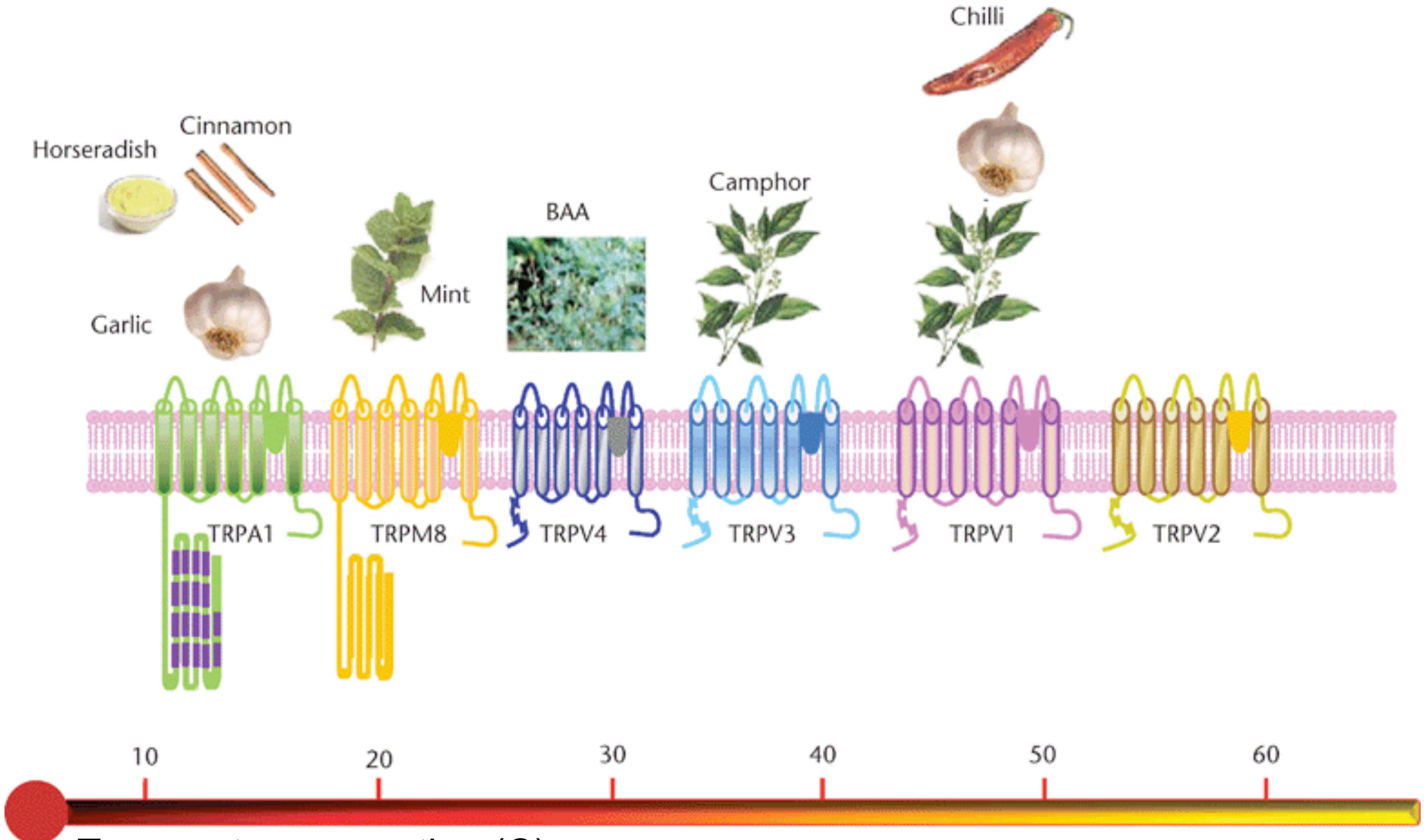




TRPV1 Receptor:
thermoreceptor
noxious heat detector

Integrating systems

There are other types of thermoreceptors as well



Temperature sensation (C)

‘Miracle Berry’ demo

‘Miracle Berry’ demo

What are miracle berries?

- *Synsepalum dulcificum*
- Plant native to West Africa
- Contains a glycoprotein called **miraculin**, which binds to the tongue’s taste buds when the fruit is consumed
- It acts as a sweetness inducer when it comes in contact with acids
- Causes bitter and sour foods to taste sweet

‘Miracle Berry’ demo

Instructions

1. Place one mberry tablet on your tongue and dissolve completely (takes about 10 minutes)
2. Taste the following items: grapefruit juice, lime juice, lemon juice, orange juice and sriracha
3. Record how the different items taste

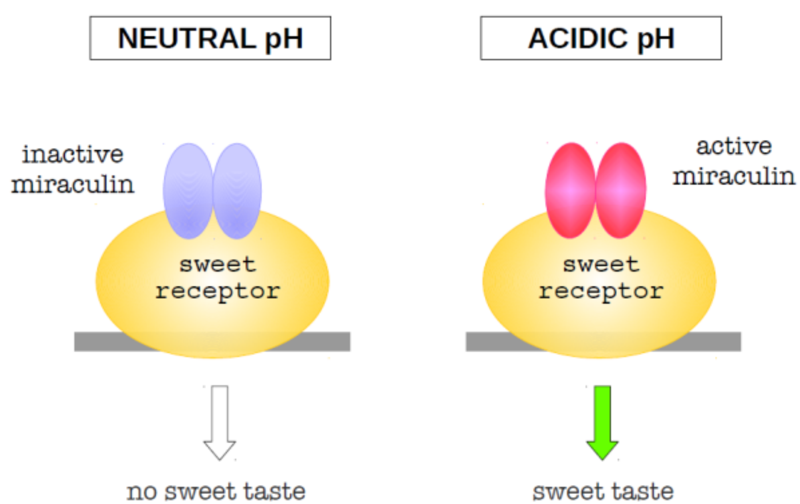
How do you think Miracle Berries work?

‘Miracle Berry’ demo

How do these berries work?

1. Mechanism understood by team of researchers at the University of Tokyo (led by Keiko Abe)
2. Used a system of cultured cells that let them test taste receptors at various levels of acidity and alkalinity
3. Found that miraculin bound strongly to sweet taste buds, but unlike sugar or aspartame, doesn’t activate them at a neutral pH
4. When acid is introduced, the protein changes shape and turns on the taste bud

This causes the ultra-sweet sensation that drowns out the sour taste.



'Miracle Berry' demo

How do these berries work?

- When sour food is swallowed, miraculin returns to its old inactive shape and remains bound to the sweet receptor for an hour or so
- Miraculin also disrupts detection of sweet foods. If you have sugar after consuming a miracle berry, you cannot taste it. However, after introducing a little acid, the sugar tastes sweeter than ever.