Chemical senses

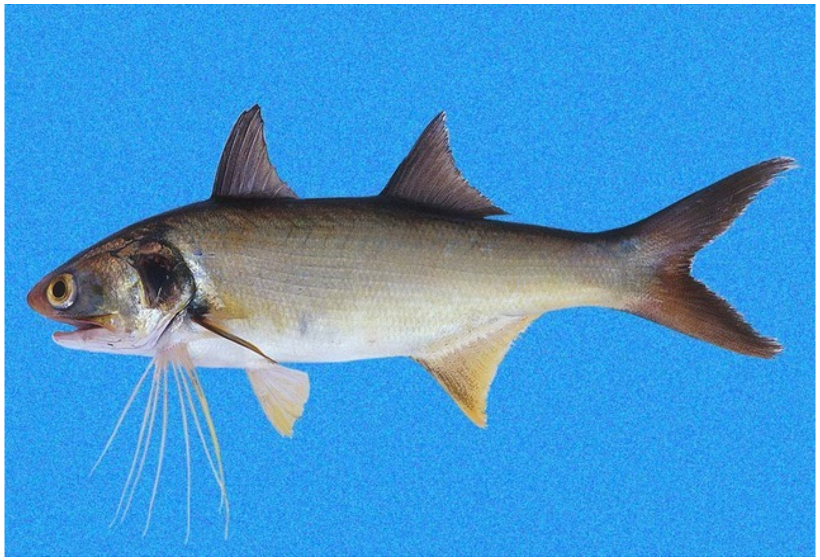
The chemical senses may be divided into four categories:

•Common chemical: all cells that are senstive to chemical substances and which respond in ways that are communicated as signals to the nervous system

•Internal receptors: subclass of common chemical receptors, which are specialized for monitoring various aspects of the chemical composition of body that are vital for life (oxygen, glucose, pH).

•Taste: sensing substances within our mouths

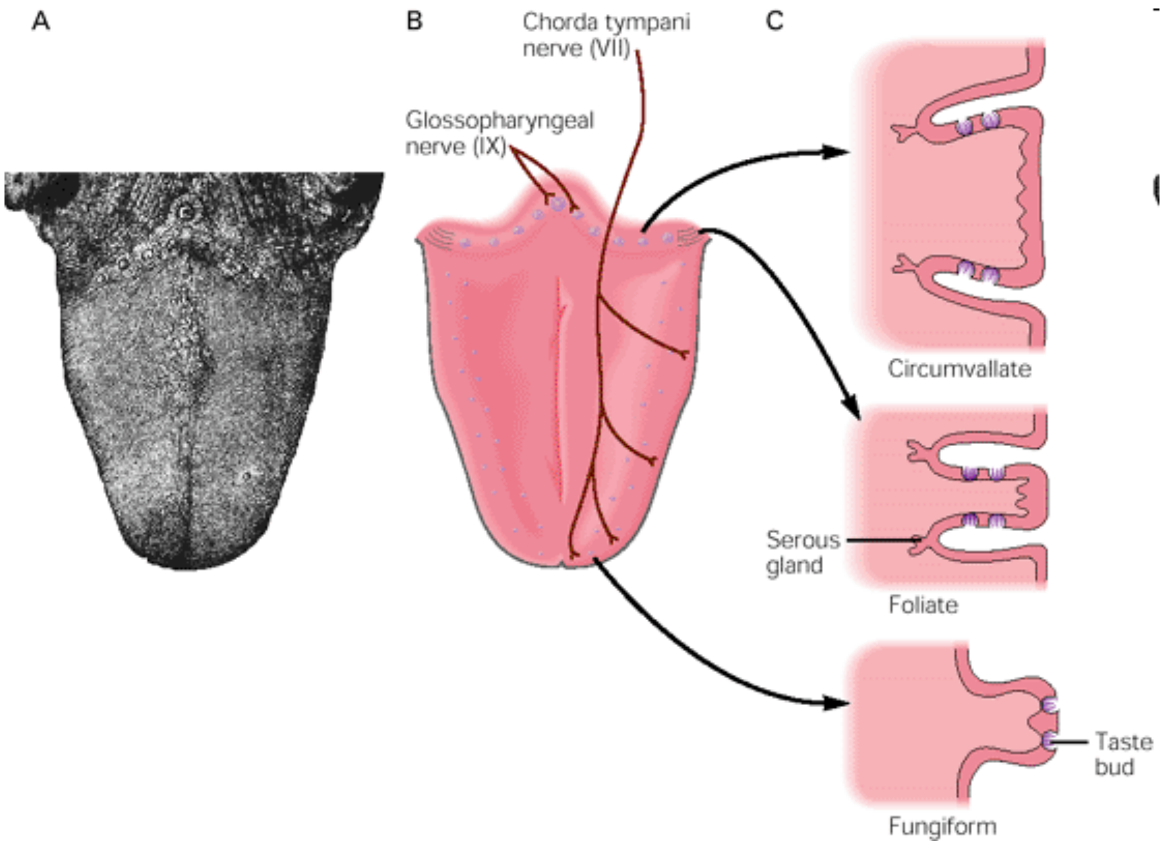
•Smell: sensing airborne substances



Taste receptors are not always limited to mouth. In Threadfins fish, taste receptors are located at the tips of the thin projections from the fins.

Tongue - the main taste organ

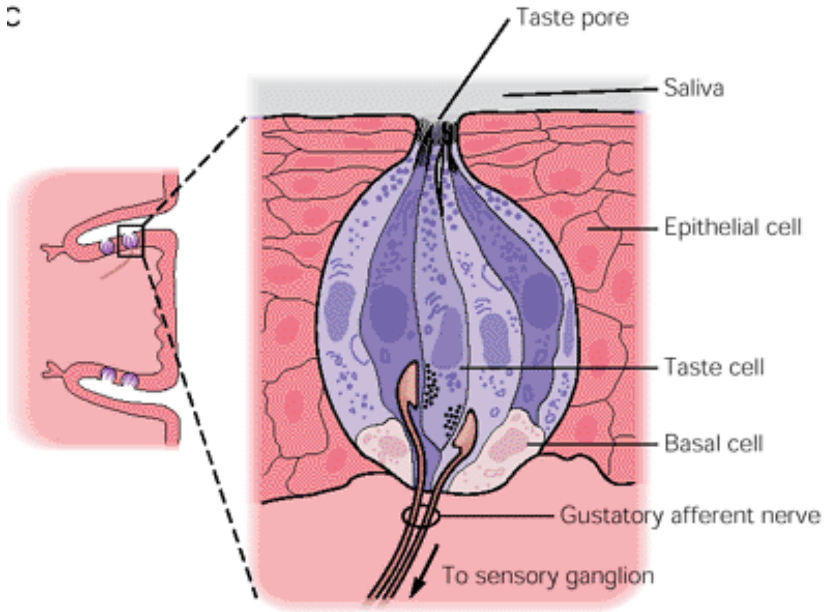
Tongue is a muscle covered by bumps and folds called papillae. Some papillae contain the taste buds. Molecules that can be tasted are detected by taste cells clustered in taste buds. There are about 5000 taste buds on average, but the number is highly variable (up to 100 times in some papillae).



Innervation of the taste buds of the tongue.

The main types of taste papillae are shown in cross sections. Each type predominates in specific areas of the tongue, as indicated by the arrows from B.

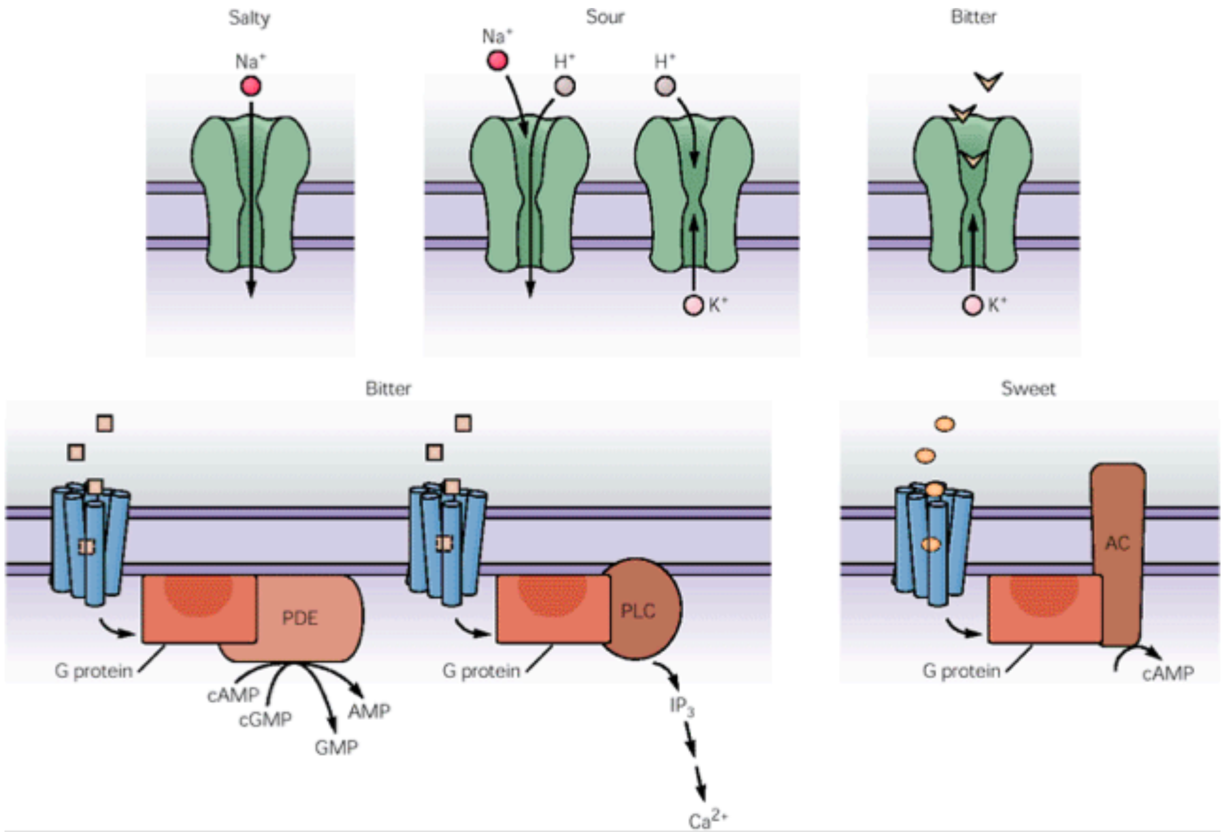
Taste buds



Each taste bud contains 50-150 taste cells that extend from the base of the taste bud to the taste pore. Taste cells are short-lived cells (10-14 days) that are replaced from stem cells at the base of the taste bud. Taste stimuli, detected at the apical end of the taste cell, induce action potentials that cause the release of neurotransmitter at synapses formed at the base of the taste cell with gustatory fibers that transmit signals to the brain.

Five taste qualities

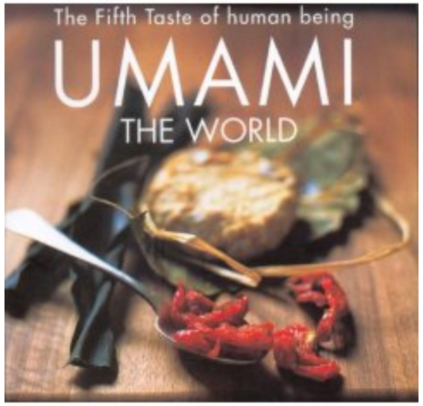
The gustatory system distinguishes five basic stimulus qualities: bitter, salty, sour, sweet and *umami*.

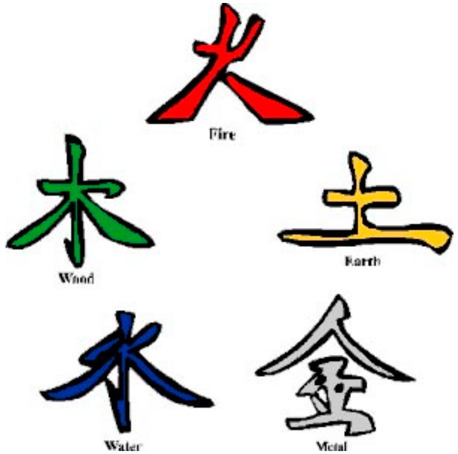


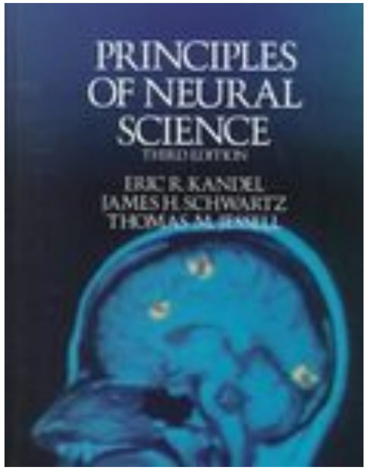
Four basic taste stimuli are transduced into electrical signals by different mechanisms.
Salty taste is mediated by Na+ influx through Na+-selective channels depolarizing the cell directly.
Sour taste can result from either the passage of H+ ions through Na+ channels or from the blockade of pH-sensitive K+ channels, which are normally open at resting potential.
Bitter, sweet and **umami** stimuli bind to G protein-coupled receptors. The common end effect of all of these mechanisms is release of Ca2+ from intracellular stores and reduction of calcium-gated K+ currents and depolarization of the cell.

Umami

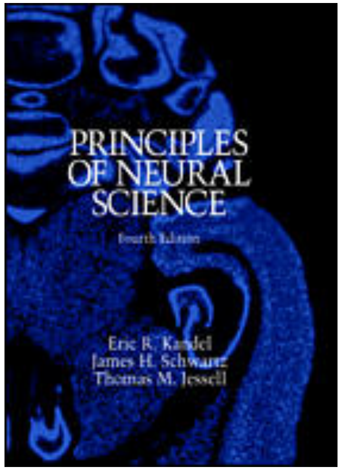
Prof. Kikunae Ikeda



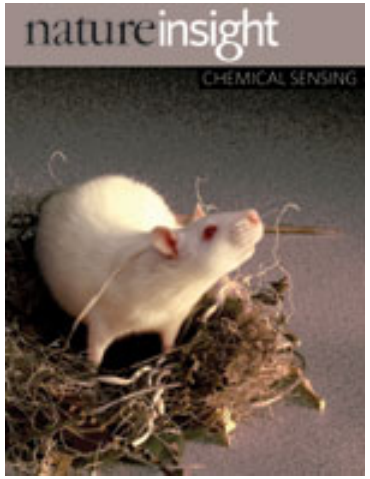




III edition, 1992: *„...Monosodium glutamate may represent a fifth category, but this is controversial".*



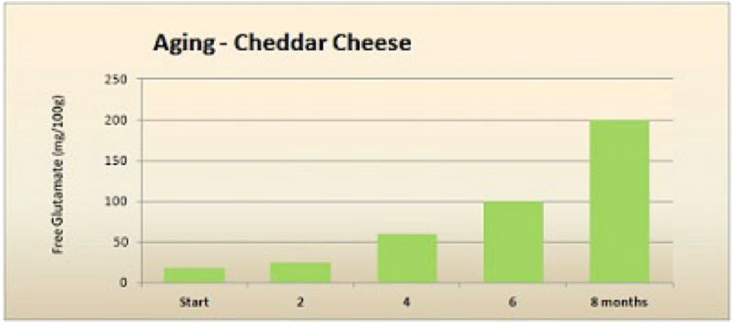
IV edition, 2000: *„...Some consider the taste of monosodium glutamate to represent a fifth category of taste stimuli, umami."*



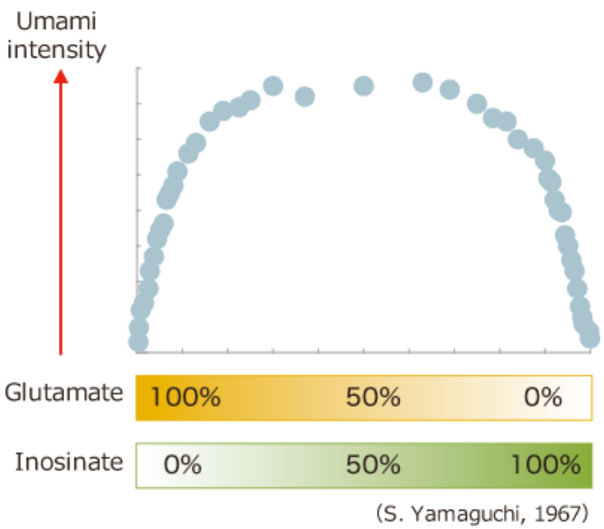
Nature, **444**, 287 (16 November 2006):

„The sense of taste comprises at least five distinct qualities: sweet, bitter, sour, salty, and umami, the taste of glutamate. „

Umami

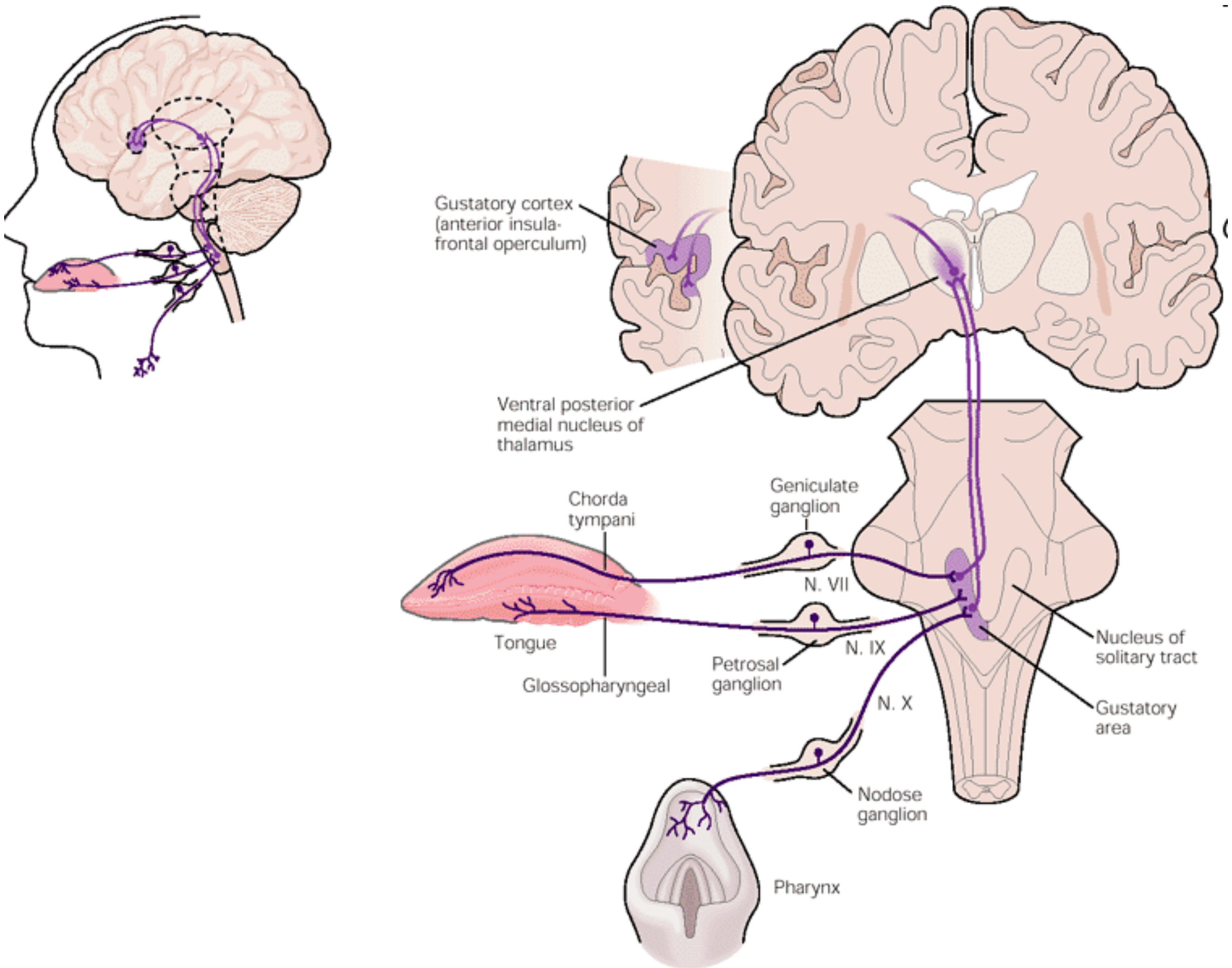


To provide umami, most raw foods need to be processed (cooking, maturing, fermenting) to break down the proteins into free amino acids and the nucleic acid into free glutamate.



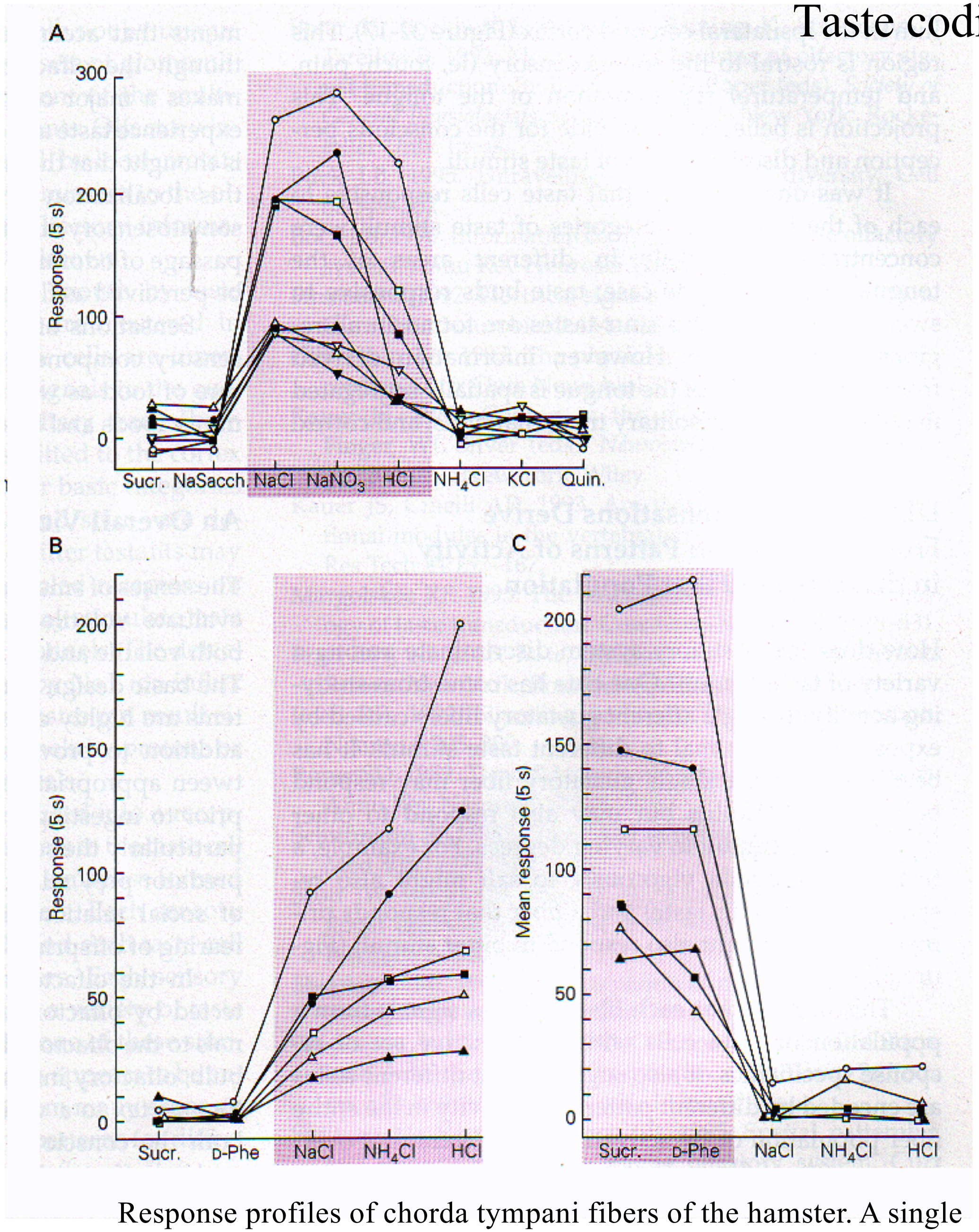
Umami comes from glutamate and a group of chemicals called ribonucleotides (inosinate and guanylate), which also occur naturally in many foods. Combining ingredients containing these different umami-giving compounds gives more flavor than the sum of its parts. E.g., this effect is part of what makes umami reach taste of pizza, cheeseburger or spaghetti Bolognese: cheese, tomato (glutamate) and meat (inosinate).

Gustatory pathway



Taste information is transmitted from the taste buds to the cerebral cortex via synapses in the brain stem and thalamus. The thalamus transmits taste information to the gustatory cortex.

Taste coding

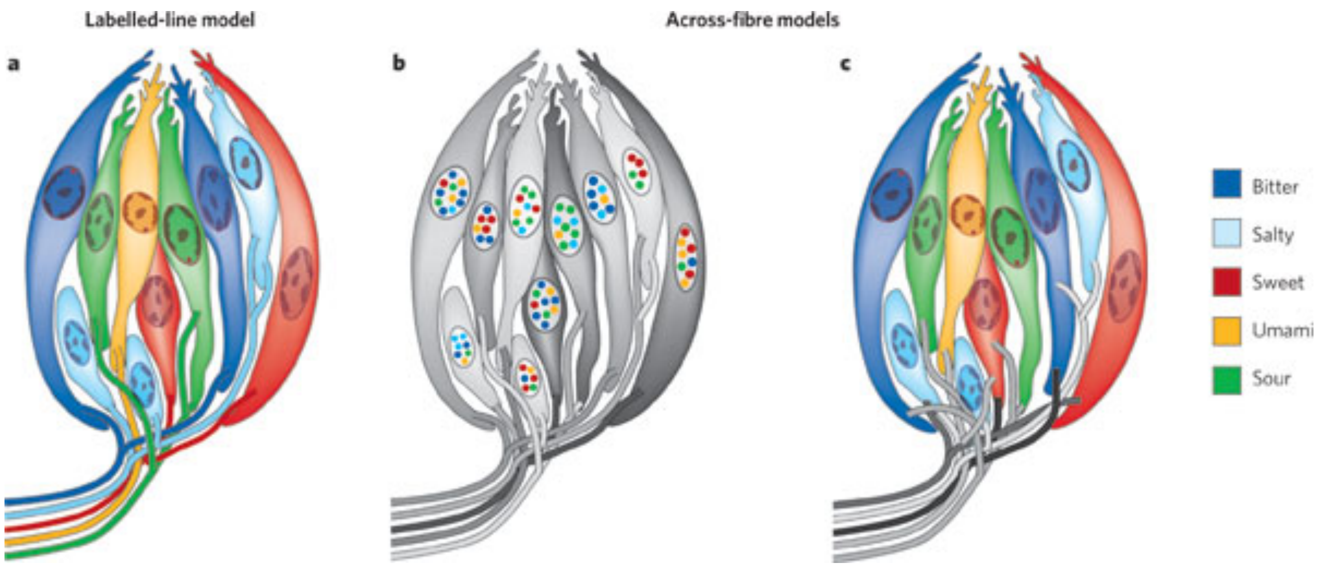


Response profiles of chorda tympani fibers of the hamster. A single gustatory fiber responds best to one stimulus but may also respond to other types of taste stimuli to varying degrees.

Taste sensation → pattern of activity in the entire fibre population

(across fiber patterns)

Labelled line vs. across - fibre

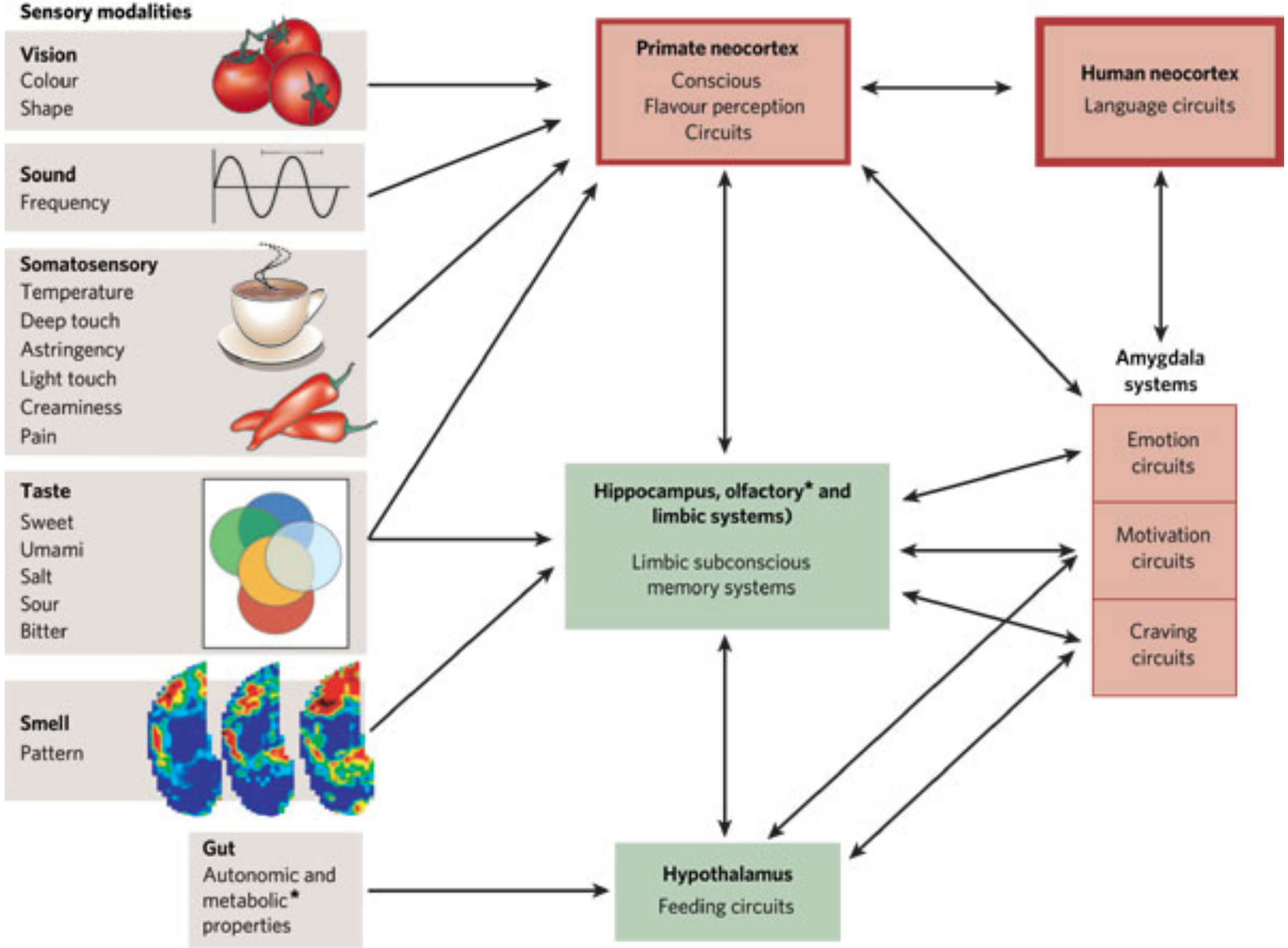


„Recent molecular and functional studies in mice have demonstrated that different TRCs define the different taste modalities, and that activation of a single type of TRC is sufficient to encode taste quality, strongly supporting the labelled-line model."

Jayaram Chandrashekar, Mark A. Hoon, Nicholas J. P. Ryba and Charles S. Zuker *The receptors and cells for mammalian taste. Nature* ***444****, 288-294 (16 November 2006)*

Flavor perception

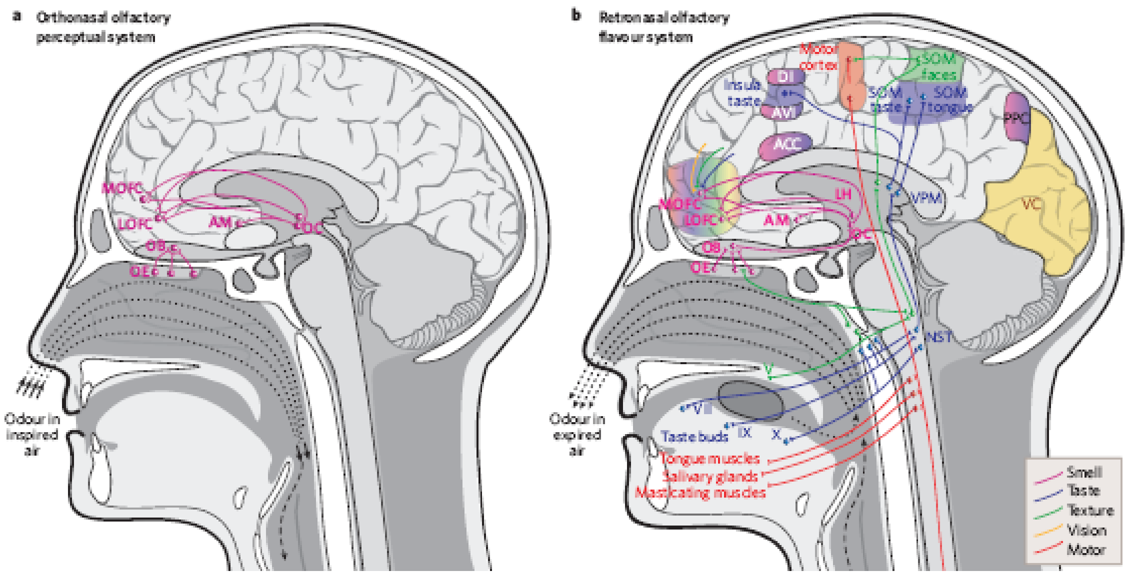
The sensation of flavors is one of the most complex human behaviors. It results from a combination of gustatory, olfactory, visual, auditory and somatosensory inputs.



From: Gordon M. Shepherd *Smell images and the flavour system in the human brain* Nature 444, 316-321(16 November 2006)

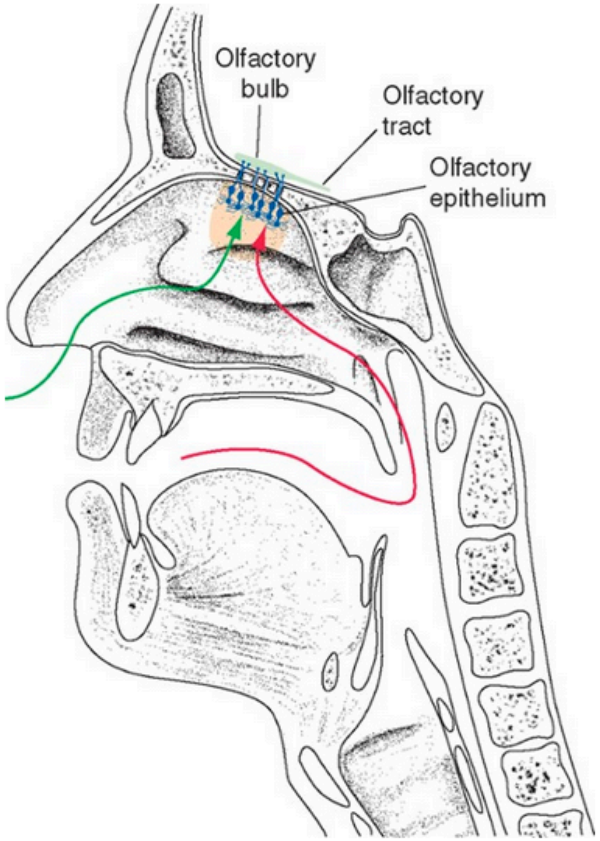
Dual nature of smell

Smell has a ‘dual nature’ — it can sense signals originating outside (orthonasal) and inside (retronasal) the body. Orthonasal stimulation refers to sniffing in through the nose. This route is used to sense odours in the environment. Retronasal stimulation occurs during food ingestion, when volatile molecules released from the food in the mouth are pumped up to the olfactory epithelium. It is activated only when breathing out through the nose. Because the molecules arise from the food in the mouth, they are perceived as if they are sensed within the mouth. This retronasal smell has been shown to be necessary for flavour identification. Thus, although a large part of flavour is due to smell, it is attributed to ‘taste’,



From: Gordon M. Shepherd *Smell images and the flavour system in the human brain* Nature 444, 316-321(16 November 2006)

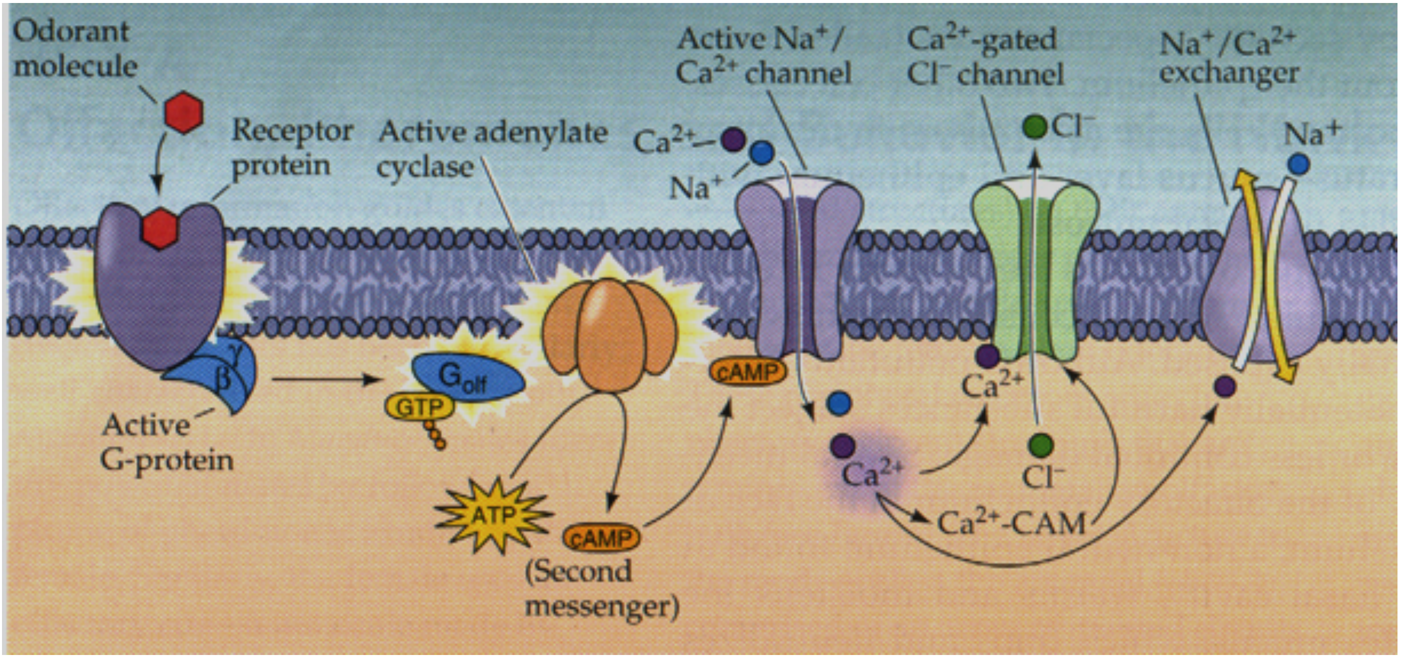
Olfactory receptors



Scanning electron micrograph of the bottom of olfactory receptor cell with receptive olfactory cilia.

The initial events in olfactory perception occur in olfactory sensory neurons in the nose. These neurons are embedded in the olfactory epithelium that in humans covers a region in the back of the nasal cavity about 5 cm^2 in size. The human olfactory epithelium contains several million olfactory sensory neurons, which are short-lived, with an average life span of only 30-60 days, and are continuously replaced.

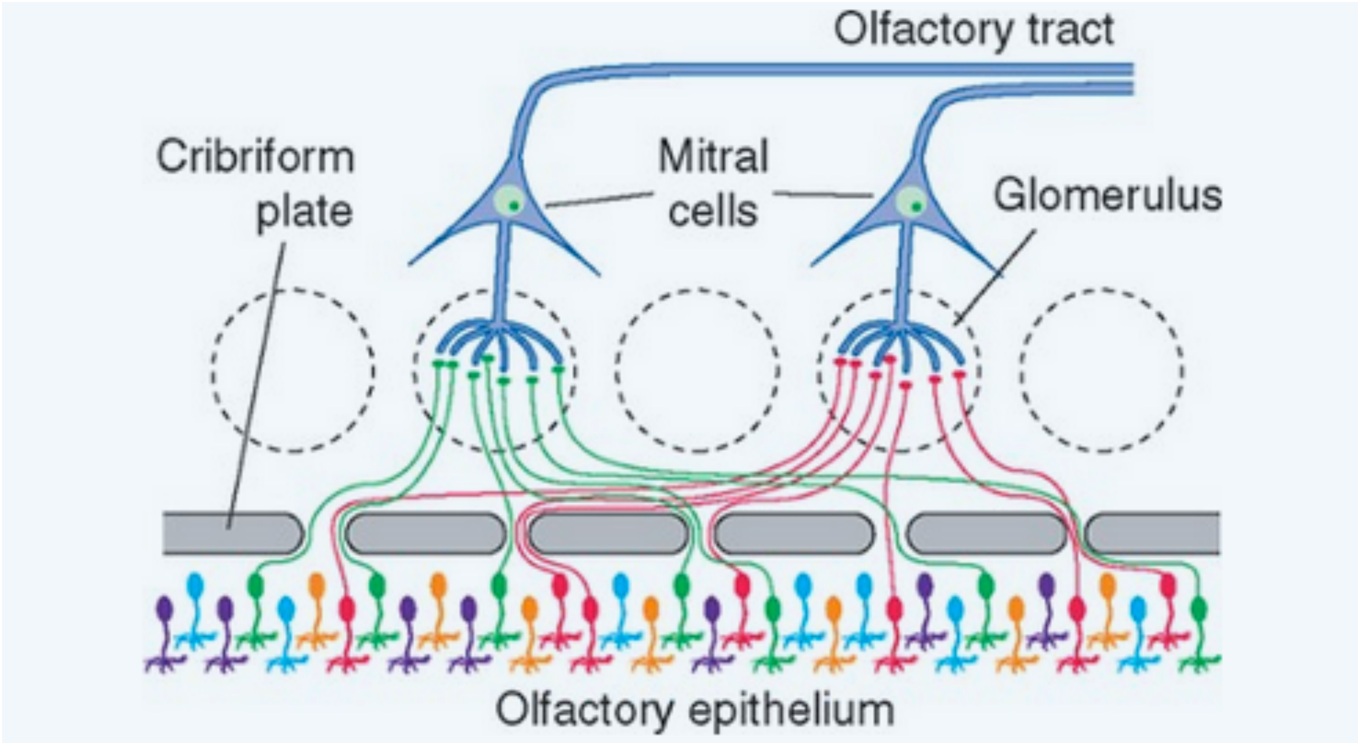
Olfactory signal transduction



Binding of an odorant to an odorant receptor causes the receptor to interact with a G protein which then stimulates adenylate cyclase. The resultant increase in second messenger (cyclic AMP) opens cyclic nucleotide-gated cation channels, leading to influx of Na+, Ca2+ and efflux of Cl- causing a change in membrane potential in the cilium membrane. The receptor potential soon adapts in most olfactory receptor neurons, even if the odorant concentration remains constant.

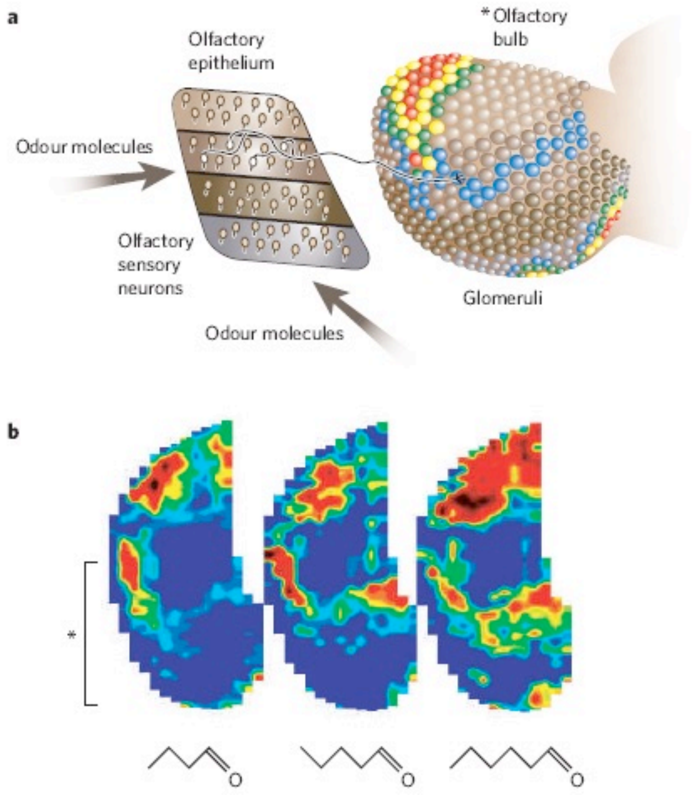
Olfactory epithelium contains about 1000 different types of receptor proteins.

Olfactory bulb



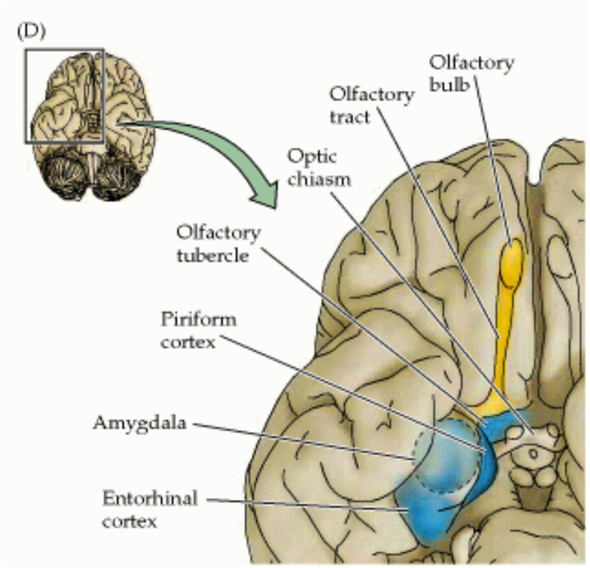
Sensory information from the nose is transmitted to the olfactory bulbs of the brain. Each sensory axon terminates in a single glomerulus, forming synapses with the output cells. The output of the bulb is carried by the mitral cells and the tufted cells, whose axons project in the lateral olfactory tract. In each glomerulus several thousand of sensory neurons converge on about 20-50 relay neurons, resulting in an approximately 100-fold decrease in the number of neurons transmitting olfactory sensory signals.
The axons of olfactory receptor neurons that express a given receptor protein converge on just one or two of these glomeruli providing amplification of the olfactory signal.

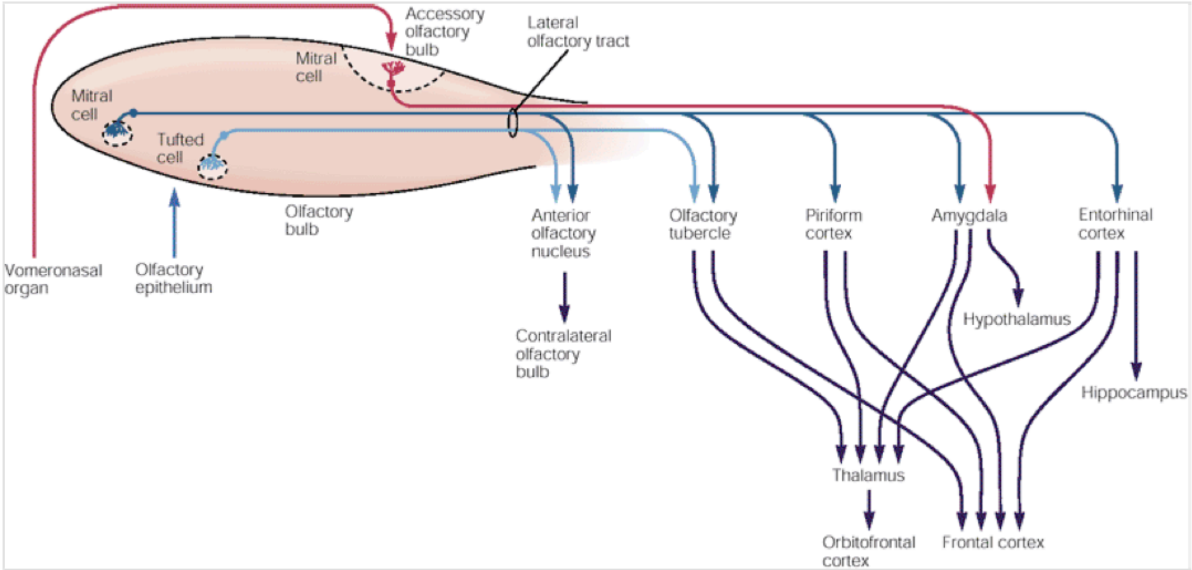
Odours are coded as activity 'images' in the olfactory bulb



Different odorants activate different sets of glomeruli in patterns that systematically map out the chemical properties of odorants across the surface of the olfactory bulb. A. Diagram showing the relationship between the olfactory receptor cells in the nose and the glomeruli of the olfactory bulb. B. fMRI images of the different but overlapping activity patterns seen in the glomerular layer of the olfactory bulb of a mouse exposed to members of the straight-chain aldehyde series, varying from four to six carbon atoms.

Olfactory information is processed in several regions of the cerebral cortex





The olfactory bulb cells project to the five different regions of olfactory cortex: the anterior olfactory nucleus; and the olfactory tubercle; the piriform (olfactory) cortex; and parts of the amygdala and entorhinal cortex. The conscious discrimination of odors is thought to depend on the neocortex (orbitofrontal cortex and frontal cortex), which may receive olfactory information via two separate projections: one through the thalamus and one directly to the neocortex. The emotive aspects of olfactory sensation are thought to derive from projections involving the amygdala and hypothalamus. The effects of pheromones are also thought to be mediated by signals from the main and accessory olfactory bulbs to the amygdala and hypothalamus.

Pheromones

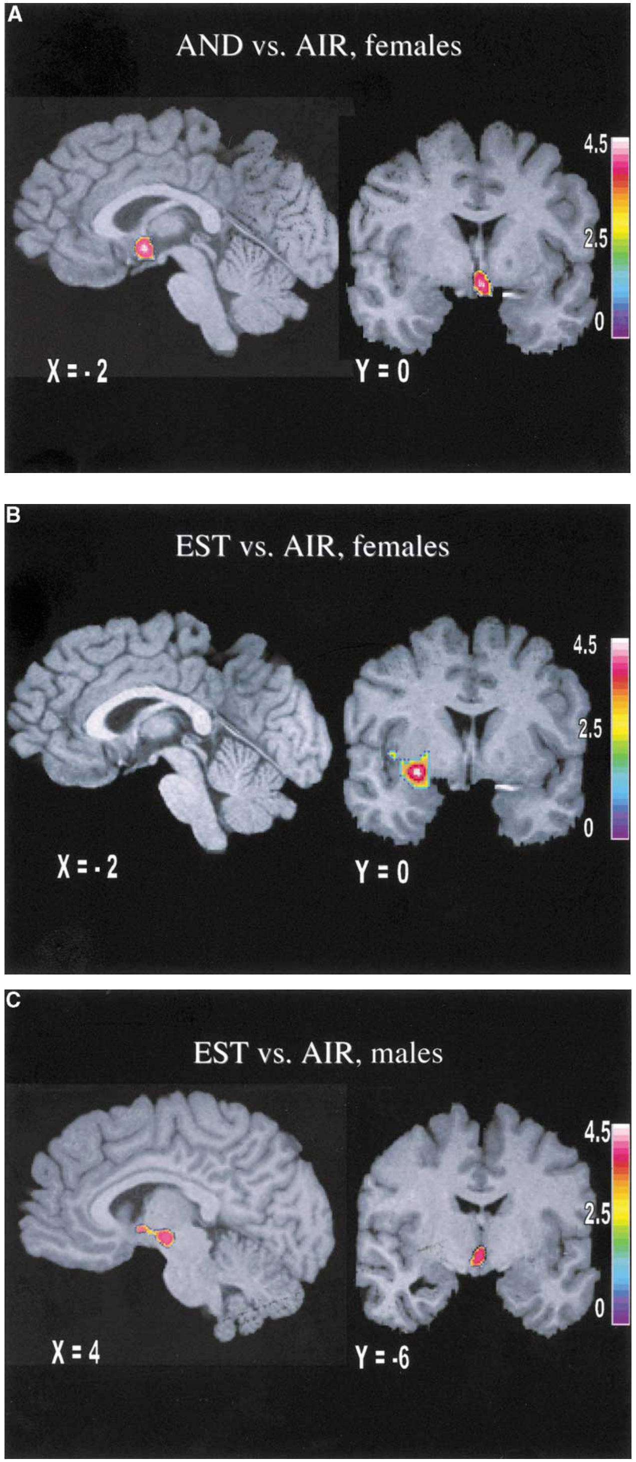
Pheromones are chemical factors that are released to the outside by an individual and trigger social responses in members of the same species. There are alarm pheromones, food trail pheromones, sex pheromones, and many others. They are used especially by insects but also by mammals.

Some studies suggest that humans may also respond to some chemical signals from other people. E.g. college women/nuns who live in the same dormitory gradually develop closer menstrual cycles (McClintock, 1971).

Subsequently, it was shown that odorless secretions from the armpit collected from women, can lengthen or shorten the menstrual cycles of other women, even without social contact (Preti, 1986).

McClintock MK. **Menstrual synchrony and suppression**. Nature, 229, 244–245, 1971

Preti et al., **Human axillary secretions influence women's menstrual cycles: the role of donor extract of females.** Horm Behav. 20(4):474-82, 1986.



Pheromones in humans exist

PET scans of brain activation in females and males smelling hormone-like synthesized compounds after components present in human sweat.

AND – androgen-like compound (derivative of testosterone, male hormone)

EST – estrogen-like substance (female hormone).

Women smelling AND and Men smelling EST activate the hypothalamus but not olfactory regions (amygdala, piriform cortex). When females smelled EST amygdala, piriform cortex were activated.

Strong hypothalamic response is seldom seen with ordinary odorants, and such an extreme sex difference is never seen with ordinary odorants. Hypothalamus mediates pheromonal effects in animals.

Ivanka Savic, Hans Berglund, Balazs Gulyas, and Per Roland. **Smelling of Odorous Sex Hormone-like Compounds Causes Sex-Differentiated Hypothalamic Activations in Humans**, Neuron, Vol. 31, 661–668, 2001

Editorial commentary: "This, along with the recent finding of genes for VNO-type receptors in humans (Rodriguez et al., 2000), lead us to conclude that the question of whether human pheromones exist has been answered. They do."

Noam Sobel and Windy M. Brown. **The Scented Brain: Pheromonal Responses in Humans.** Neuron, Vol. 31, 512–514, 2001