Lecture 30. Chemical Senses

Professor Nilay Yapici

Pre-lecture preparation – Posted on the course website before the lecture

Reading – Chapter 8- Pages 265-291

Optional Readings- Posted on the course website before the lecture

Lecture Objectives

- To understand the basic function of the chemical senses – taste and olfaction.
- Be able to describe why chemical stimuli are inherently different from auditory and visual stimuli.
- Be able to draw the molecular receptors and pathways involved in taste and olfactory perception
- Be able to understand the anatomical organization of the taste and olfactory systems.
- Be able to understand different types of olfactory information, retronasal and orthonasal olfaction, pheromone perception and vomeronasal system.
- Be able to discuss the interactions between taste and smell, flavor perception.
- Understand human olfaction and its dimensions.

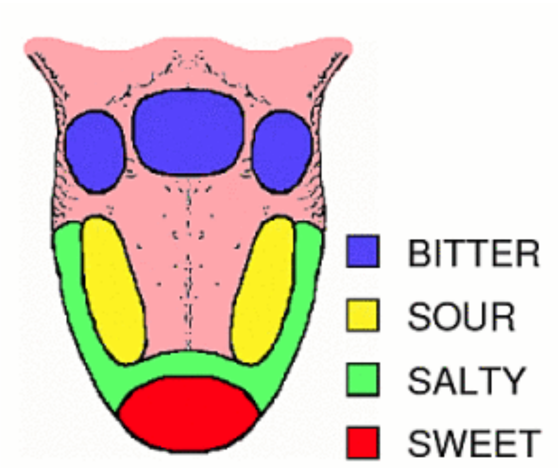
Lecture outline

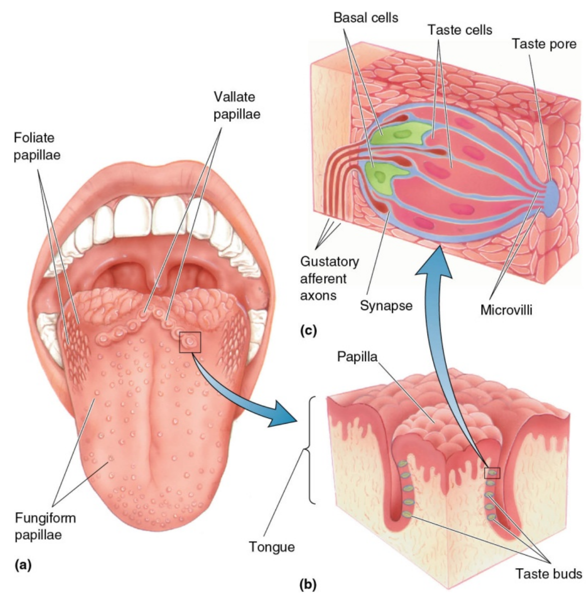
Gustation and olfaction have similar tasks: to detect and process environmental chemicals. This lecture will discuss the anatomical and functional structures of these two sensory systems.

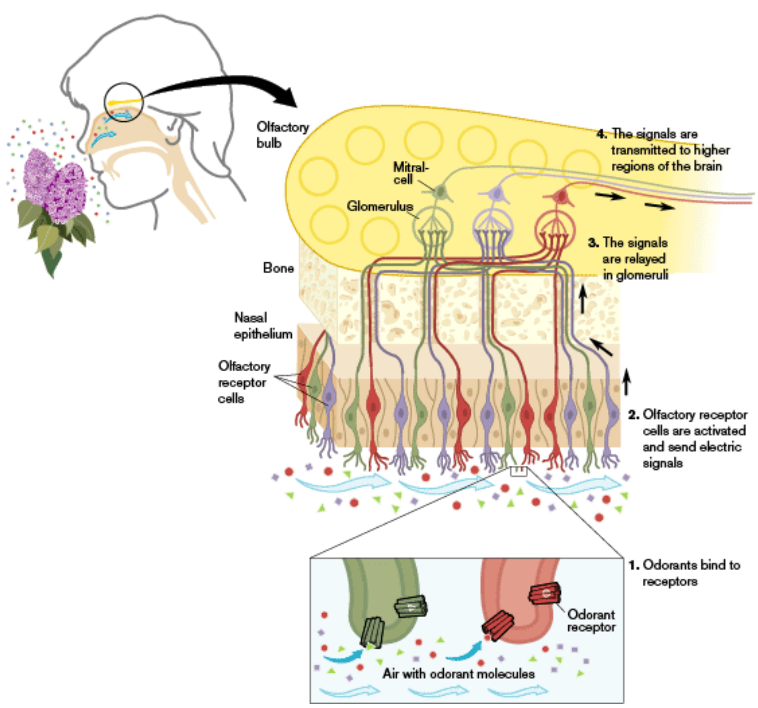
1) In most sensory systems, physical stimuli vary along one or more continuous axes of quality, for example frequency for sounds, color for light or location for touch. Chemical stimuli do not vary along such a continuous axis and therefore have to be processed in a manner different from other sensory stimuli.
2) The neural pathway for taste processing is similar to that of other sensory systems whereas the olfactory system bypasses the thalamic relay to enter cortical areas directly (Figure 8.17 p 287).
3) The receptors for taste and olfaction has been identified. We will discuss these sensory pathways and the receptors that mediate them in the lecture. The concepts of labeled line, distributed coding and temporal coding will be also discussed.
4) In addition to the main olfactory system, non-primate mammals have an additional olfactory system which is called the vomeronasal system that particularly response to pheromones. These two systems process a different type of signal and are wired differentially to the rest of the brain. The accessory olfactory system has disappeared in humans.
5) Taste system is organized different than the olfactory system. Recent research suggests that cortical maps exists for distinct tastants; for example bitter and sugar areas have been mapped in the insula cortex.
6) Flavor perception involve more than just the activation of taste receptors in the tongue. Texture and odor deliver important components of taste perception. We will discuss how olfactory information specifically adds to the perception of taste through retronasal olfaction.

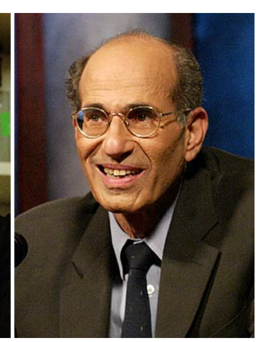
Study questions:

1) What is the main difference between chemical senses (smell and taste) and physical senses (vision, sound and touch)?
2) How are different tastants sense by the tongue? Is there a map for different tastes?
3) How many odors can humans smell? Is there a limit? Do odors have innate valiances or do we learn what is a good odor and a bad odor?
4) What are the main differences between taste and smell perception?









Lecture 30: Chemical Senses

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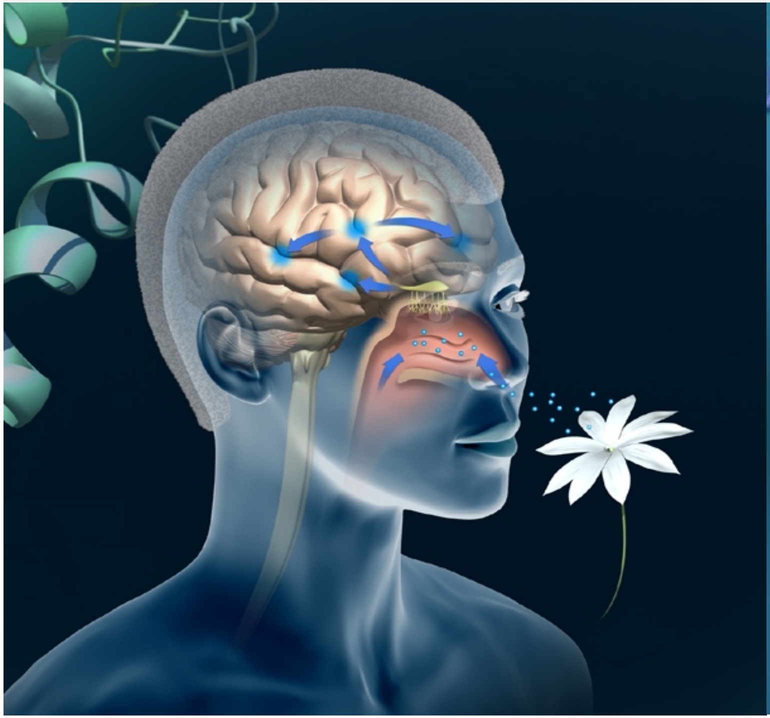

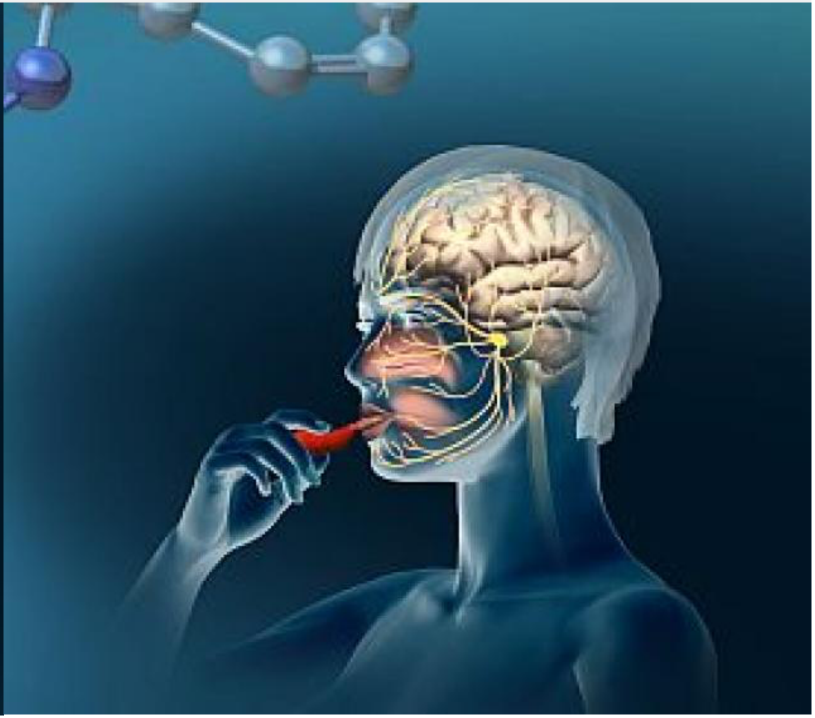

Learning objectives

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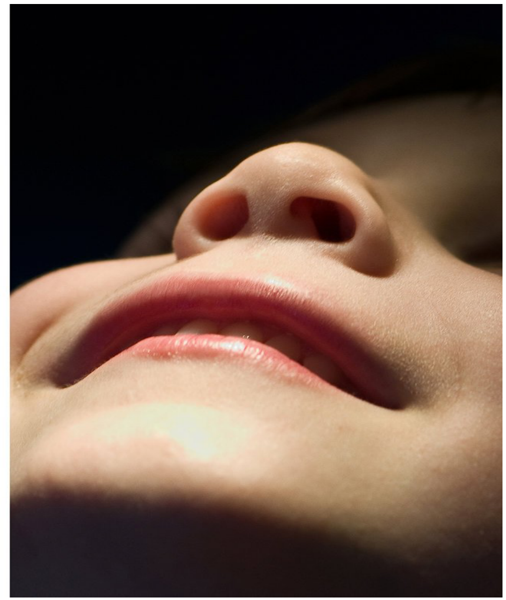
Chemical Senses

Animals depend on the chemical senses to identify nourishment, poison, or potential mates



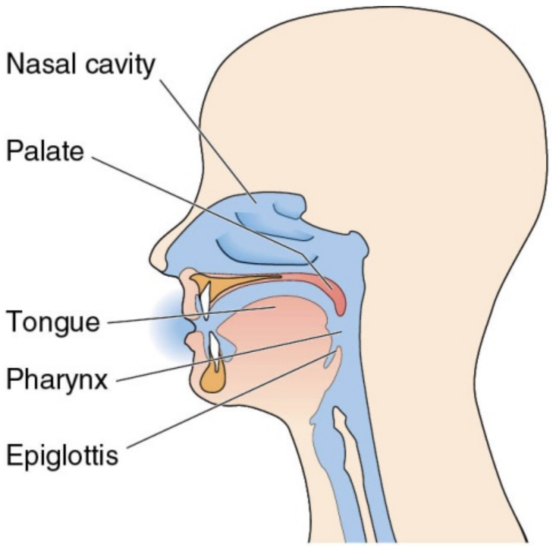
Chemical Senses

Chemical sensation is the most ancestral and most common sensory system in biological organisms

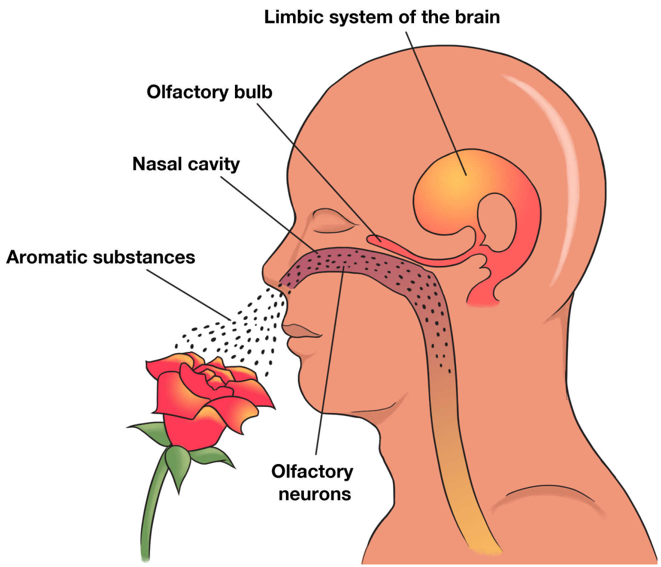


Chemical Senses is divided to two classes

Gustation-Taste

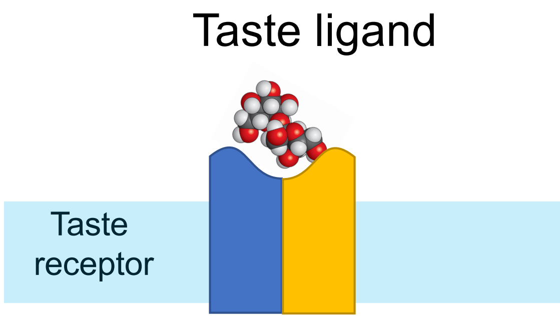


Olfaction-Smell

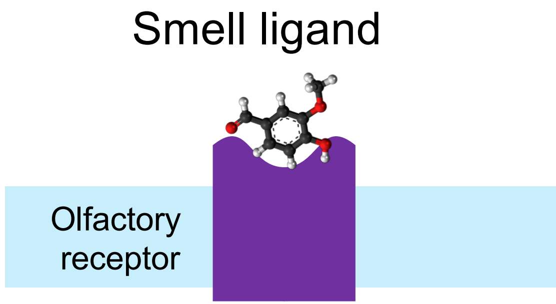


Chemical Senses are detected by chemoreceptors

<u>Gustation-Taste</u>



<u>Olfaction-Smell</u>



Ligands of chemoreceptors

Gustation-Taste

Taste modalities

Sugars

Protein

Water

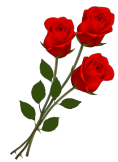
Sour

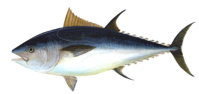
Salt

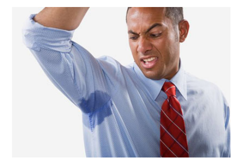
Bitter

Olfaction-Smell

Multi dimensional

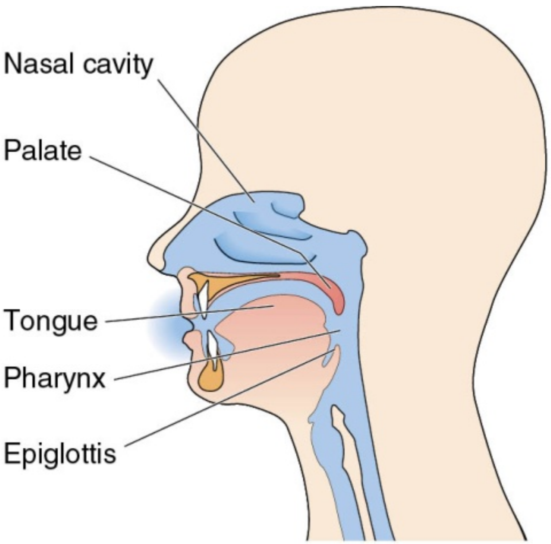


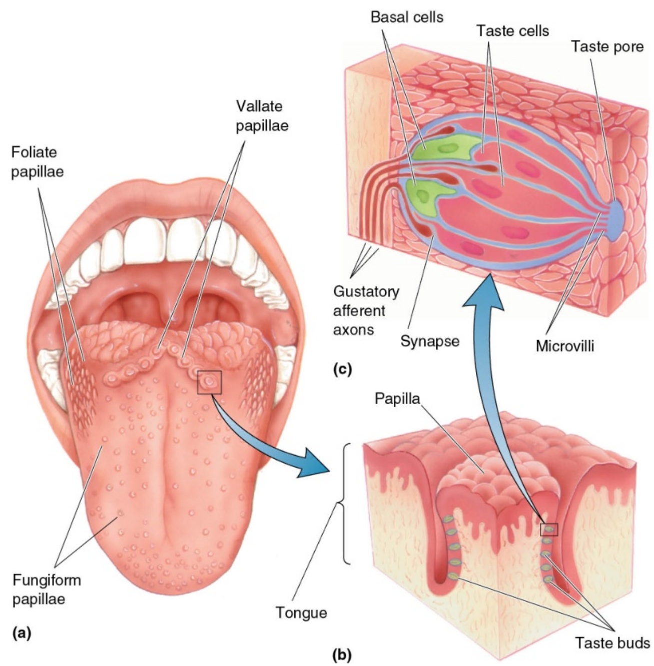




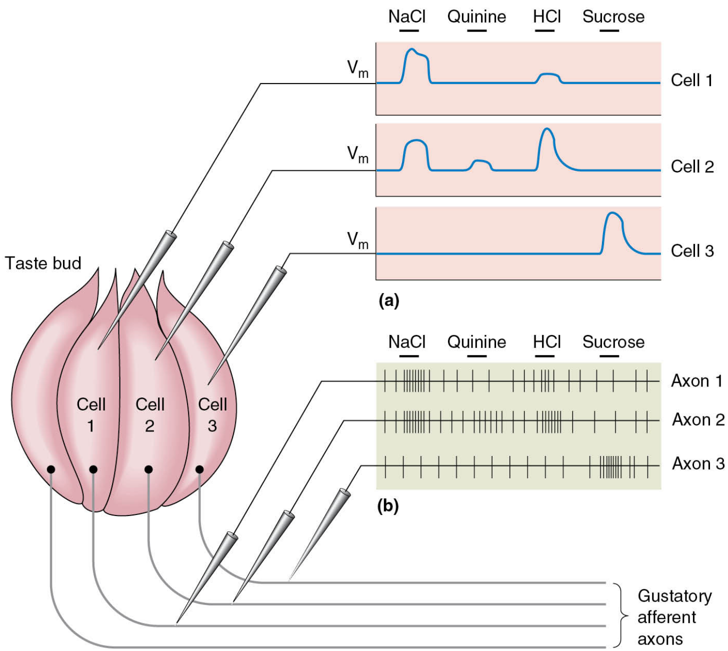
Gustation-Taste System

Gustation-Taste System





Taste receptors are located in the taste buds

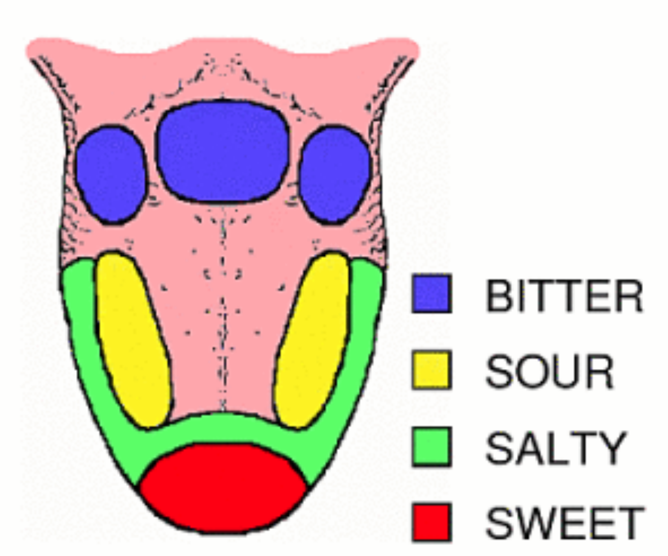


Important

- Taste buds are not neurons
- They are cells from epithelial origin
- Taste buds are innervated by neurons

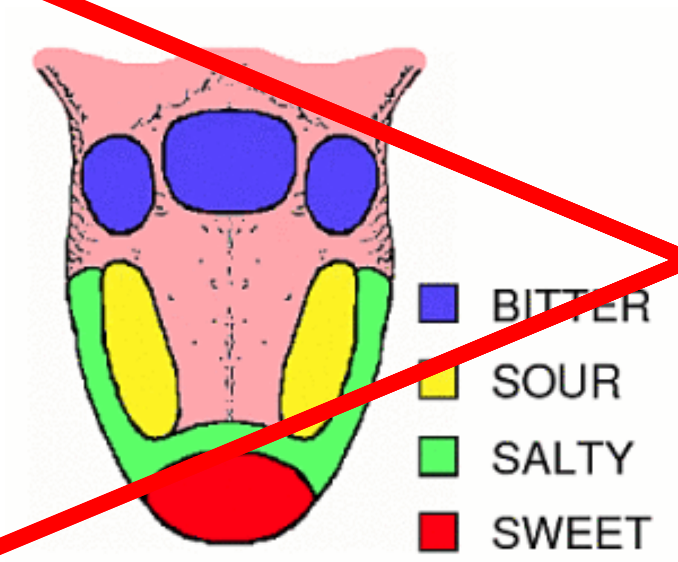
There are five basic tastes

Urban legend about your tongue



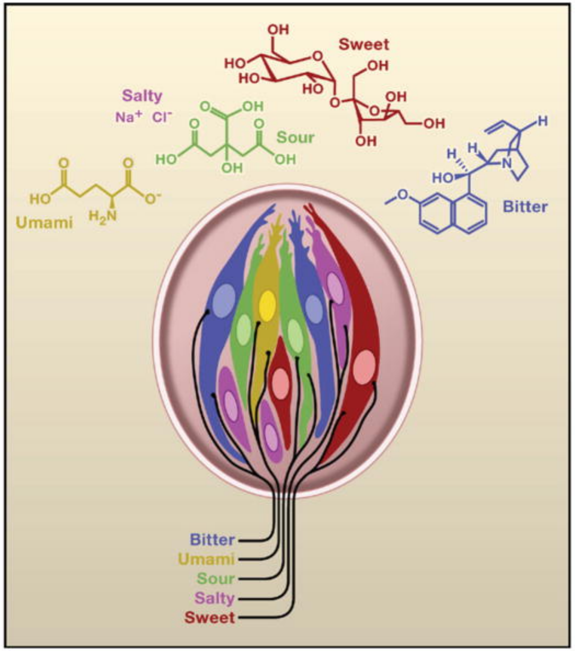
There is a map of tastants in the tongue

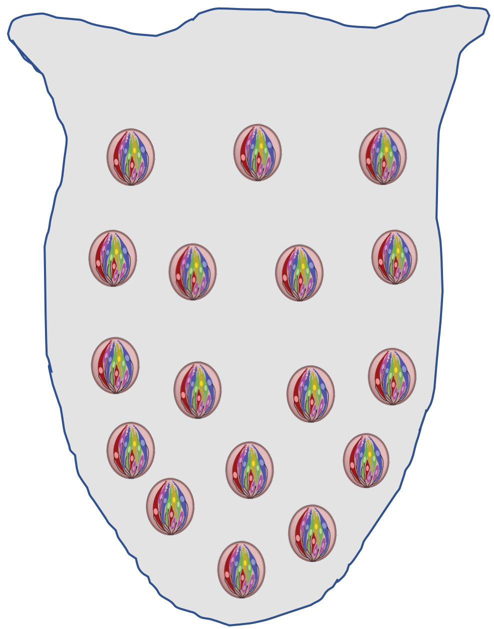
Urban legend about your tongue



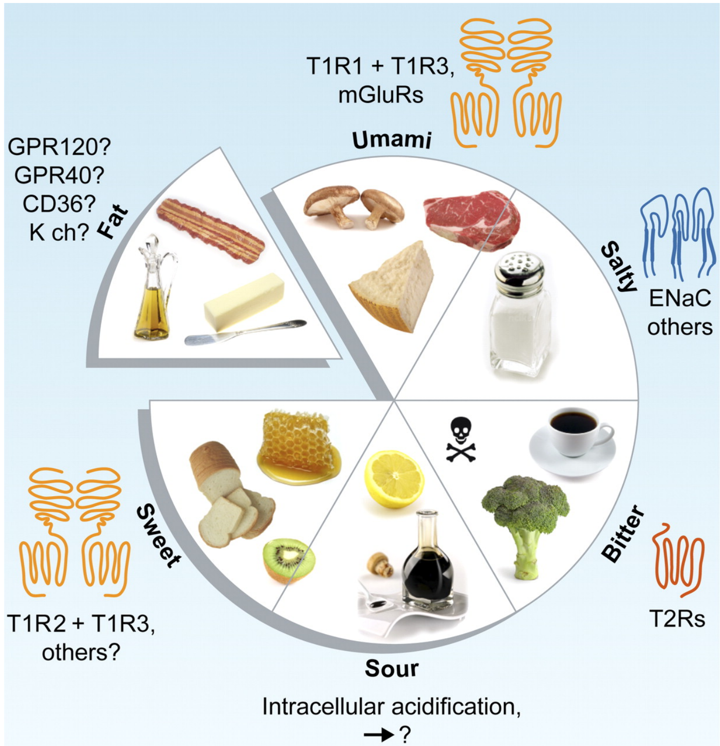
There is a map of tastants in the tongue

Each taste bud responds to multiple tastants





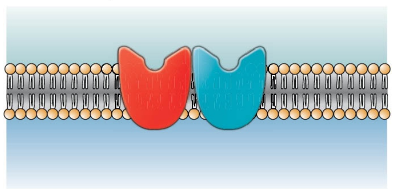
Many taste receptors have been identified



Main family of taste receptors are T1Rs and T2Rs

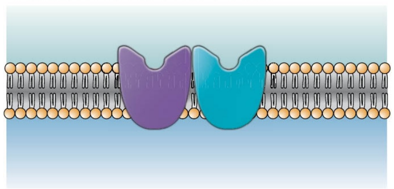
T1Rs

Sweet receptor: T1R2 + T1R3



- Sweet tastants—natural and artificial
- Expressed in different taste cells from bitter receptors

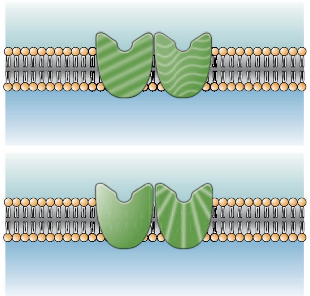
Umami receptor: T1R1 + T1R3



- Detects amino acids
- Expressed in different taste cells from bitter receptors

T2Rs

Bitter receptors: the T2Rs



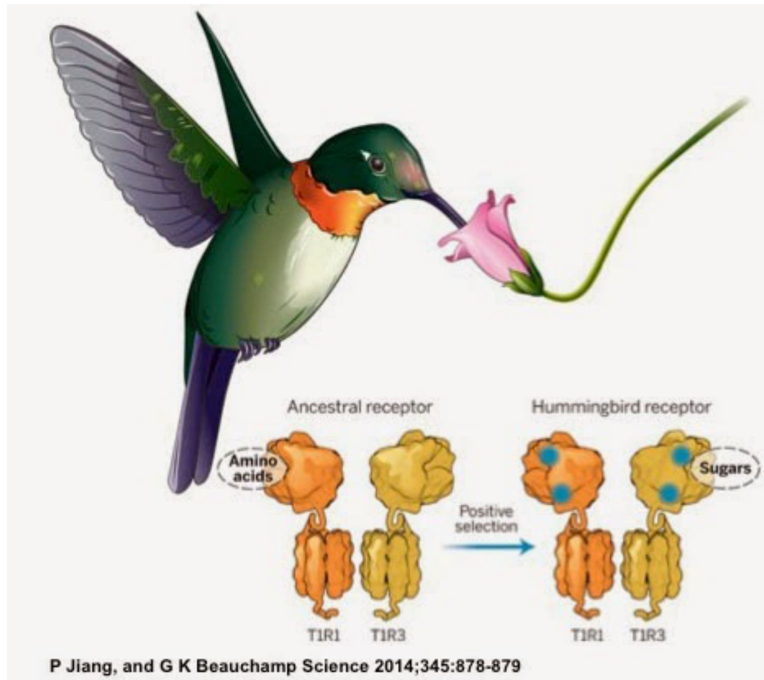
- Detects a variety of bitter compounds
- Expressed in different taste cells from sweet receptors

Variation of sugar receptor (T1R2/T1R3) among animals

- Cats cannot taste sugars because the T1R2 gene in the cat genome has become a pseudogene.
- Thus, cats do not have a functional sugar receptor in their tongue.

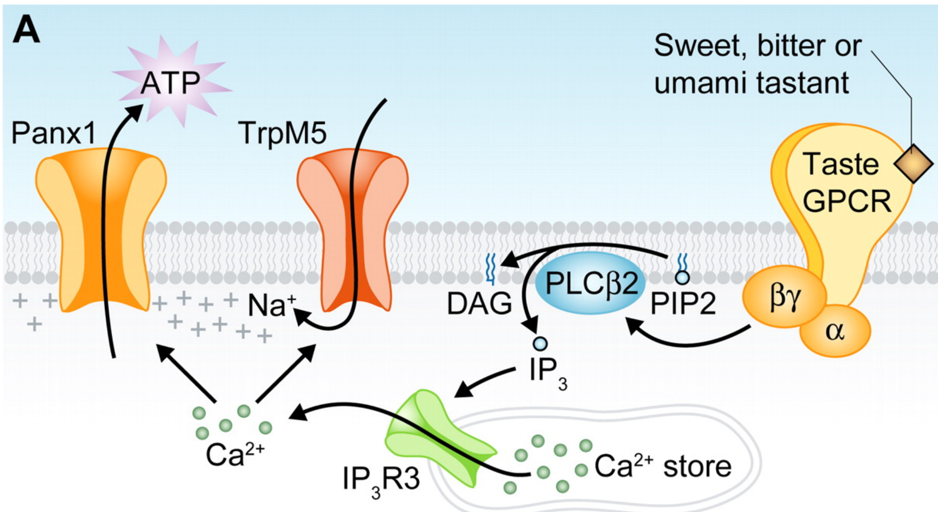
Variation of sugar receptor (T1R2/T1R3) among animals

- Huming birds have converted their amino acid (umami) receptors to an extra sugar receptor.
- Thus they can't sense meat products but have high sensitivity of nectar in flowers



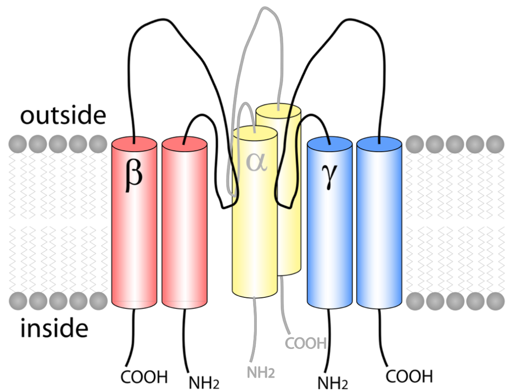
Cellular mechanisms of taste transduction

Sweet, bitter and umami (amino acids) receptors are
G-protein coupled receptors (GPCRs)



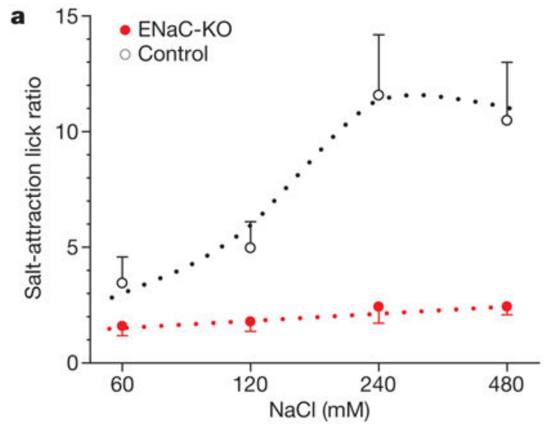
Taste of salt

Epithelial sodium channel (ENaC)



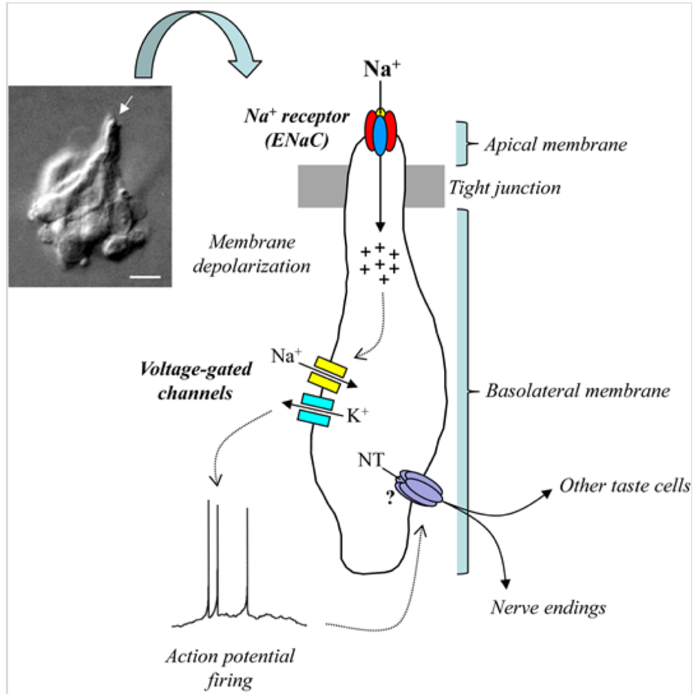
Taste of salt

ENaC mutant mice loose sensitivity to low concentrations of salt

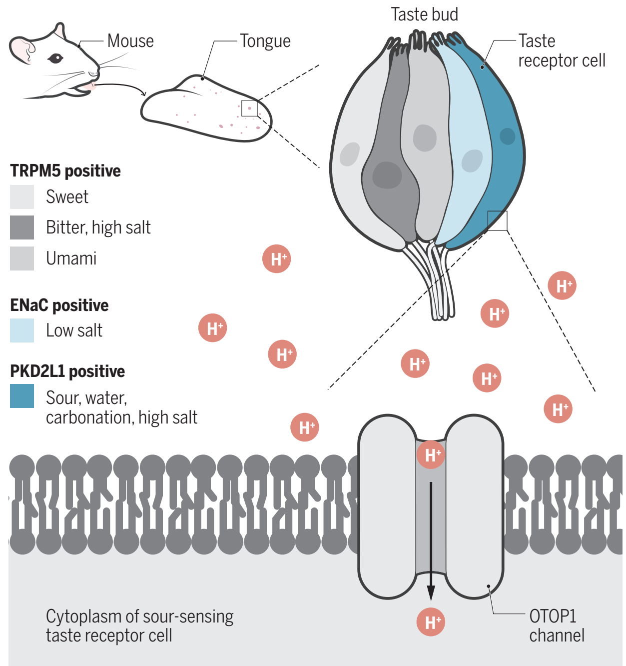


Taste of salt

- ENaC is a Na+ channel which upon activation allow Na+ ions to flow in to the taste cell.
- This inward current leads to membrane depolarization, which in turn activates voltage-gated ion channels underlying action potential firing.
- Communication between sodium-chemosensitive cell and nerve endings could be mediated by neurotransmitter (NT) release, although this is **speculative** at the moment.

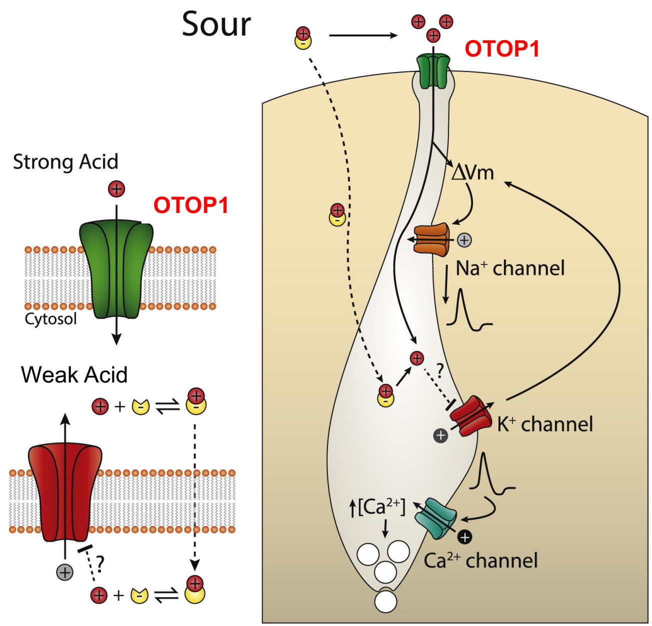


Taste of sour

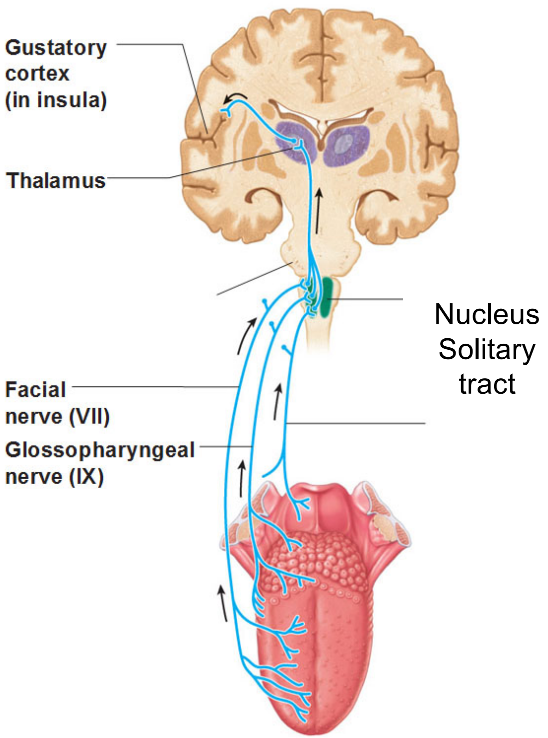


Taste of sour

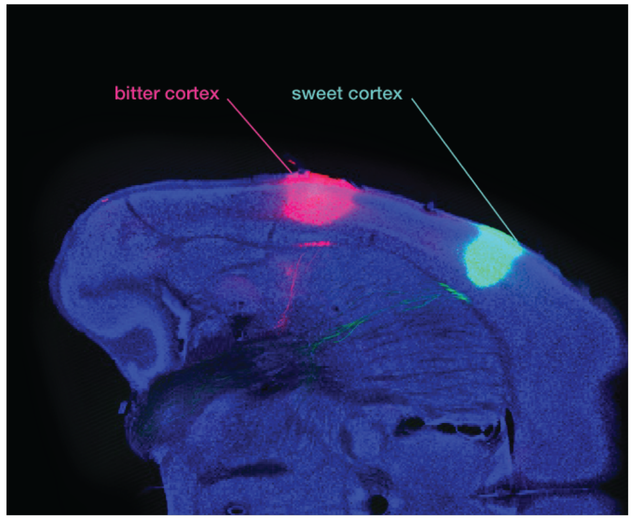
- Weak acids (e.g., acetic acid, HOAc) may nonspecifically diffuse across the membrane in their neutral form.
- H+ channel Otop1 directly mediate entry of strong acids (HCl) equivalents across the apical membrane.
- Proton entry through the H^+ channel result in intracellular acidification ($\downarrow pH_i$), which rises intracellular free Ca^{2+} and triggers neurotransmitter release from the taste cell.



Central Taste Pathways



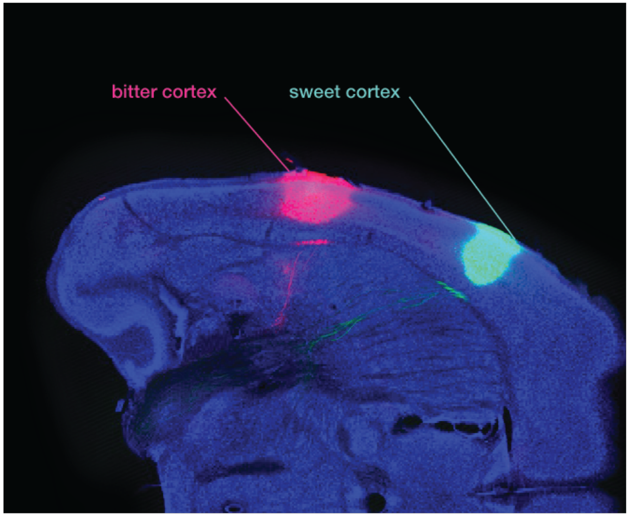
Taste responses is in the cortex



Charles Zucker/Columbia University Medical Centre

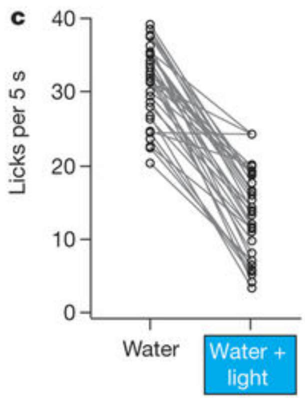
Stimulating bitter cortex inhibits drinking water

Taste responses is in the cortex

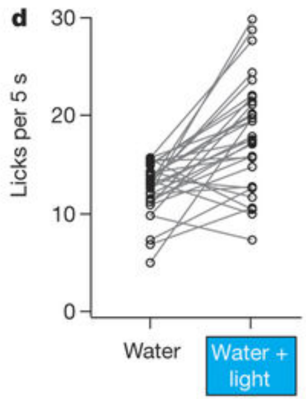


Stimulating sweet cortex stimulates drinking water

Bitter cortex stimulation



Sweet cortex stimulation



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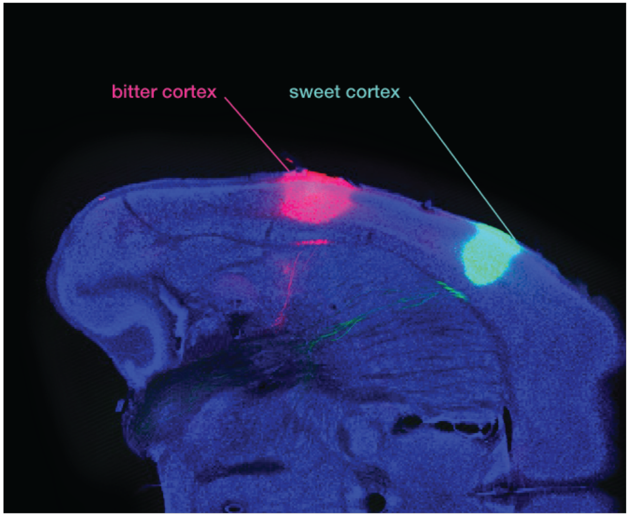


Taste perception two theories

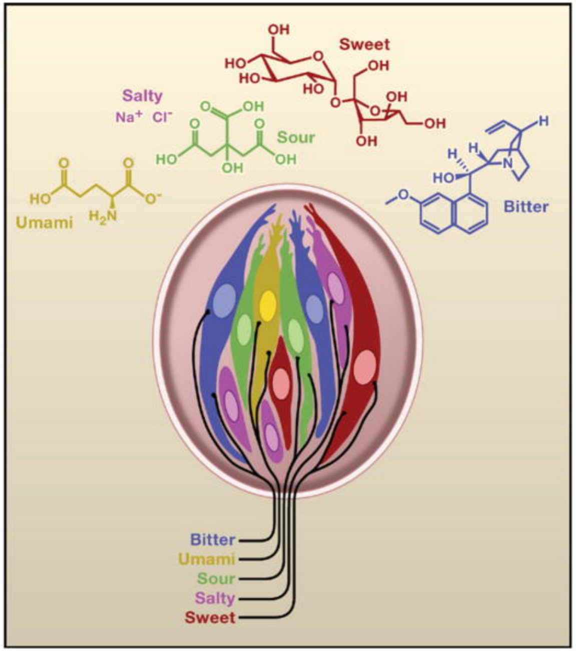
Our brain generates taste perception by integrating the identity and the intensity information that is generated in the taste responsive neurons that innervate the tongue.

Taste perception two theories

1. The first, called “labelled line” refers to a coding model in which peripheral (or central) neurons that respond the most robustly to a given taste modality carry the totality of the information on segregated pathways. This coding scheme may simply be thought of as a wire that goes from the periphery to the higher areas that signals a particular modality (e.g., sucrose). Intensity increases are indicated by an increase in neuronal activity.

2. The second view affirms that a modality and its quantity (intensity) are encoded by ensembles of broadly tuned neurons. This “ensemble code” is also known as “combinatorial” or “across fiber pattern”.

Clicker Question 1:



Assuming there are 5 basic tastes and 10 levels of intensities each taste neuron can generate, what is the number of maximum taste percepts humans theoretically have?

A. 10
B. 5
C. 50
D. 100,000
E. 9,765,625

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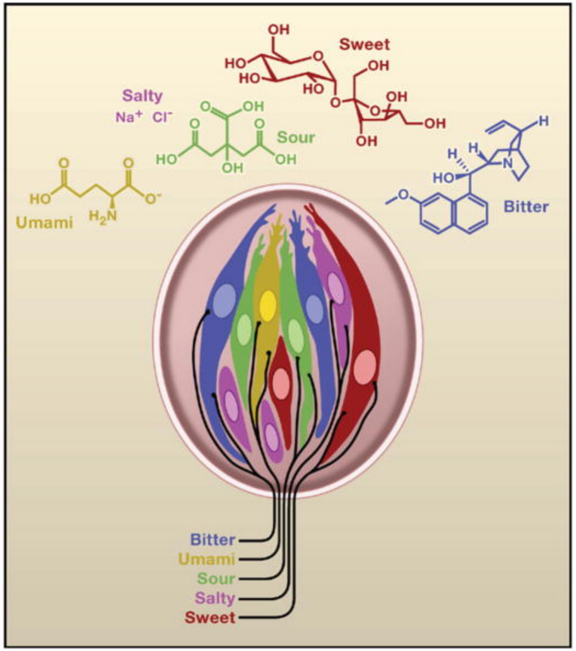

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Clicker Question 2:

Although classified as carnivores Giant Panda's prefer to eat bamboos compared to meat. Which taste receptor has lost its function in pandas?

A. T1R1
B. T1R2
C. T2Rs
D. ENaC
E. OTOP1

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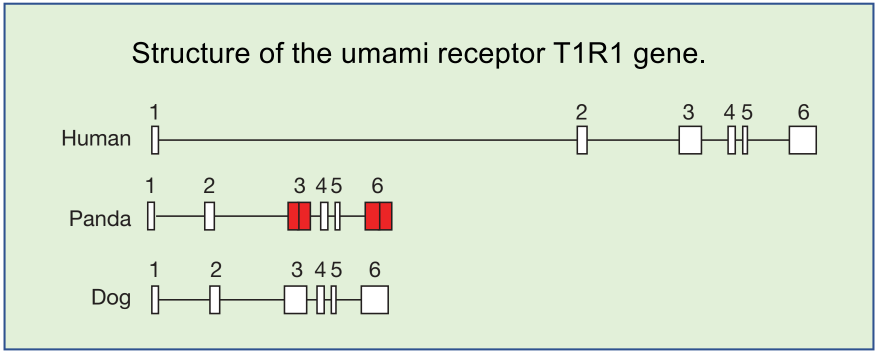

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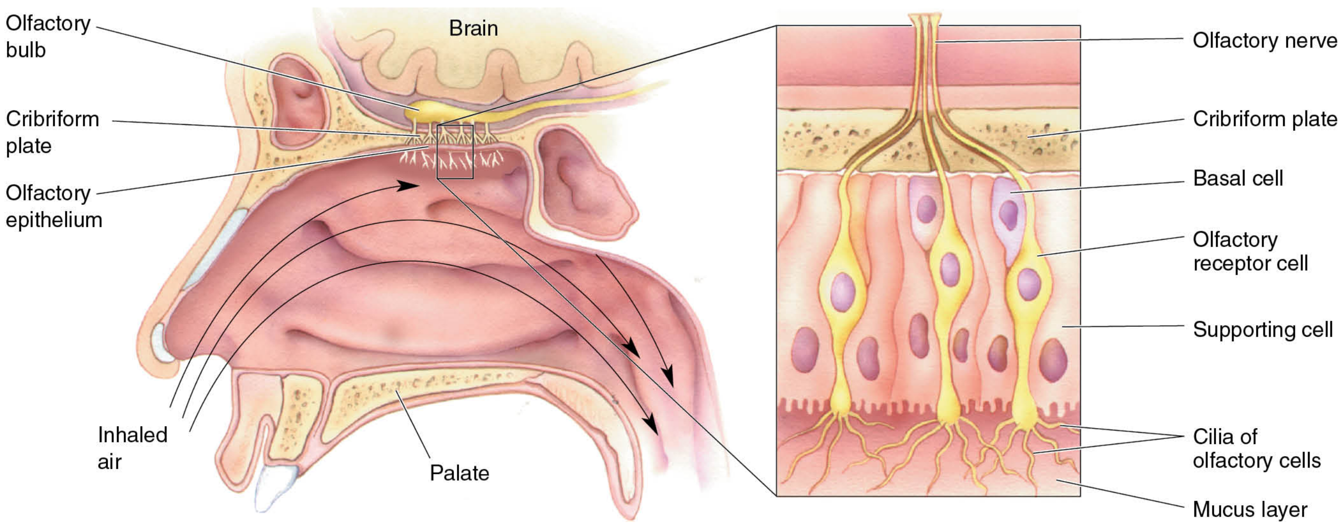
Olfaction-Smell System

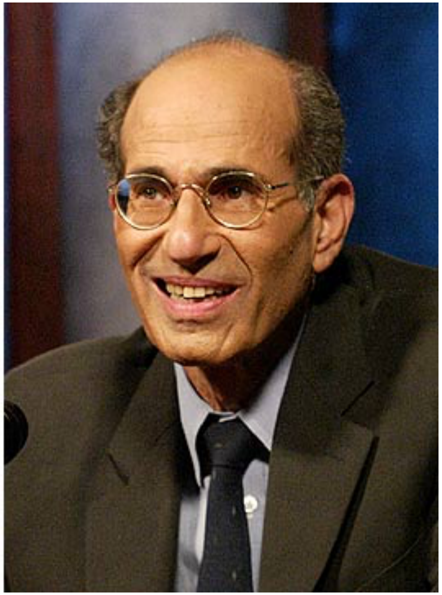
Olfaction-Smell System



Nobel prize for the identification of olfactory receptors

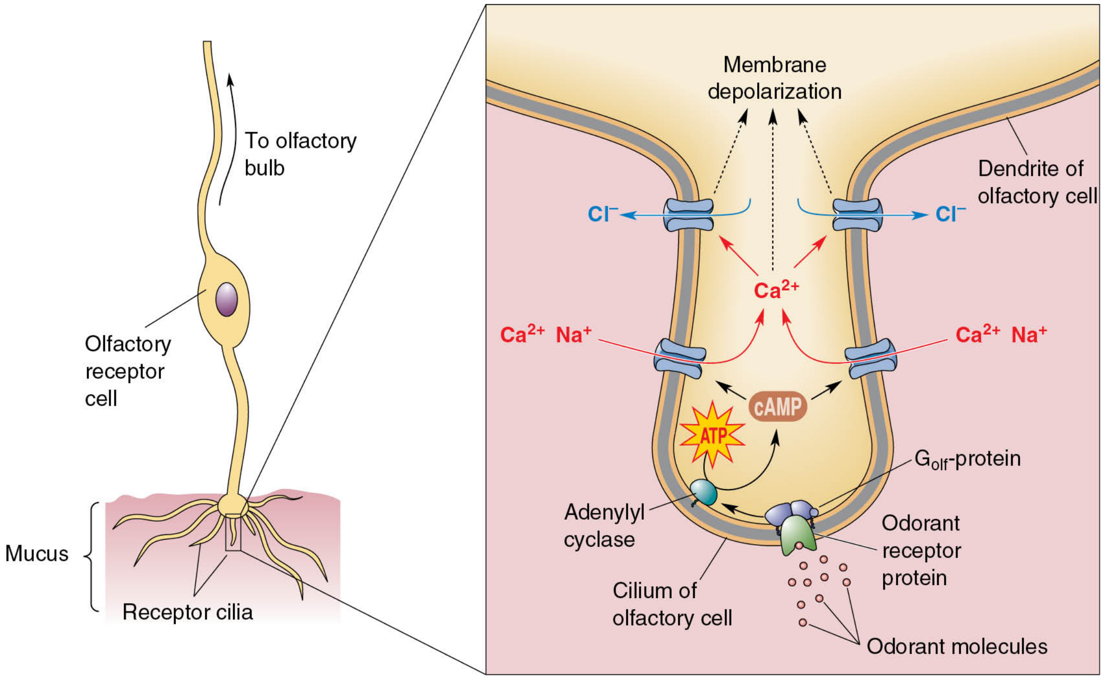
2004

Linda Buck

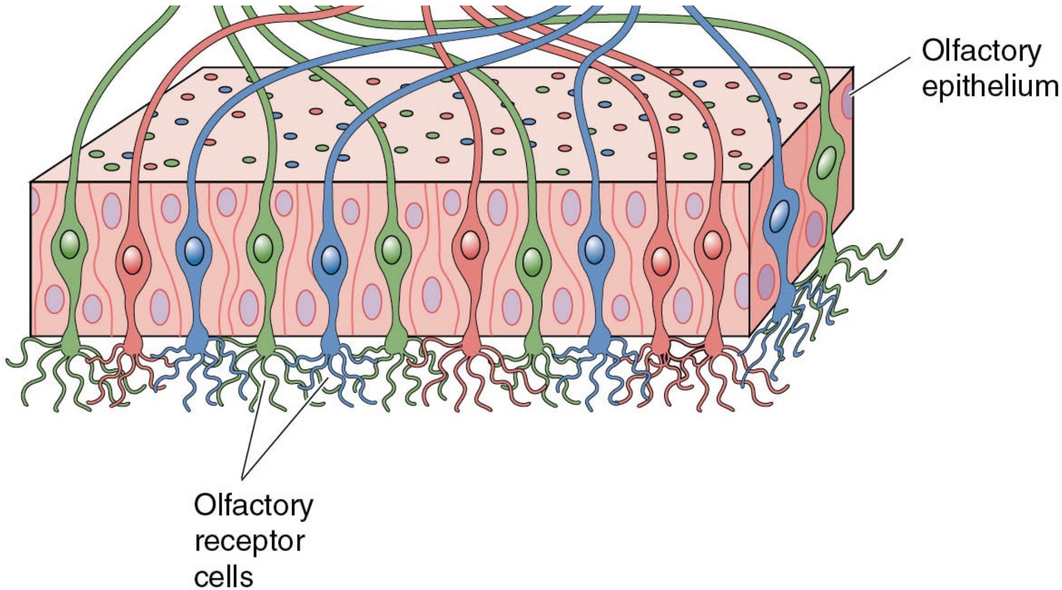


Richard Axel

Olfactory receptors are located in the olfactory sensory neurons

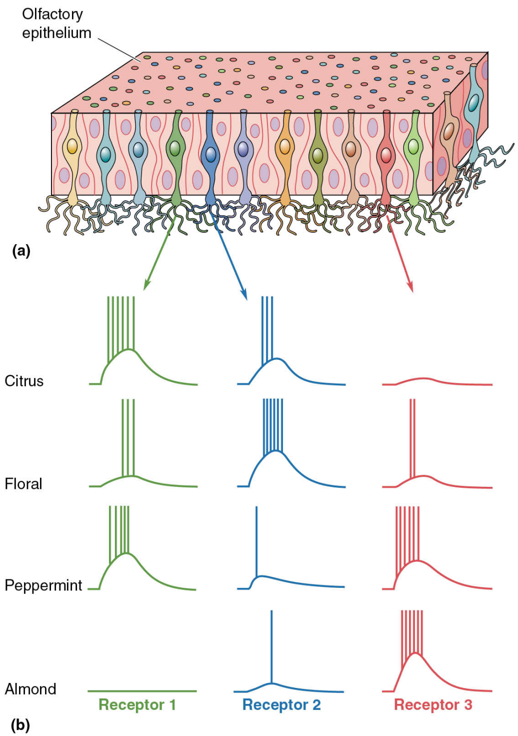


Each olfactory neuron express only one receptor



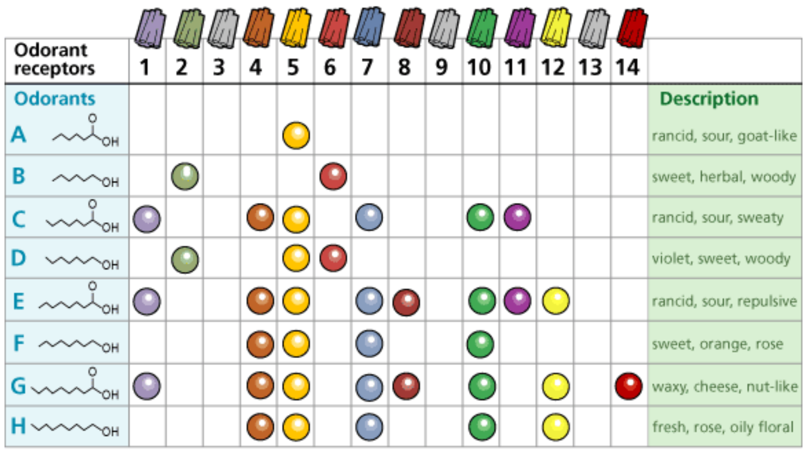
Each olfactory neuron can be stimulated by multiple odors

Unlike taste receptors, olfactory receptors can be activated by multiple odorants



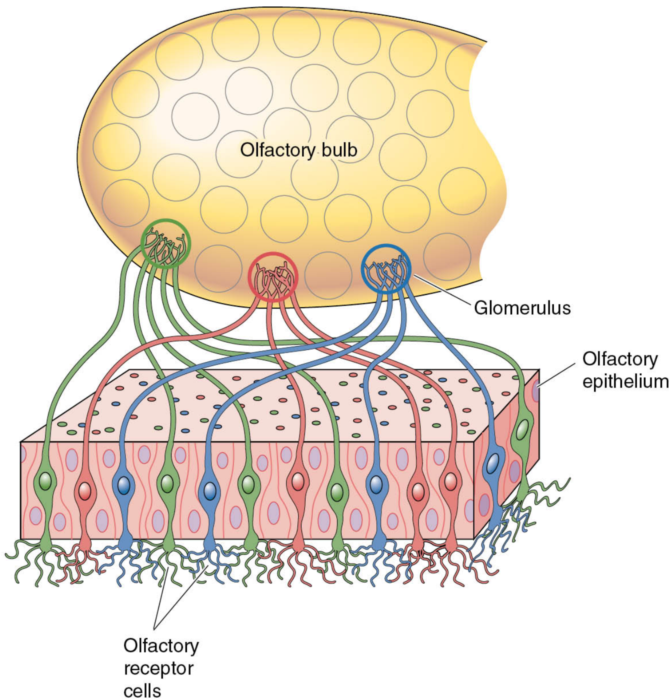
Combinatorial code of olfaction

- One olfactory receptor can be activated by multiple odorants
- Activation of different combinations of olfactory receptors can generate different olfactory percepts



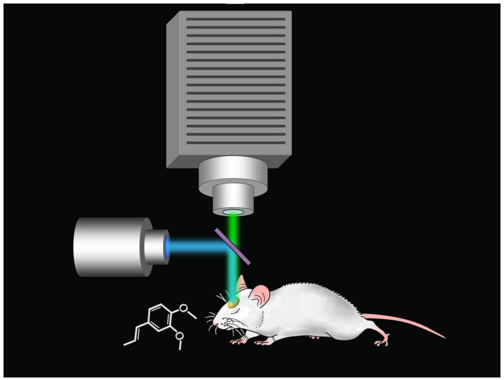
MODIFIED AFTER LINDA BUCK AND COLLEAGUES IN CELL VOL 96, MARCH 5, 1999

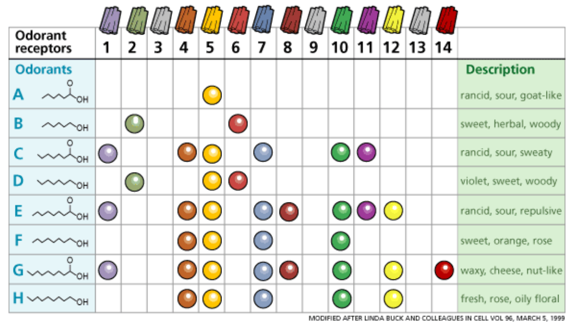
Olfactory sensory neurons project to the olfactory bulb in the brain

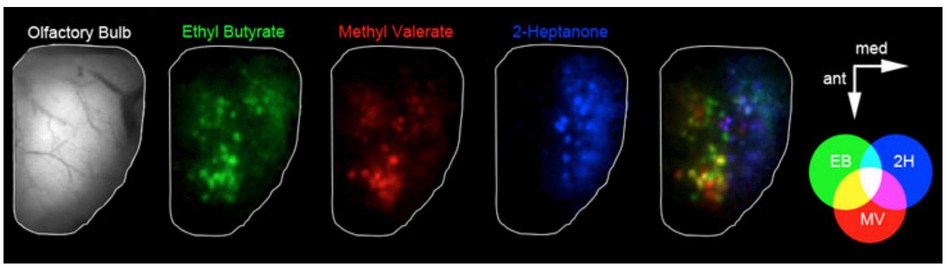


- Each olfactory neuron expressing the same receptor project to the same are called a “glomerulus” in the bulb.

Odor responses overlap in the olfactory bulb



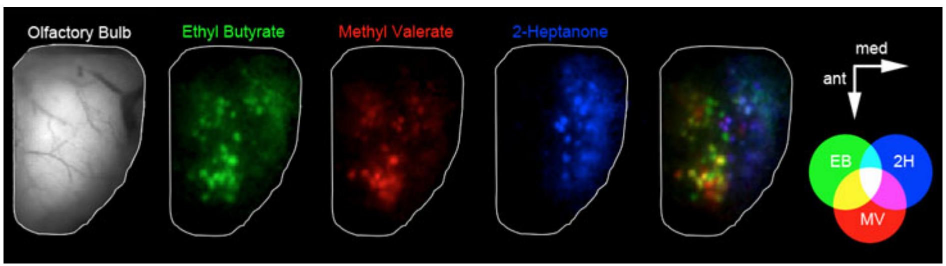




Odor responses overlap in the olfactory bulb

At the level of olfactory bulb, even pure odorants (single molecules) are represented by unique combinations of activity. Rat olfactory system express 1,284 differently tuned receptors, this enables the system to represent

A. 1,284 different pure molecules
B. $2^{1,284}$ different pure molecules
C. Almost an infinite number of pure molecules
D. $3^{1,284}$ different pure molecules
E. None of the above



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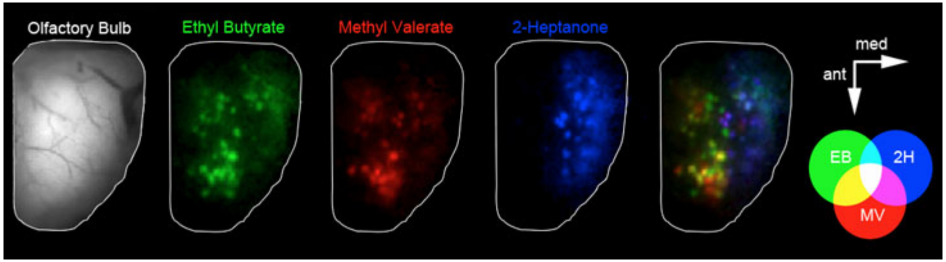
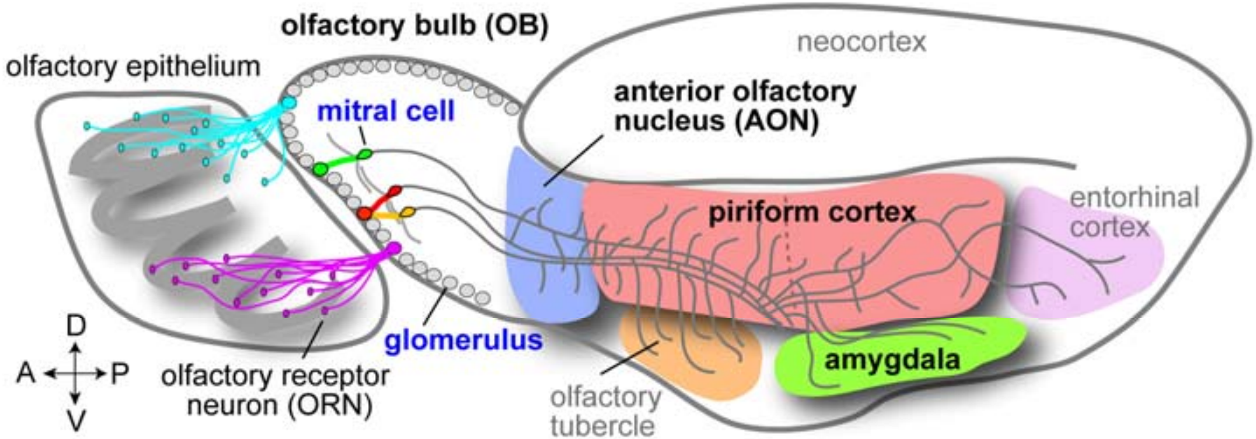


Central pathways of olfaction

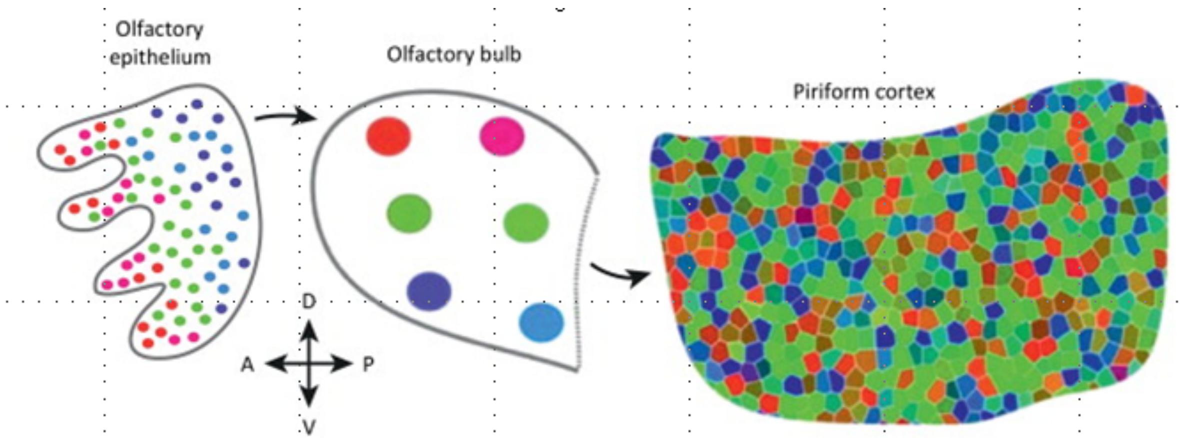
Second order olfactory neurons (mitral cells) project to multiple areas

- Priform Cortex
- Anterior Olfactory Nucleus
- Amygdala



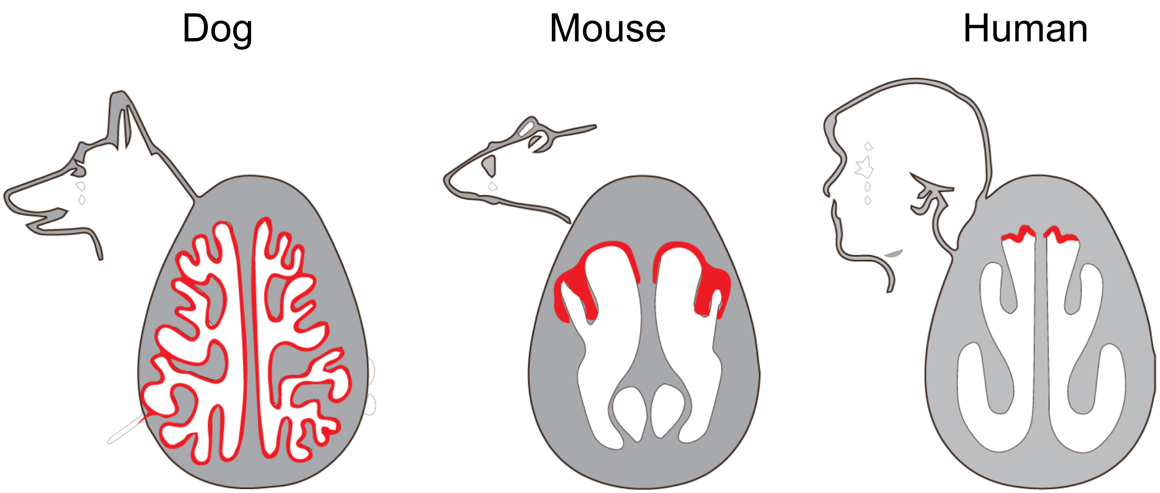
Olfactory representations in the cortex

Different from other senses, there has not been any cortical maps identified in the piriform cortex which evaluates olfactory information.



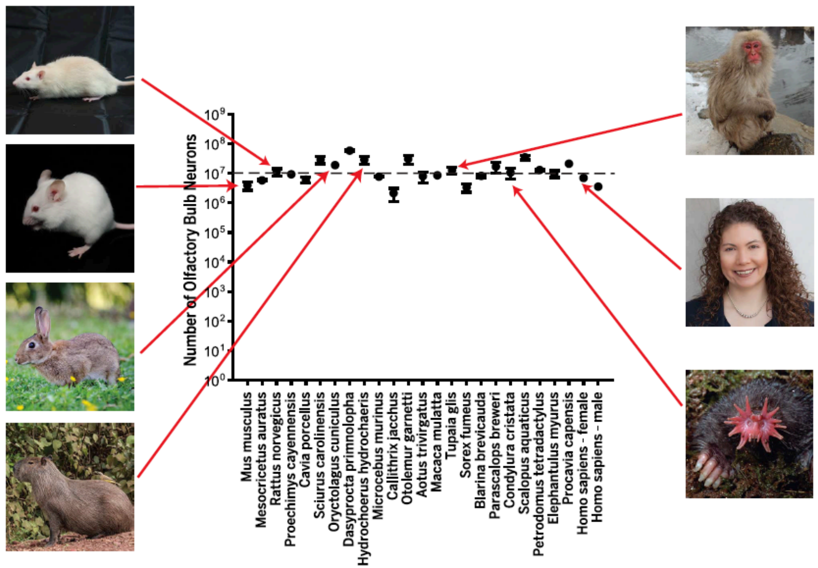
Humans are thought to be poor smellers compared to other animals

The olfactory epithelium of dogs are 40 times larger than humans



Is Poor human olfaction a 19th-century myth?

Comparison of olfactory bulb neuronal numbers across mammalian species.

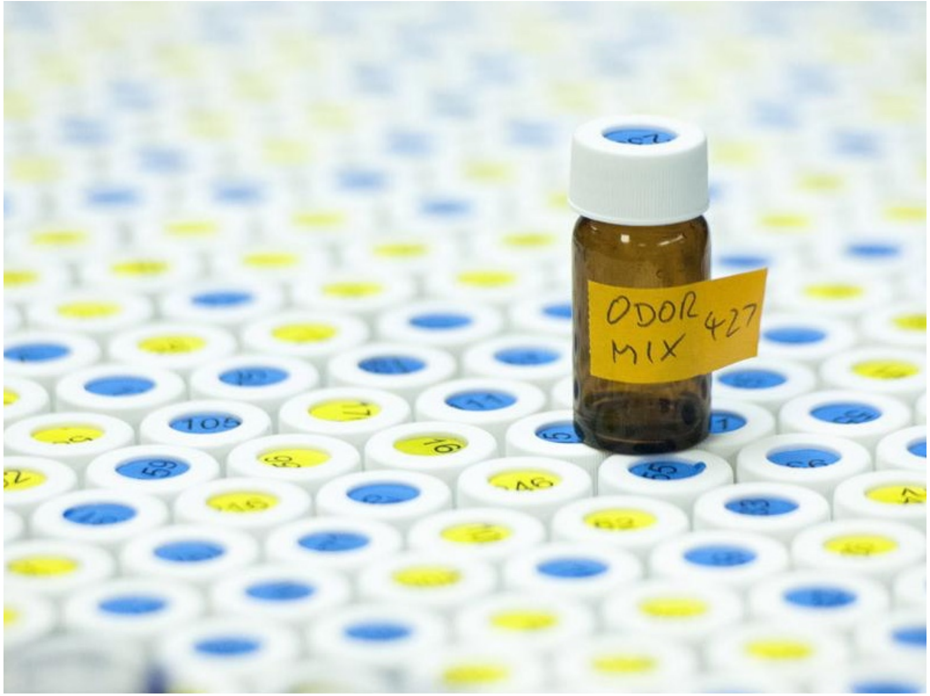


How many odors can humans smell?

Classic view 10,000.

New research ~1 trillion!

More research is needed to expand our knowledge!



Human Sniffer

Jess Porter and Noam Sobel at the University of California in Berkeley, US, and colleagues tested whether 32 people were able to follow a 10-metre-long scent trail of chocolate essence through open grass using only their noses. Two-thirds of them could.

Super Human smellers

Clicker Question 4:

Androstenone, an odorous steroid derived from testosterone, is variously perceived by different individuals as offensive ("sweaty, urinous"), pleasant ("sweet, floral") or odorless. **OR7D4** is the major receptor for androstenone. Why do people perceive androstenone differently?

A. OR7D4 gene does not exist in some people
B. People carry different variants of the OR7D4 gene that has different binding sensitives to androstenone
C. Some people lack the olfactory neuron that responds to androstenone
D. Some people have defects in piriform cortex that effects perception of androstenone specifically.
E. B and D

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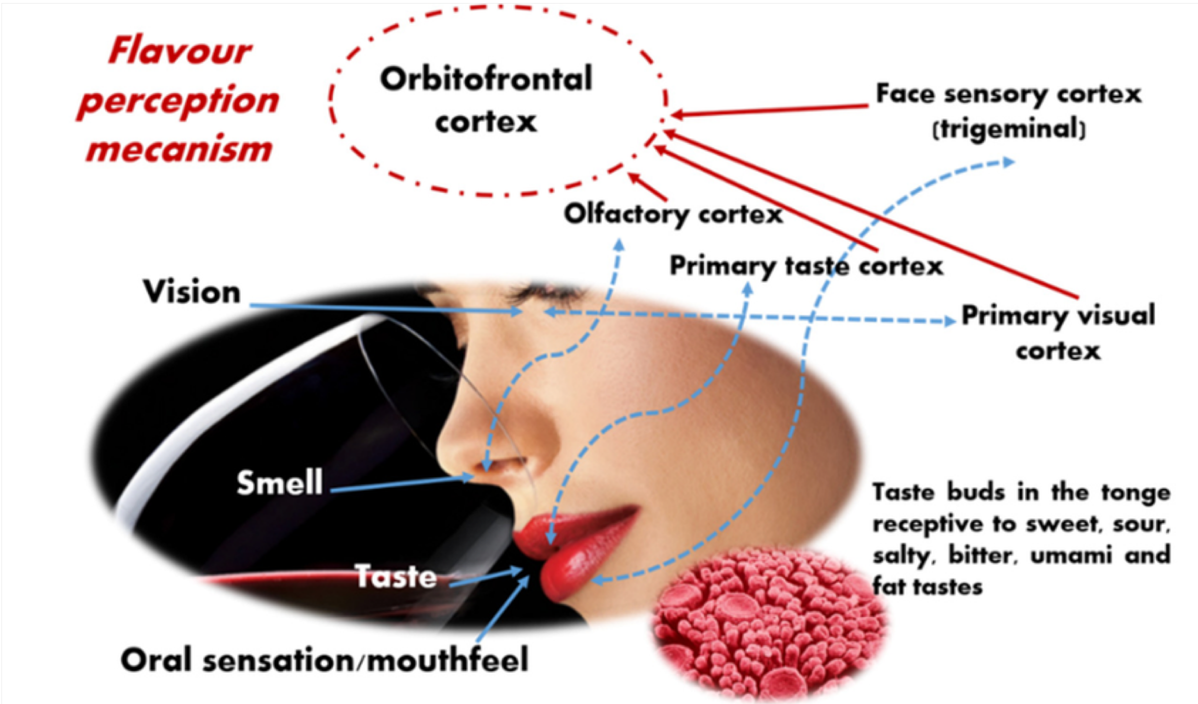
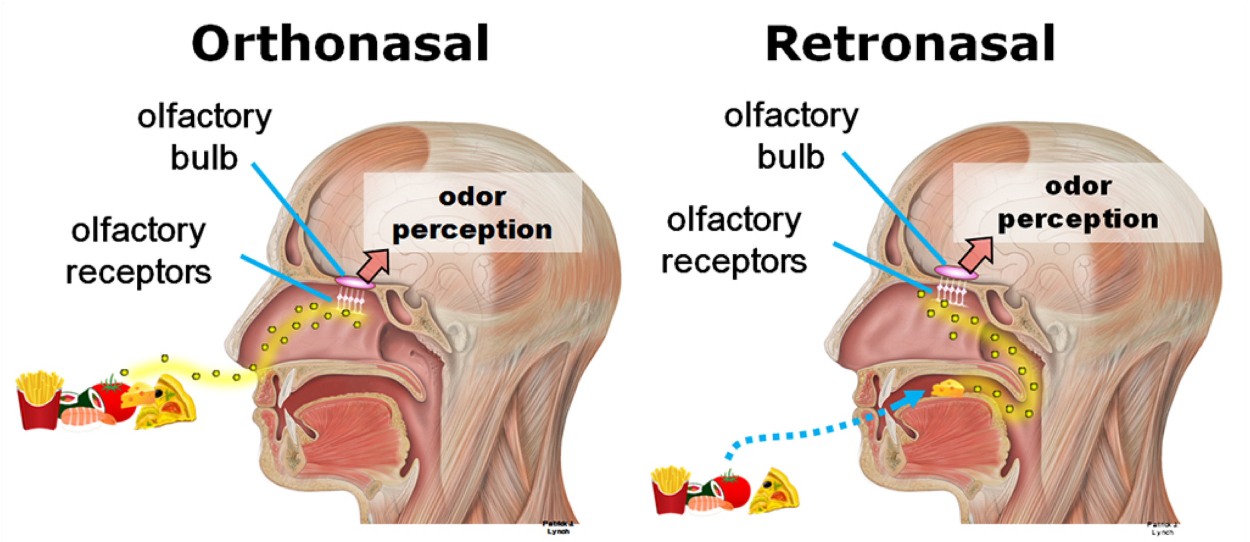
Vison+Taste+Smell= Flavor



Both ortohonasal and retronasal olfaction contributes to flavor perception



Take home messages

- Chemical stimuli, taste and olfaction is different from other senses because they are multi dimensional.
- The neural pathway for taste processing is similar to that of other sensory systems whereas the olfactory system bypasses the thalamic relay to enter cortical areas directly.
- Taste receptors are expressed in epithelial cells called taste buds. Taste buds are innervated with sensory neurons that carry taste information to the brain. Taste buds that sense sugar, bitter, sour and salt are distributed across the tongue.
- Olfactory receptors (ORs) recognizes multiple odorants and that one odorant is recognized by multiple ORs. Thus, the olfactory system uses a combinatorial receptor coding scheme to encode odor identities.

Next Lecture : Auditory System