

CHEMORECEPTCE



Všechny buňky a všichni živočichové jsou citliví na chemické složení jejich životního prostředí. To je důležité nejen při rozeznávání potravy, ale i při páření, vztazích matka-mládě, značení teritoria a při dalších případech sociálního chování. Citlivost na chemické signály je jedním z charakteristických rysů živých soustav.

Využití membránové sensitivity
ve službách celku:

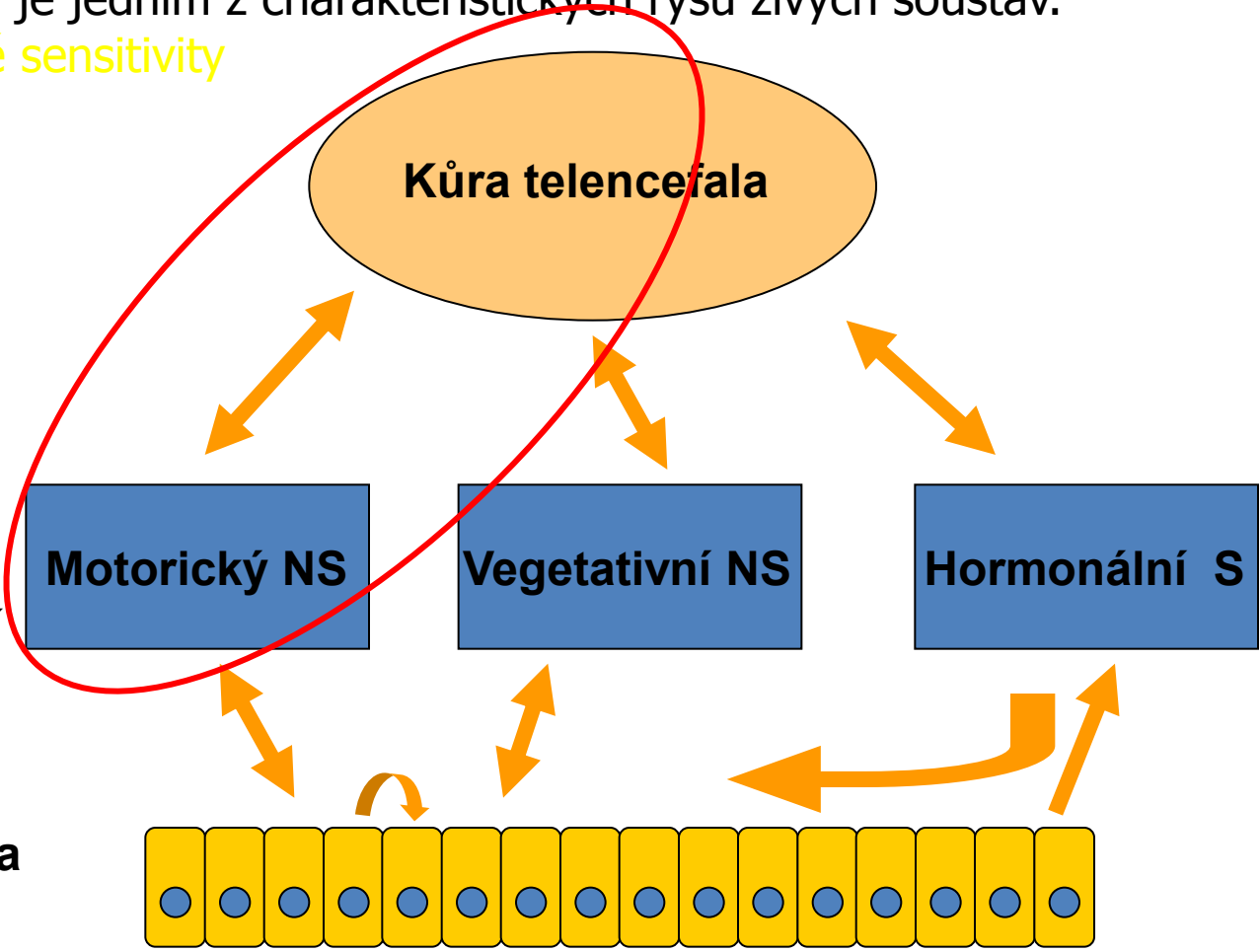
VĚDOMÍ

PODVĚDOMÍ
Reflexní,
automatické řízení

**Buněčná recepce a
komunikace**

Vnější podněty:
zvuky, vůně...

Vnitřní podněty:
hladina Glc,
apoptotický signál,
tah v membráně...



Čich

**The Nobel Prize in Physiology or
Medicine 2004**



**"for their discoveries of odorant receptors and the organization
of the olfactory system"**



Richard Axel

1/2 of the prize

USA

**Columbia University
New York, NY, USA; Howard
Hughes Medical Institute**

b. 1946



Linda B. Buck

1/2 of the prize

USA

**Fred Hutchinson Cancer
Research Center
Seattle, WA, USA; Howard
Hughes Medical Institute**

b. 1947

Čich - Distanční chemorecepce

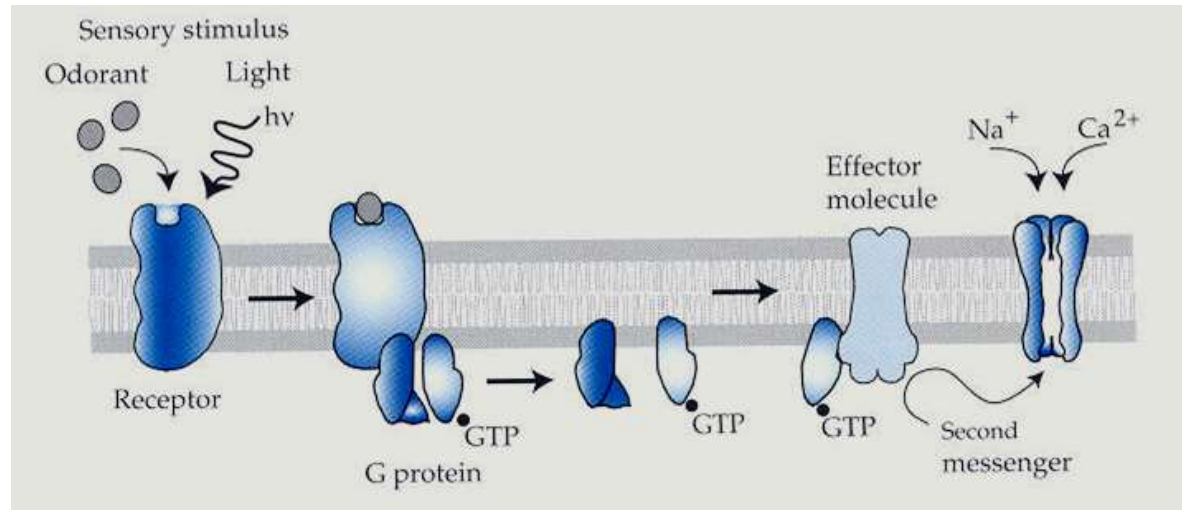
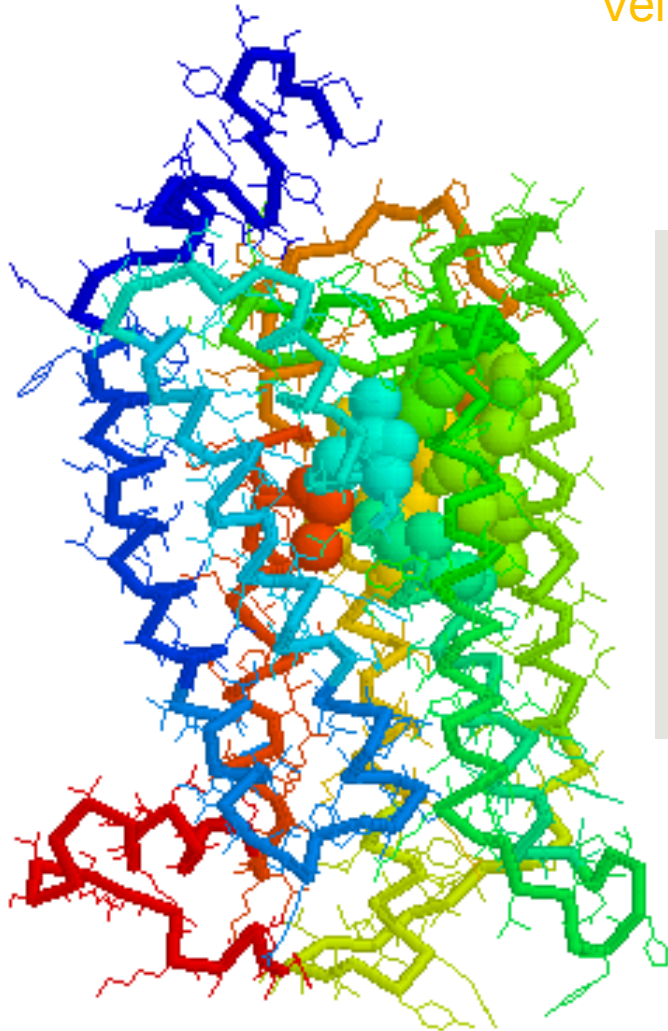
Modelový objekt pro mnoho dalších signálových drah

7TM receptory

Metabotropní signalizace prostřednictvím G proteinů

Otevřený systém podobný imunitnímu

Velká část (4%) genomu věnovaná čichovým receptorům



Savci: 1000 genů pro čichové receptory – největší genová rodina

Člověk: 350 funkčních genů

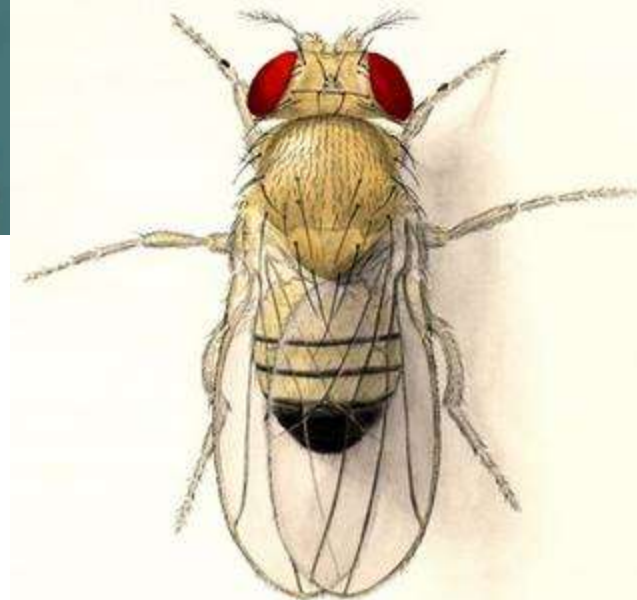
Drosophila: 62

Háďátko 1500 GPCR –

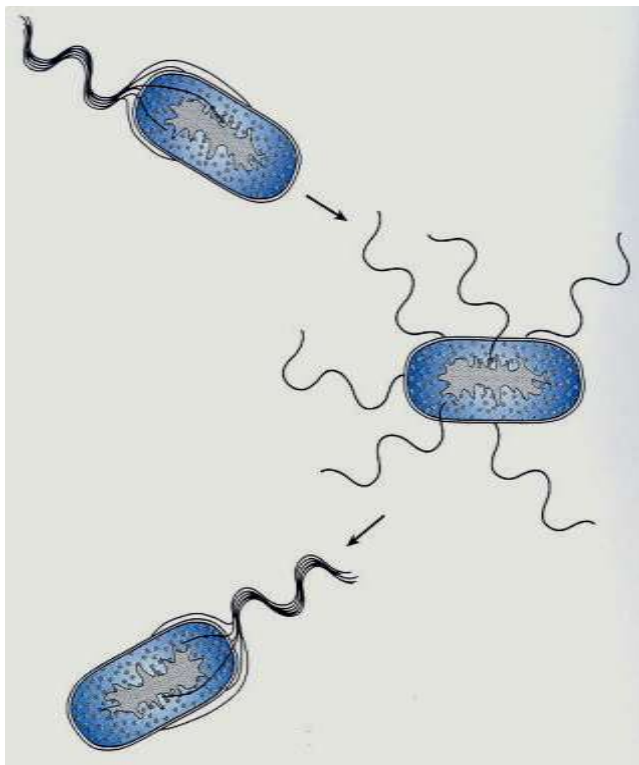
– G prot. coupled rec.

1031 buněk

302 neuronů



Už u prokaryot chemosensitivita E.coli



Repelent a atraktant roztáčí flagelární motor na opačné strany, jako lodní šroub.

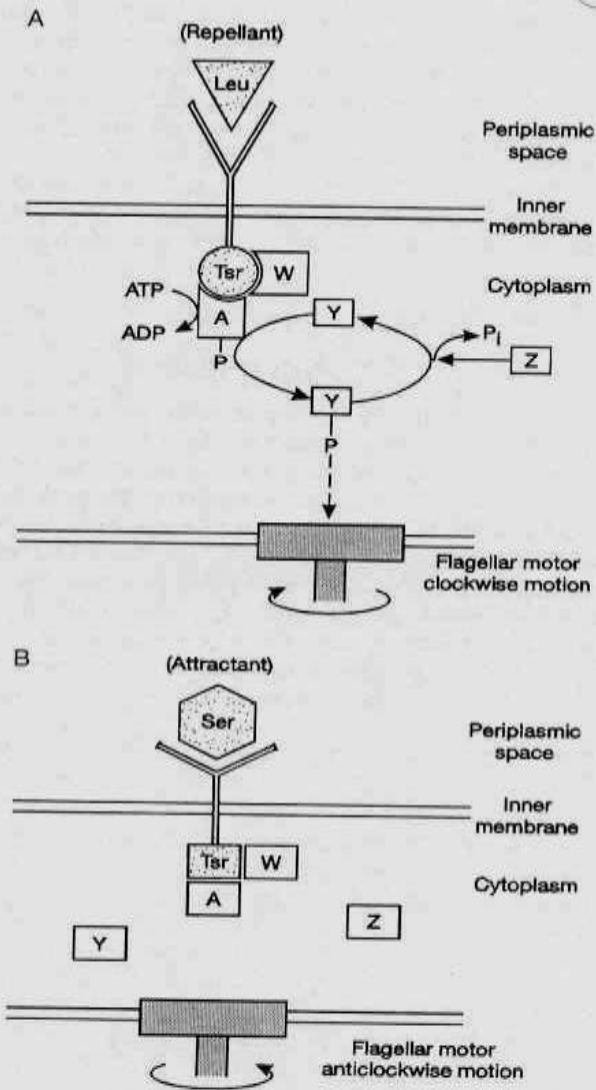
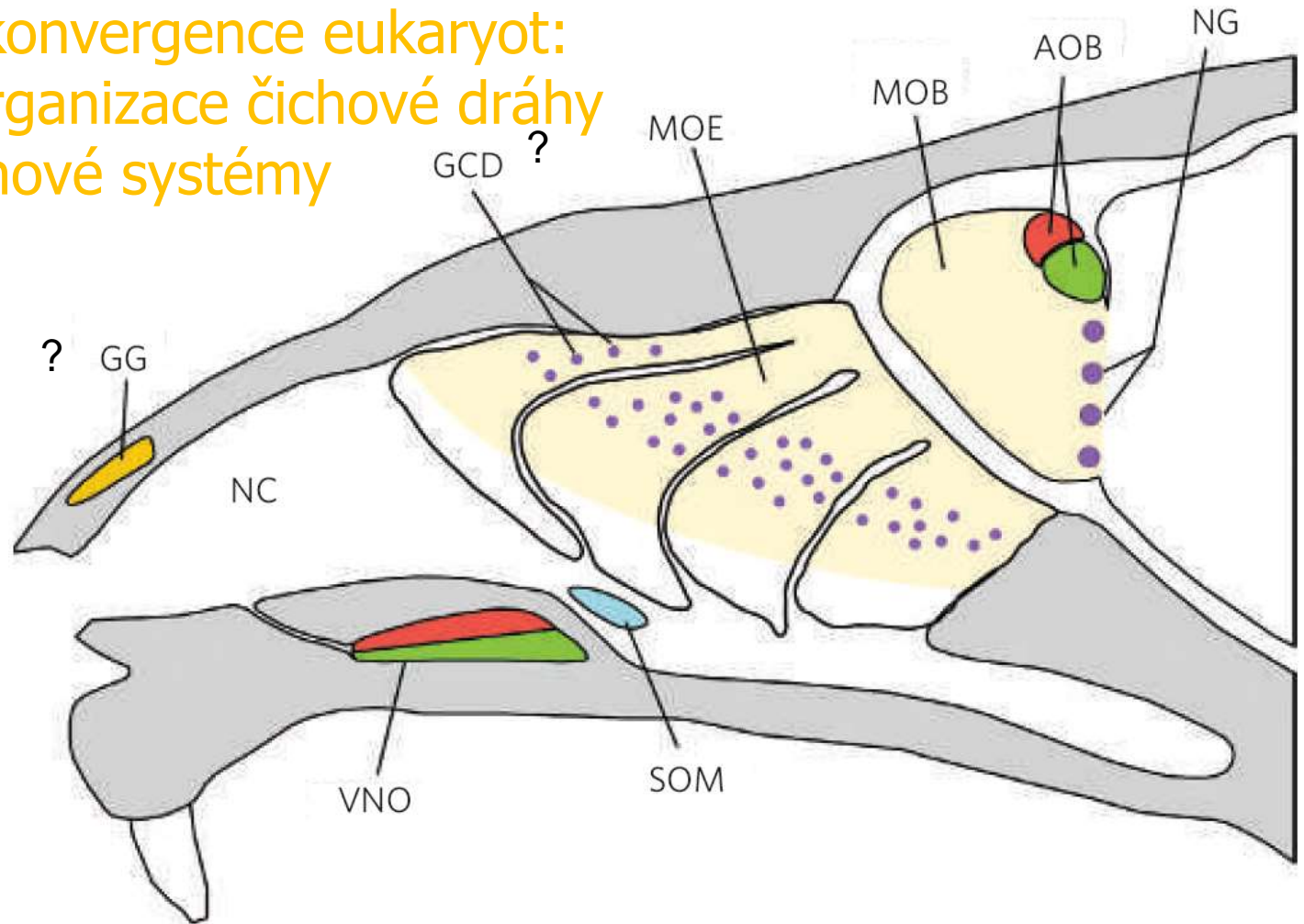


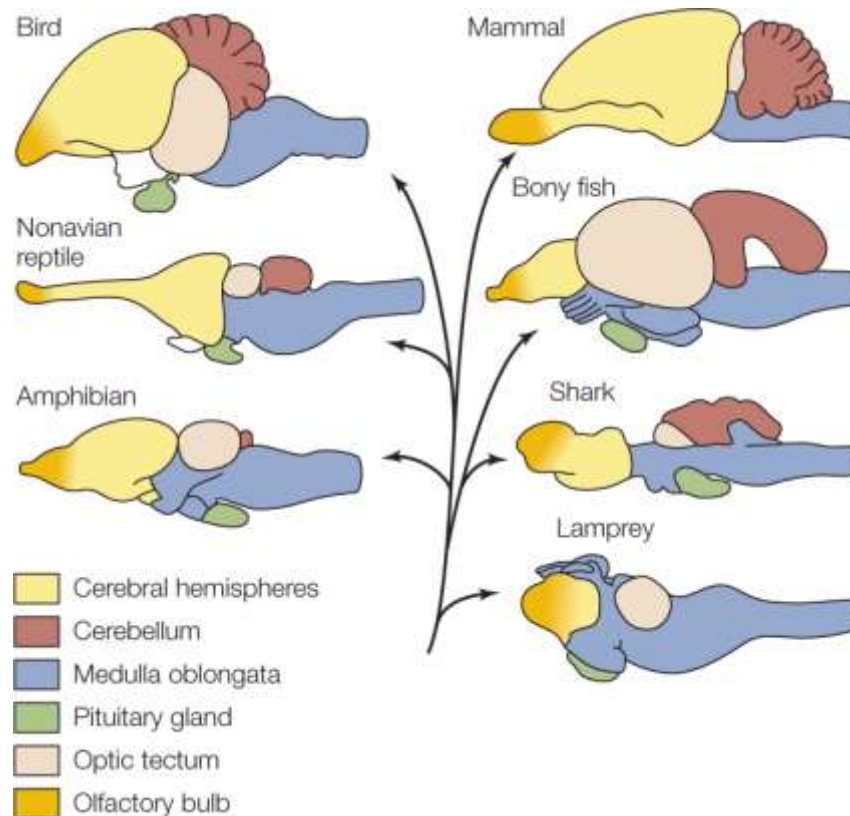
Figure 10.6 Molecular signalling in the *E. coli* chemosensory system. (a) The Tsr receptor-transducer protein accepts a repellent molecule (Leu). CheW and CheA are activated. CheA accepts phosphate from ATP and passes it on CheY. CheY diffuses to the flagellar motor and induces a clockwise rotation and hence tumbling. CheY is eventually dephosphorylated by CheZ. (b) The Tsr receptor-transducer accepts an attractant molecule (Ser). The consequent conformational change inactivates CheA and CheW so that CheY remains unphosphorylated and consequently inactive. The flagellum resumes its anticlockwise motion and the bacterium swims smoothly forward. A = CheA; W = CheW; Y = CheY; Z = CheZ. Data from Bourrett, Borkovich and Simon, 1991

Pozoruhodná konvergence eukaryot:
Transdukce, organizace čichové dráhy
2 paralelní čichové systémy



Vomeronasální orgán pro vnitrodruhovou komunikaci a
čichový systém pro ostatní pachy.

Neuroanatom 19. století Paul Broca označil lidi jako anosmické, protože věřil, že rozvoj čelních laloků telencefala spojený s uvažováním a osobností na úkor čichových laloků, vedl ke ztrátě důležitosti čichu.



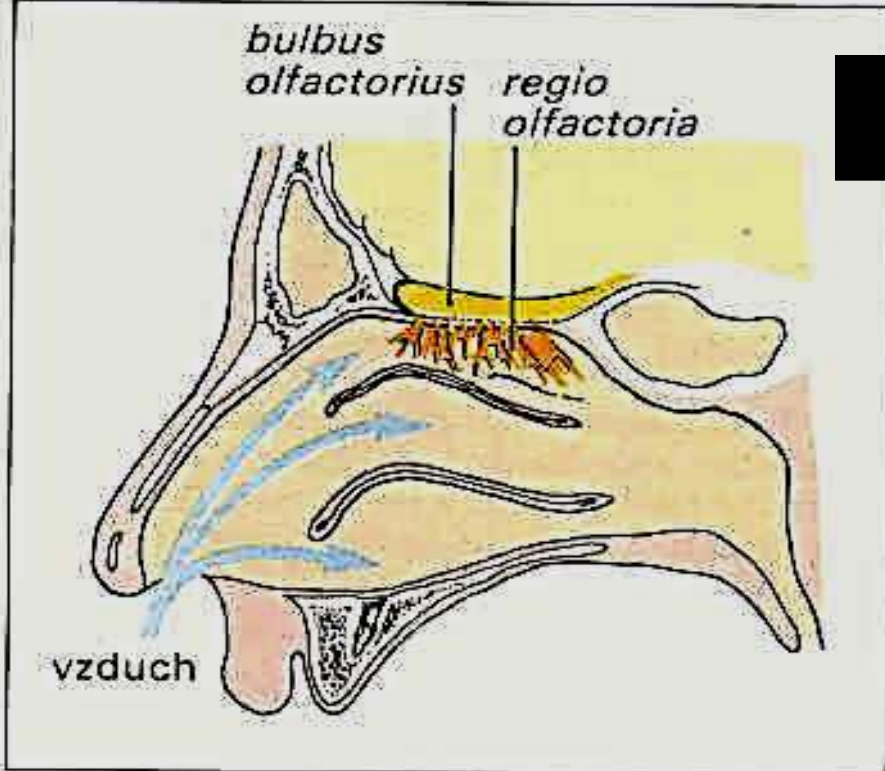
Ale: ačkoliv je čichový lalok relativně menší, má stejně neuronů jako u myši a je mnohem větší absolutně.

Srovnávají-li se výkony, velmi záleží na volbě dané vůně. Zřejmě kvůli existenci různé výbavě receptory. Pro některé vůně lidé předstihnou myš i psa. Množství vůní je i u lidí obrovské a i člověk dokáže sledovat pachovou stopu.

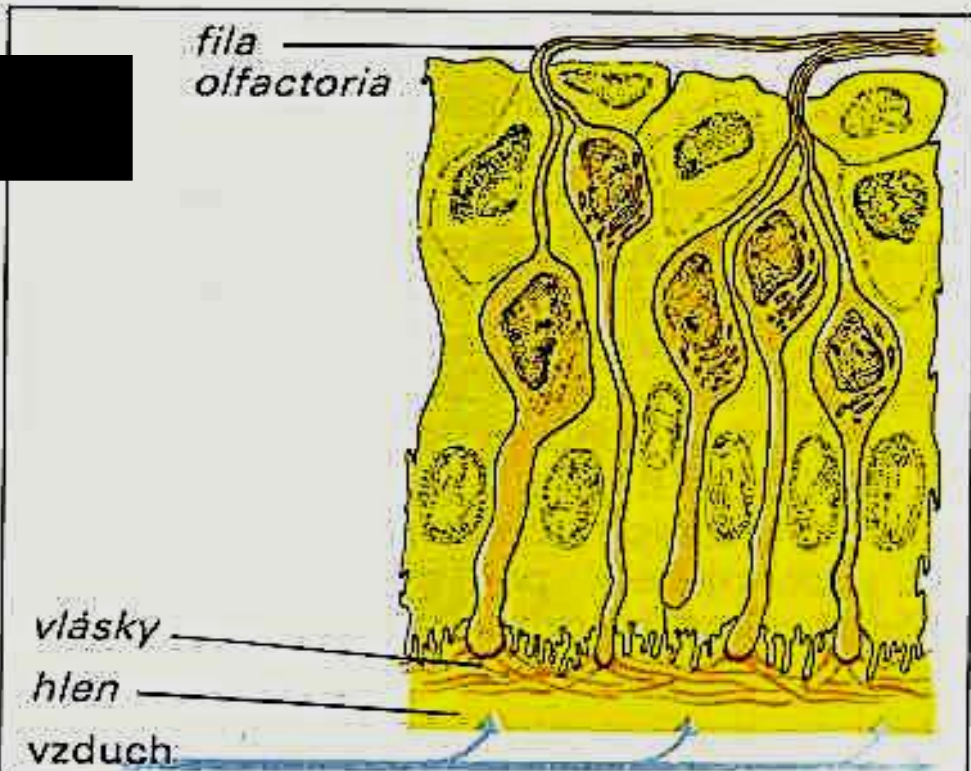
Pachová komunikace existuje i mezi lidmi a nese informaci o příbuzenství, stresu, reprodukčním stavu, i když často podvědomě. Jde o vysoce dynamický smysl spojený s pamětí, emočním doprovodem a okolnostmi.

Poruchy čichu mohou informovat o postupující neurodegenerativní chorobě.

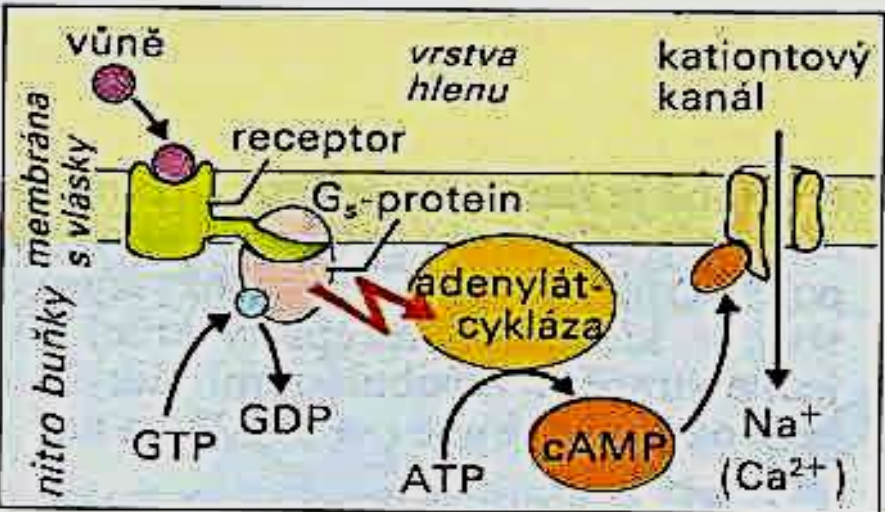




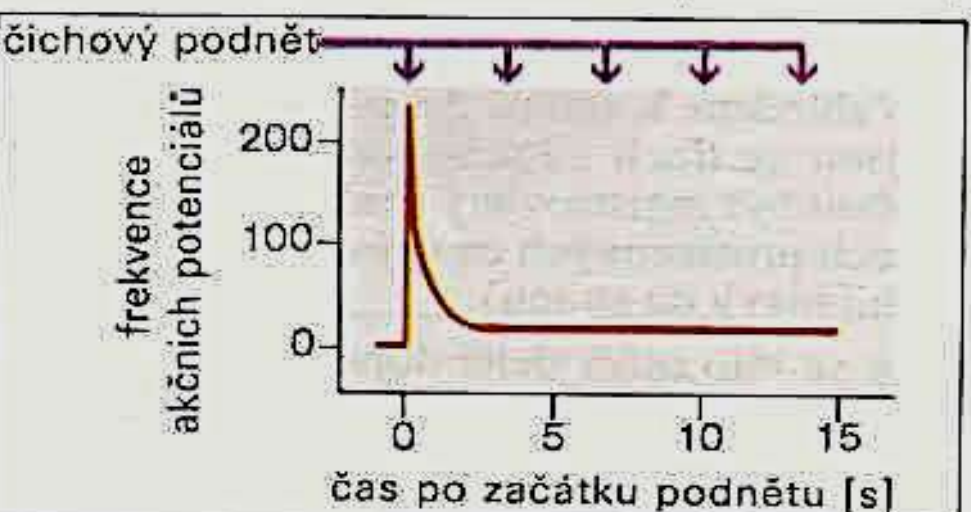
A. Nosní dutina a čichový orgán



B. Čichový epitel (podle Andrese)

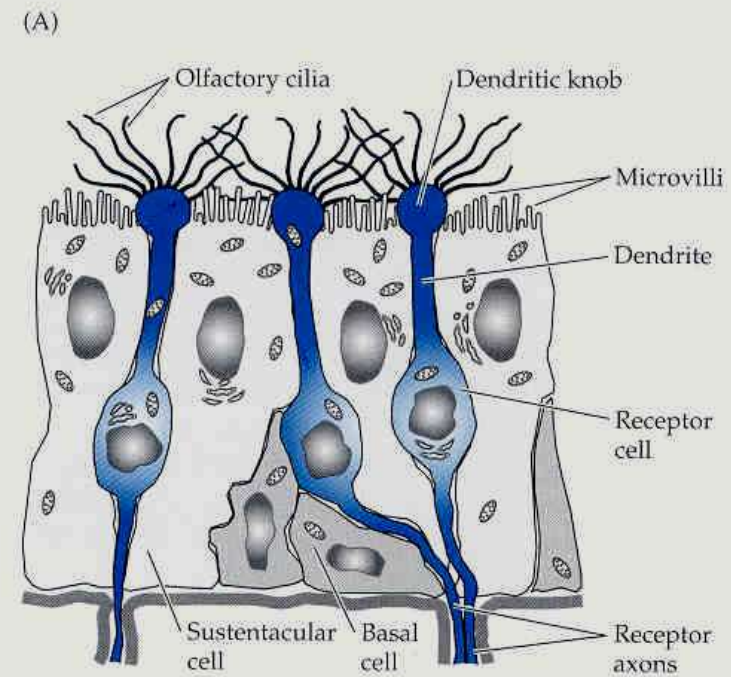


C. Transdukce čichového podnětu

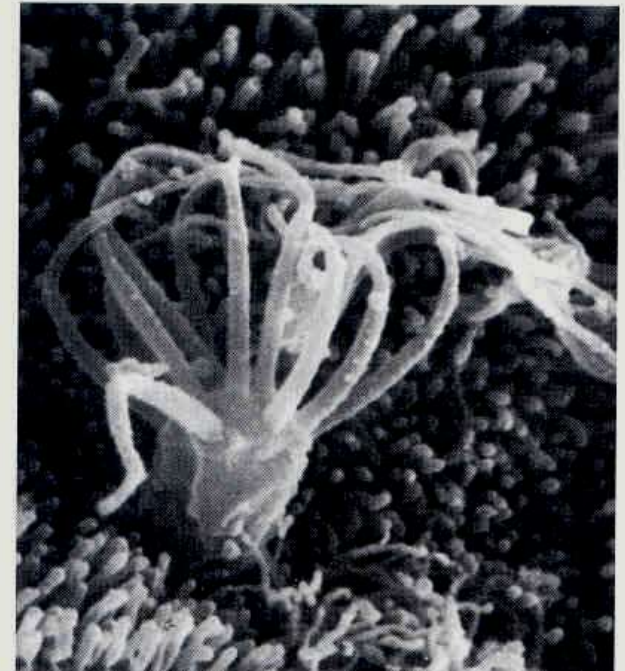


D. Adaptace čichu

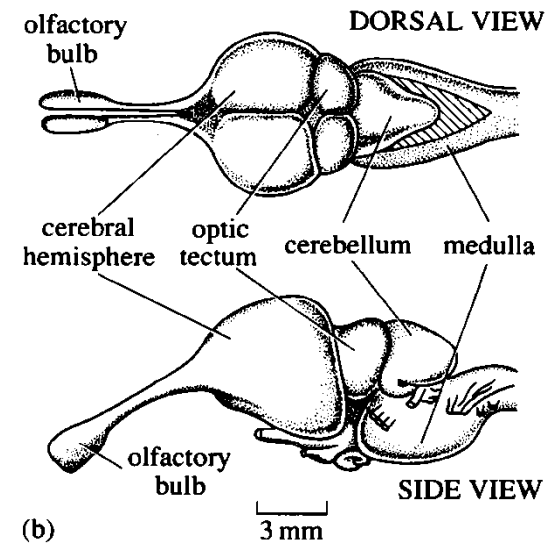
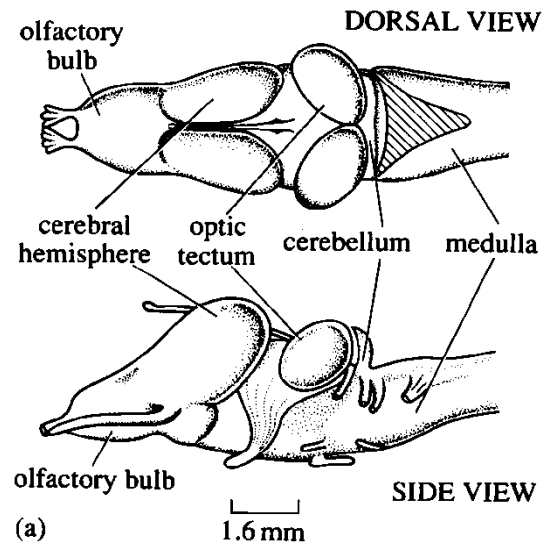
Figure 7.7
Olfactory epithelium (A) Schematic cross section of olfactory epithelium. (B) Scanning micrograph of a dendritic knob and dendrites of a human olfactory receptor neuron. Magnification: 18,500 \times . (From Morrison and Costanzo, 1990.)



(B)

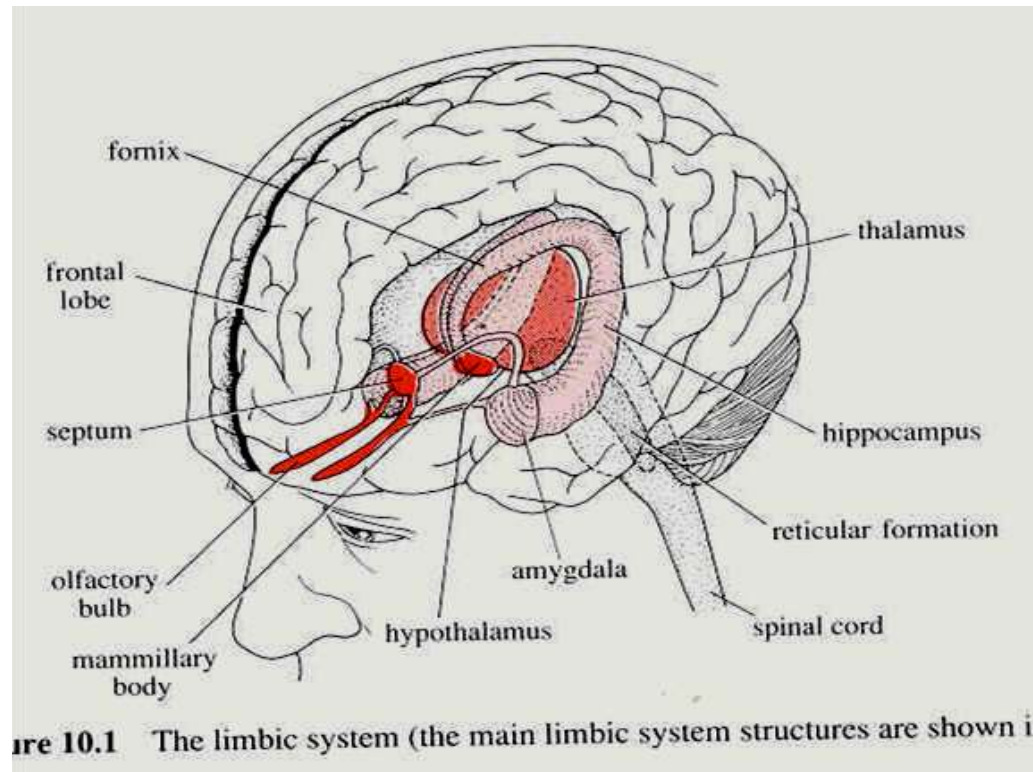


Čichové buňky savců jsou bipolární, primární r., je jich 6-10 milionů, dendrit má na konci 5-20 vlásků - cilií, řasinek.



Čichový lalok – součást
koncového mozku

Začátek nervové trubice se
formoval jako čichové
centrum.



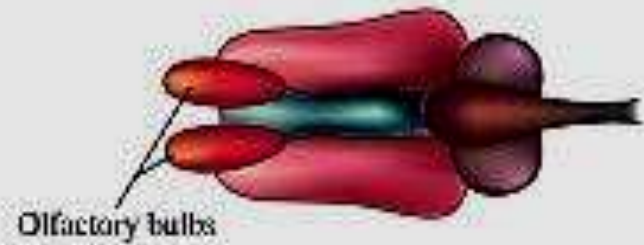
Čichový lalok – součást
koncového mozku

Side view



Rat

Bottom view

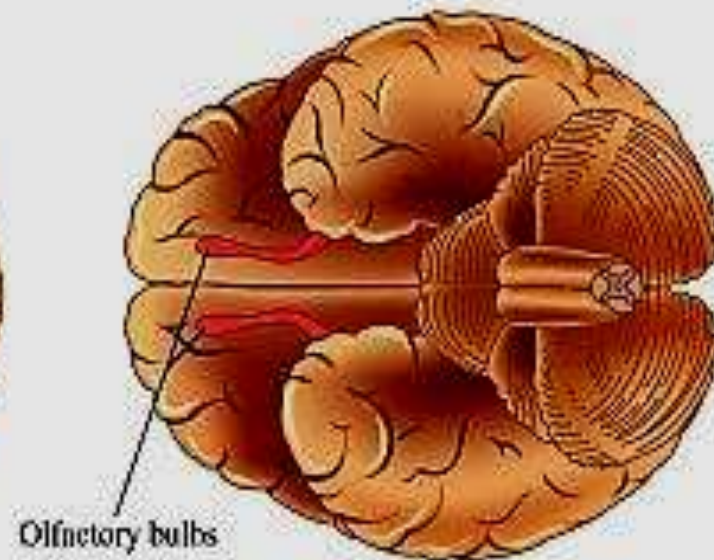


Side view



Human

Bottom view



Univerzální receptor G prot. signální dráhy

7TM α -helix receptor

Čichové receptory tvoří největší rodinu GPCR – G prot. coupled rec.

s jedinou zvláštností: velmi dlouhou druhou extracelulární smyčkou.

Možná nejzajímavější je hypervariabilní oblast na 3., 4. a 5. transmembránové doméně.

Na prostorových modelech se tyto oblasti přikládají k sobě a vytváří jakousi kapsu. Ta je pravděpodobným místem pro vazbu těkavých ligandů .

insight review articles

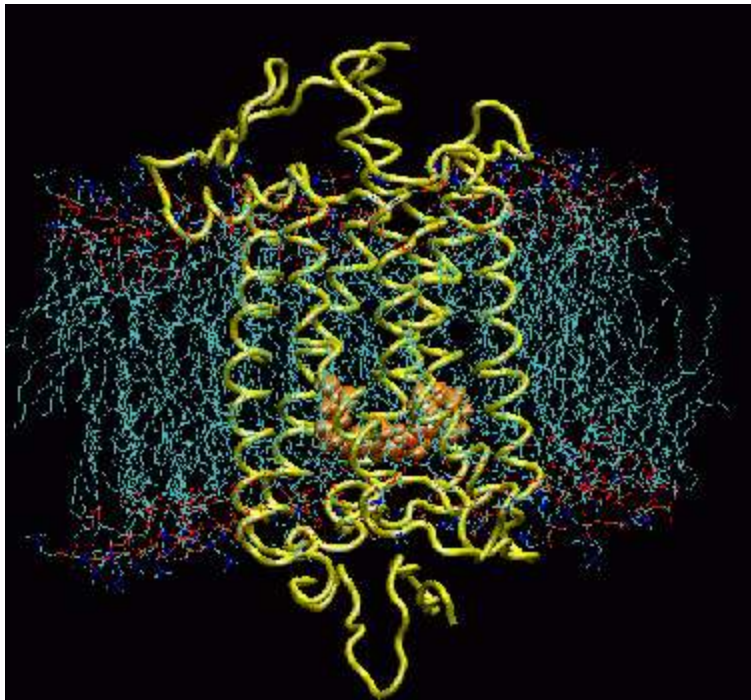
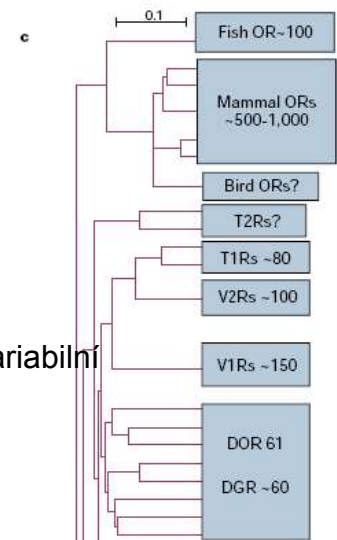
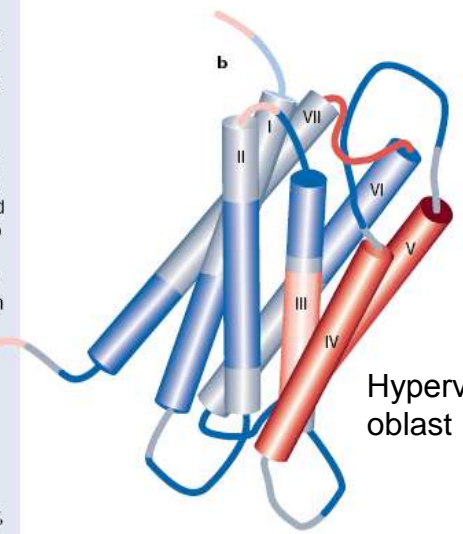
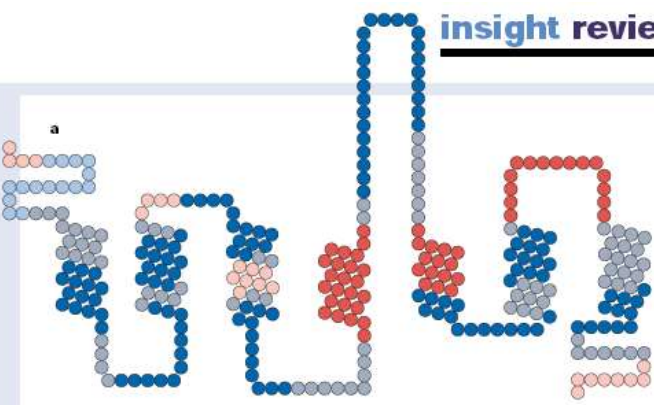
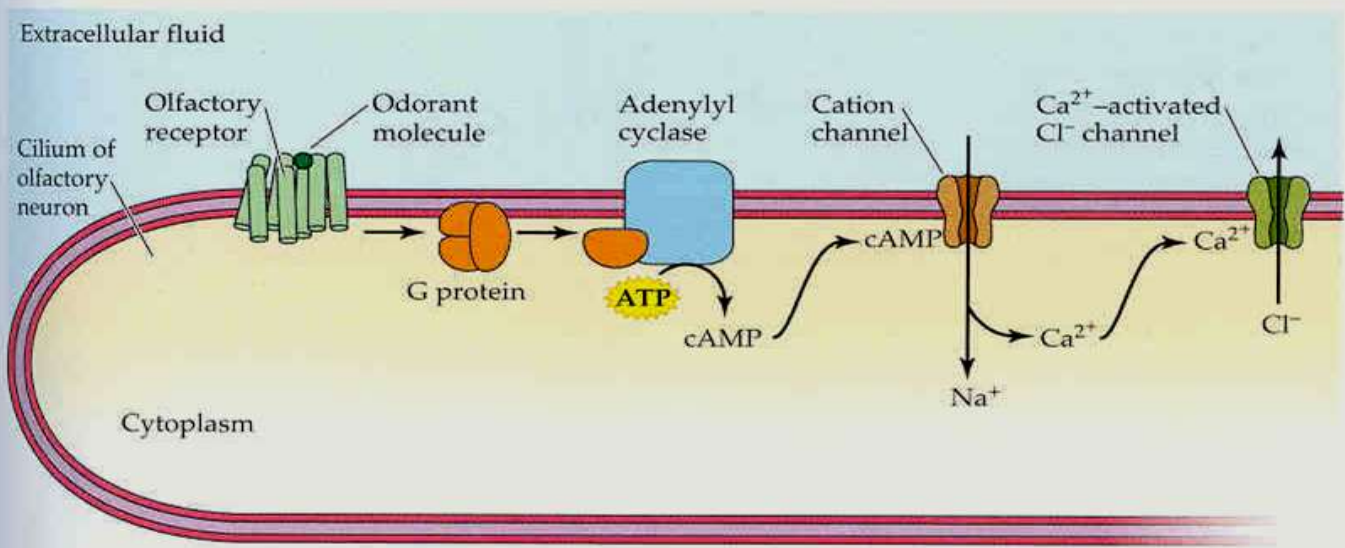


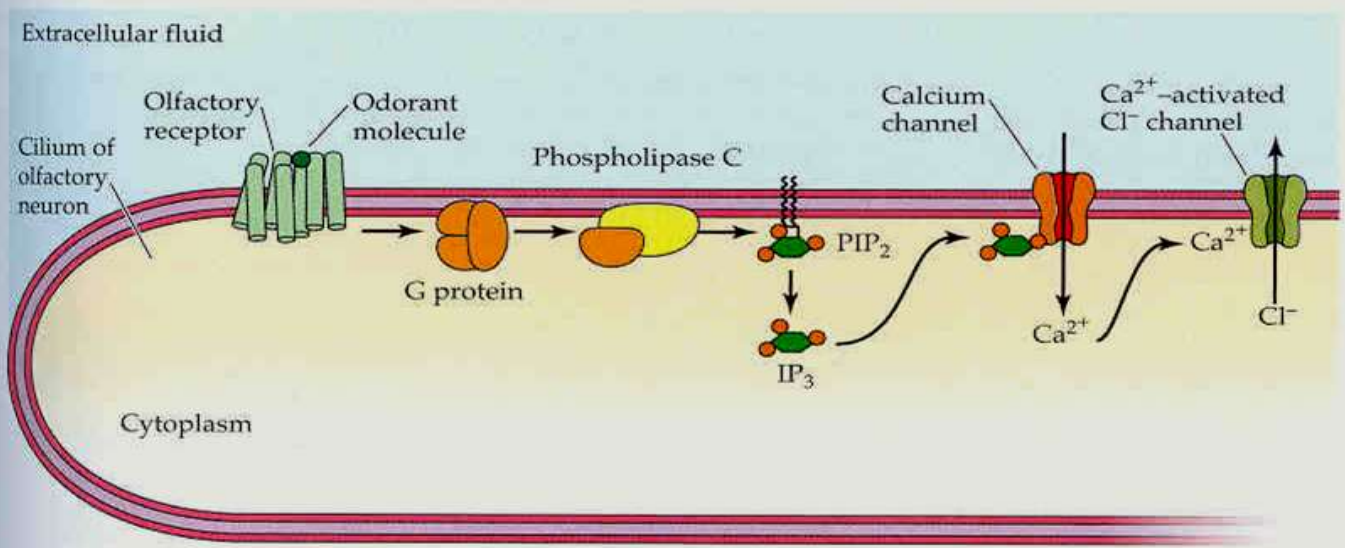
Figure 2 Odorant receptors are the jewel of olfactory research in the past 10 years. The odorant receptors comprise the largest family of GPCRs. In mammals, odour receptors are represented by as many as 1,000 genes and may account for as much as 2% of the genome. Sequence comparison across the receptors has revealed many regions of conservation and variability that may be related to function. **a**, In a 'snake' diagram showing the amino acids for a particular receptor (M71), those residues that are most highly conserved are shown in shades of blue and those that are most variable are shown in shades of red. The seven α -helical regions (boxed) are connected by intracellular and extracellular loops. **b**, A schematic view of the proposed three-dimensional structure of the receptor based on the recently solved structure of rhodopsin. Each of the transmembrane regions is numbered according to that model. The conserved (blue) and variable (red) regions are sketched onto this qualitative view and suggest that a ligand-binding region may be at least partially formed by the variable regions of the receptor. **c**, Mammalian odour receptors are related phylogenetically to other chemosensory receptors. In the tree depicted here the numbers refer to the approximate number of receptors in each family. OR, Odorant receptors; T1R, T2R, taste receptors; V3R, vomeronasal receptors; DOR, DGR, *Drosophila* odour and gustatory receptors; worm refers to *C. elegans*. The scale bar is a graphical distance equal to 10% sequence divergence.

Univerzální mechanismy transdukce

(a) Increase in cAMP



(b) Increase in IP₃



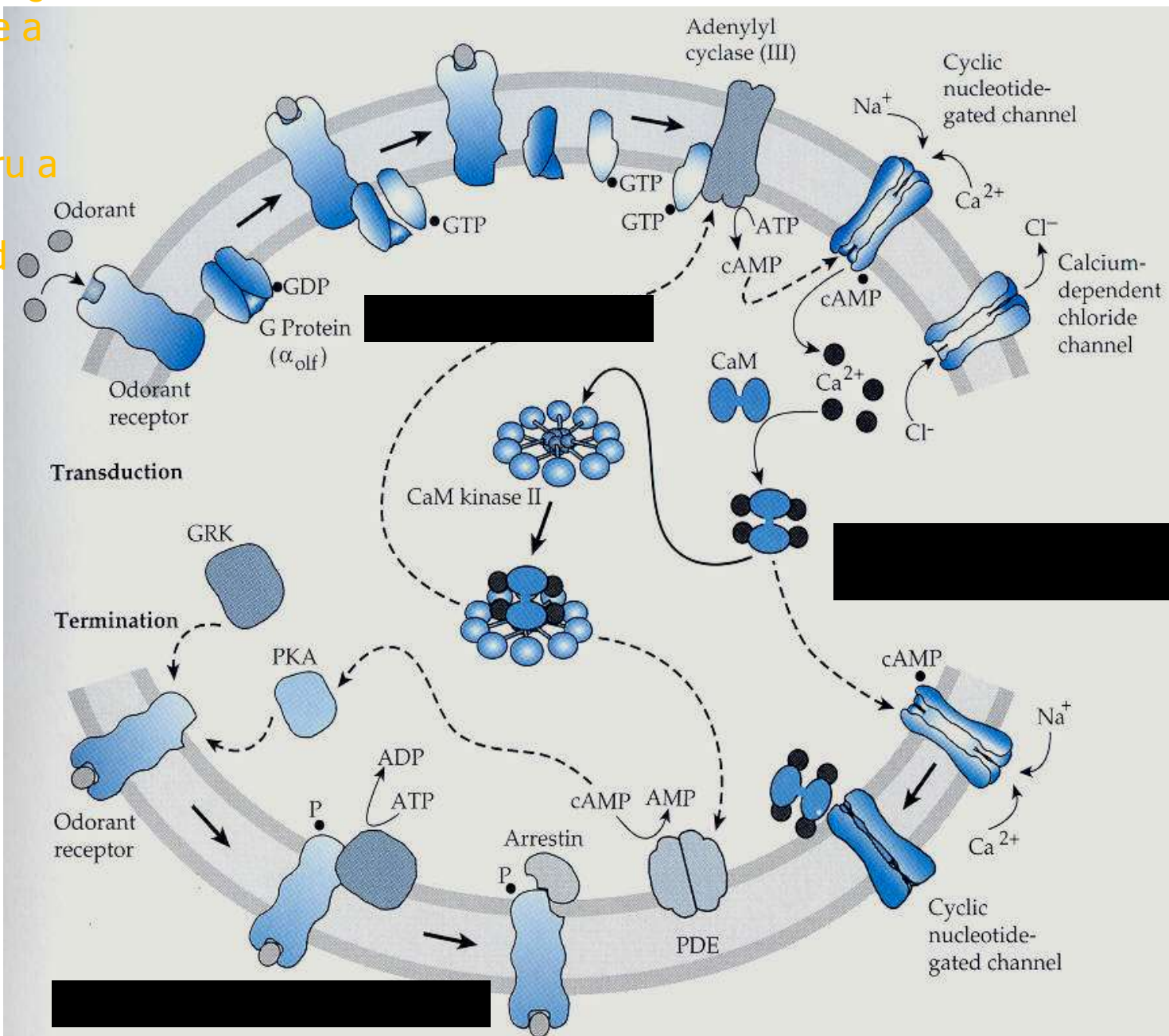
Cl iony také depolarizují – výjimka kvůli vysoké koncentraci uvnitř

Ca iony mají i adaptační význam

Aktivace
Zesílení, max. $4 \cdot 10^{-15} \text{g/l}$
Adaptace, terminace a
modulace

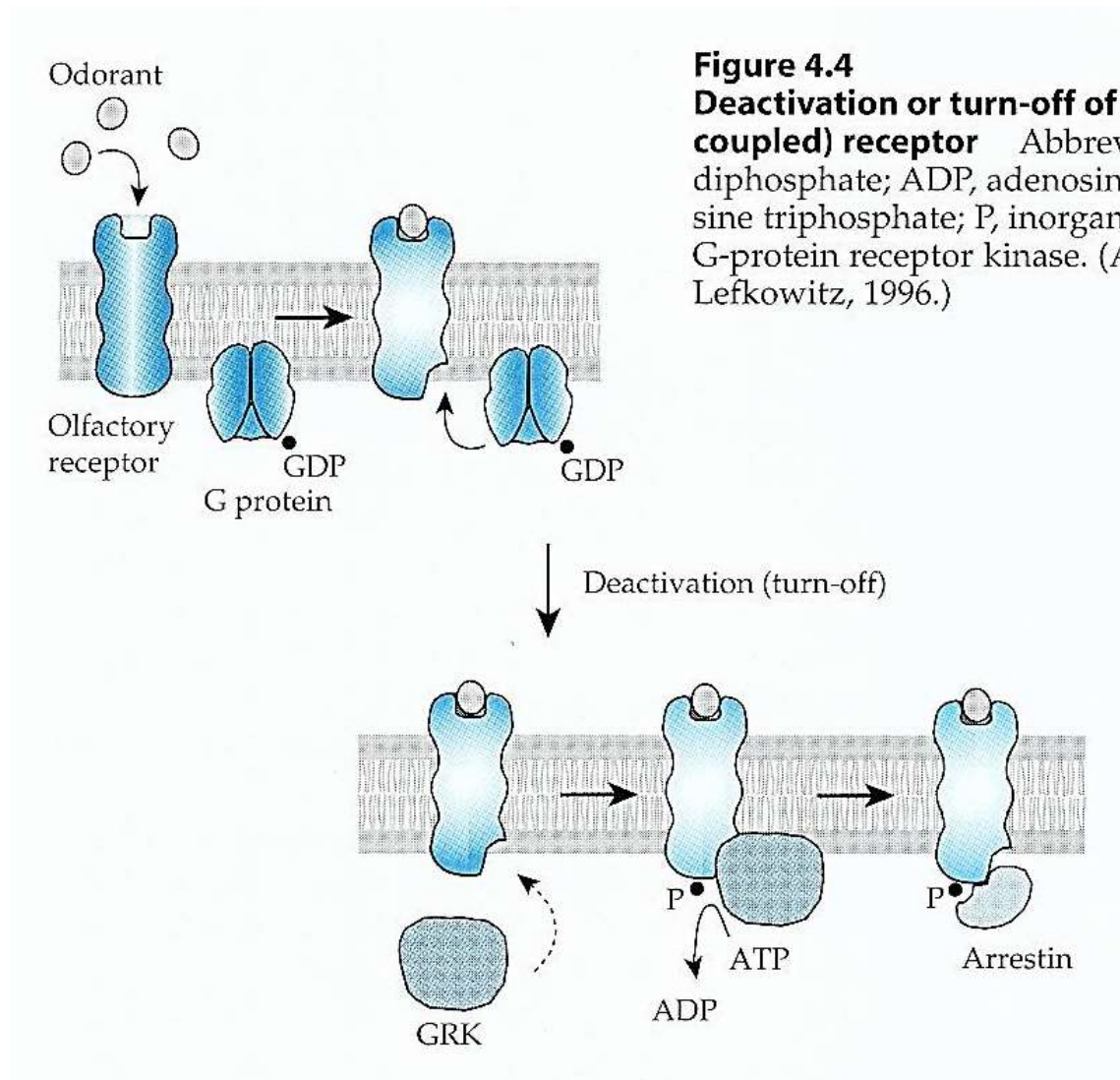
Fosforylace receptoru a
navázání Arrestinu
GRK-G prot. coupled
rec. Kináza

Vše závisí na Ca



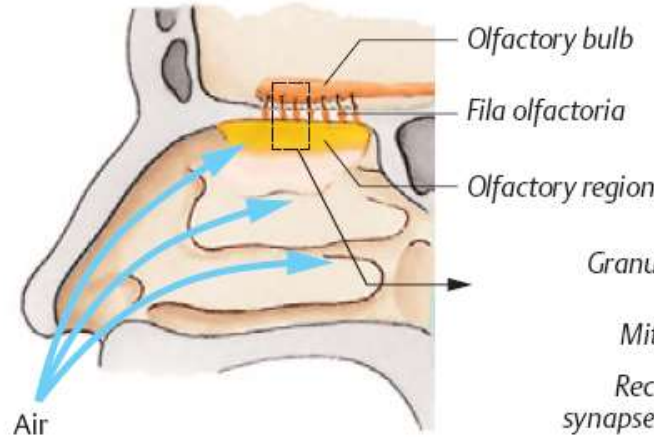
Obecný mechanismus vypínání metabotropního receptoru

Nejen aktivace G prot., ale i
vystavení Ser a Thre zbytků
blízko C konce a usnadní
navázání G protein coupled
receptor kinázy (GRK). Ta
katalyzuje připojení fosfátové
skupiny z ATP na am.kys.
GPCR. Fosforylovaný receptor
váže arrestin, který zasahuje do
vazebného místa receptoru pro
G protein a brání jeho další
aktivaci. Tím ukončuje aktivitu
receptoru.

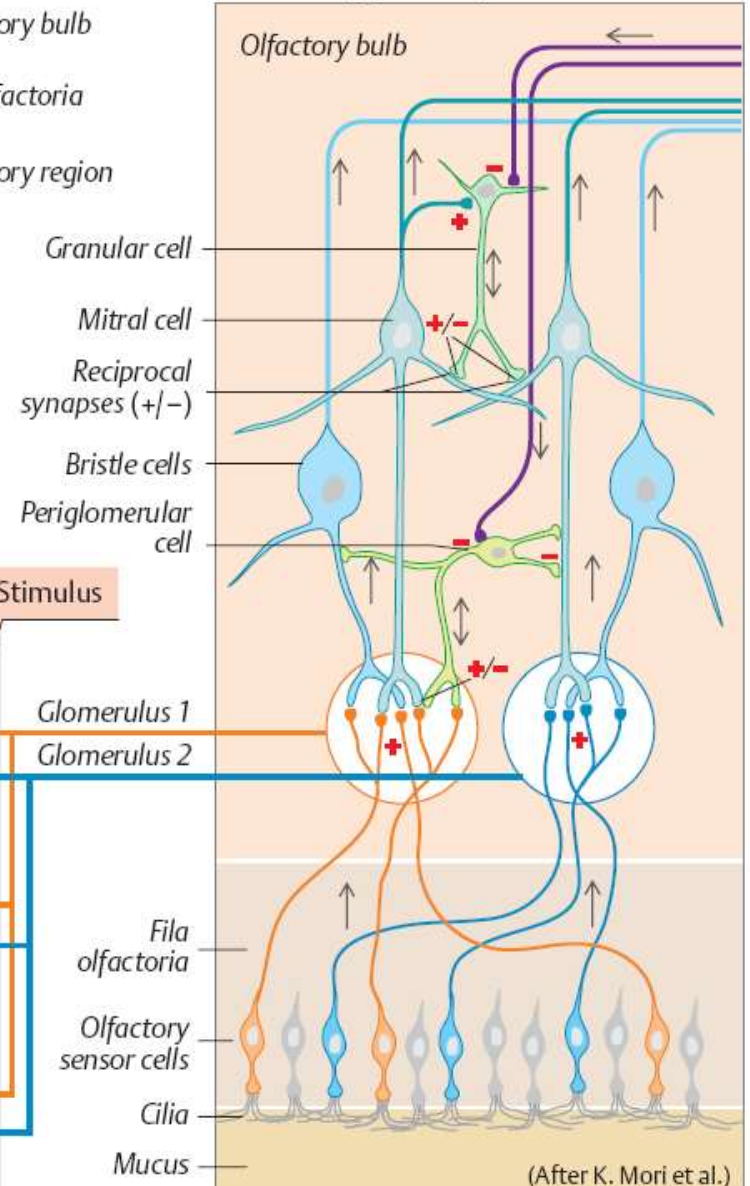


A. Olfactory pathway and olfactory sensor specificity

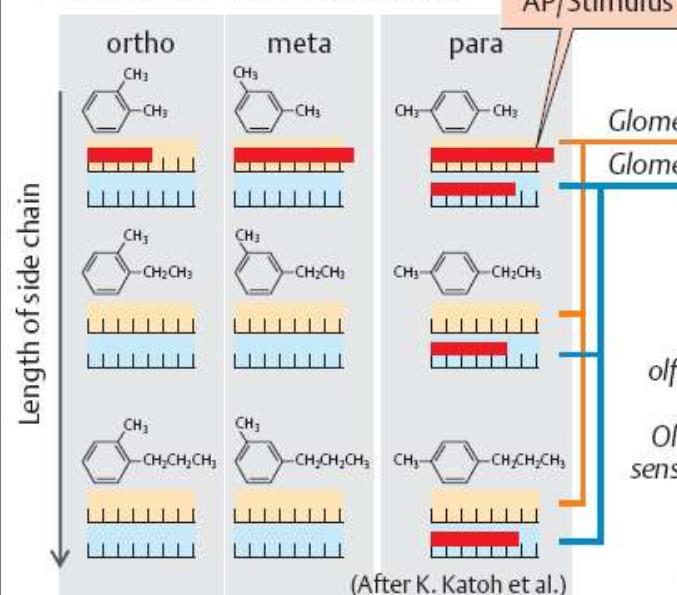
1 Nasal cavity



2 Olfactory pathway



3 Sensor specificity (example)



Periferie
čichové dráhy

Rozlišování chem.
Struktury podle:
a) pozice skupin
b) Délky řetězce

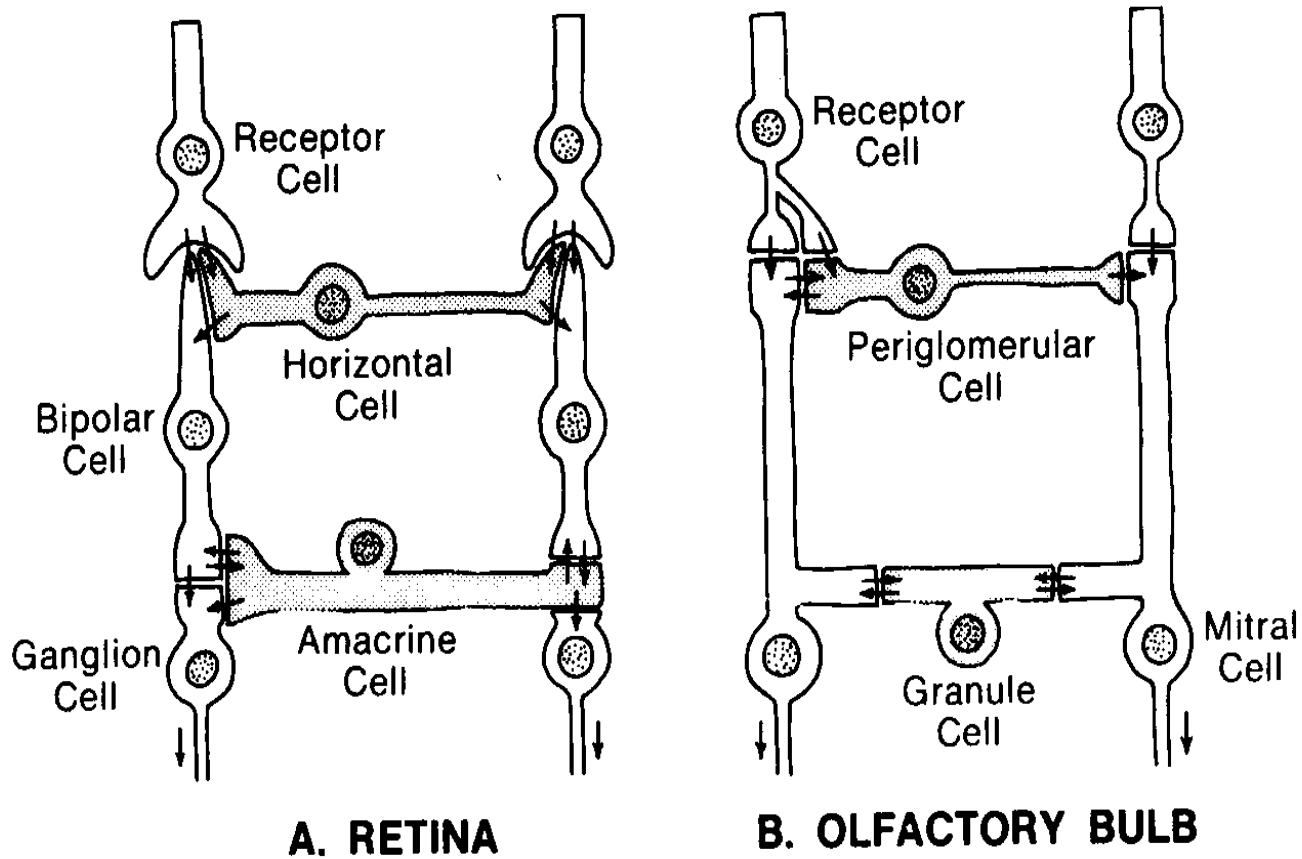
Laterální inhibice
Kontrastování

Eferentní inhibice

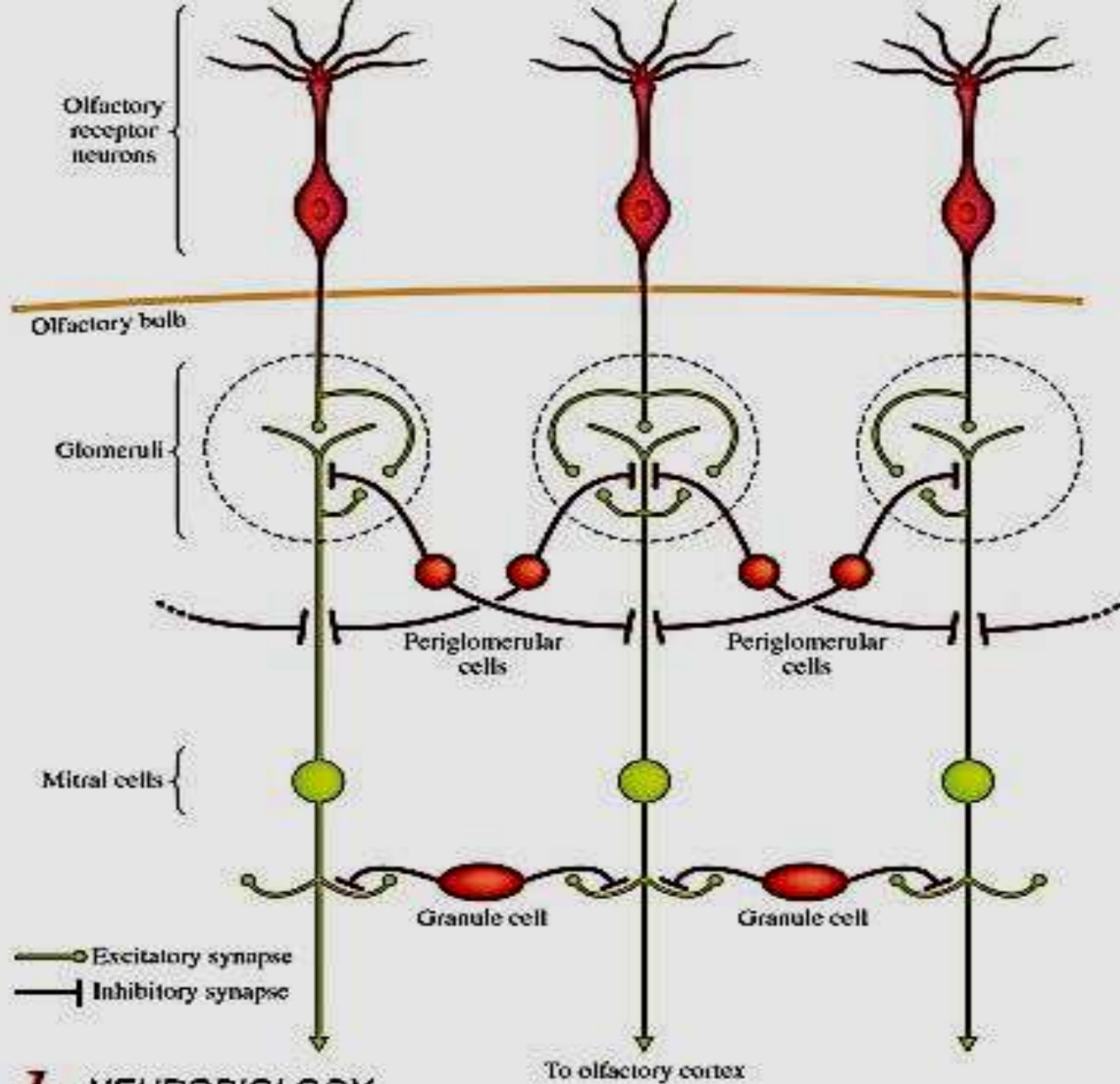
Všechny neurony exprimující určitý receptor, bez ohledu na to, kde je umístěn na sliznici, konvergují na jedno jediné místo na čichovém laloku. Těmito místy jsou glomeruly, kulovité shluky šedé hmoty, asi 50-1000 mikrometrů, sestávající z přicházejících axonů z receptorů a z dendritů mitrálních buněk. V jednom zvláště extrémním případě konverguje několik tisíc smyslových neuronů na asi 10 mitrálních buněk, což je v nervovém systému rekord.

https://oup-arc.com/access/content/sensation-and-perception-5e-student-resources/sensation-and-perception-5e-14-1-olfactory-anatomy?previousFilter=tag_chapter-14

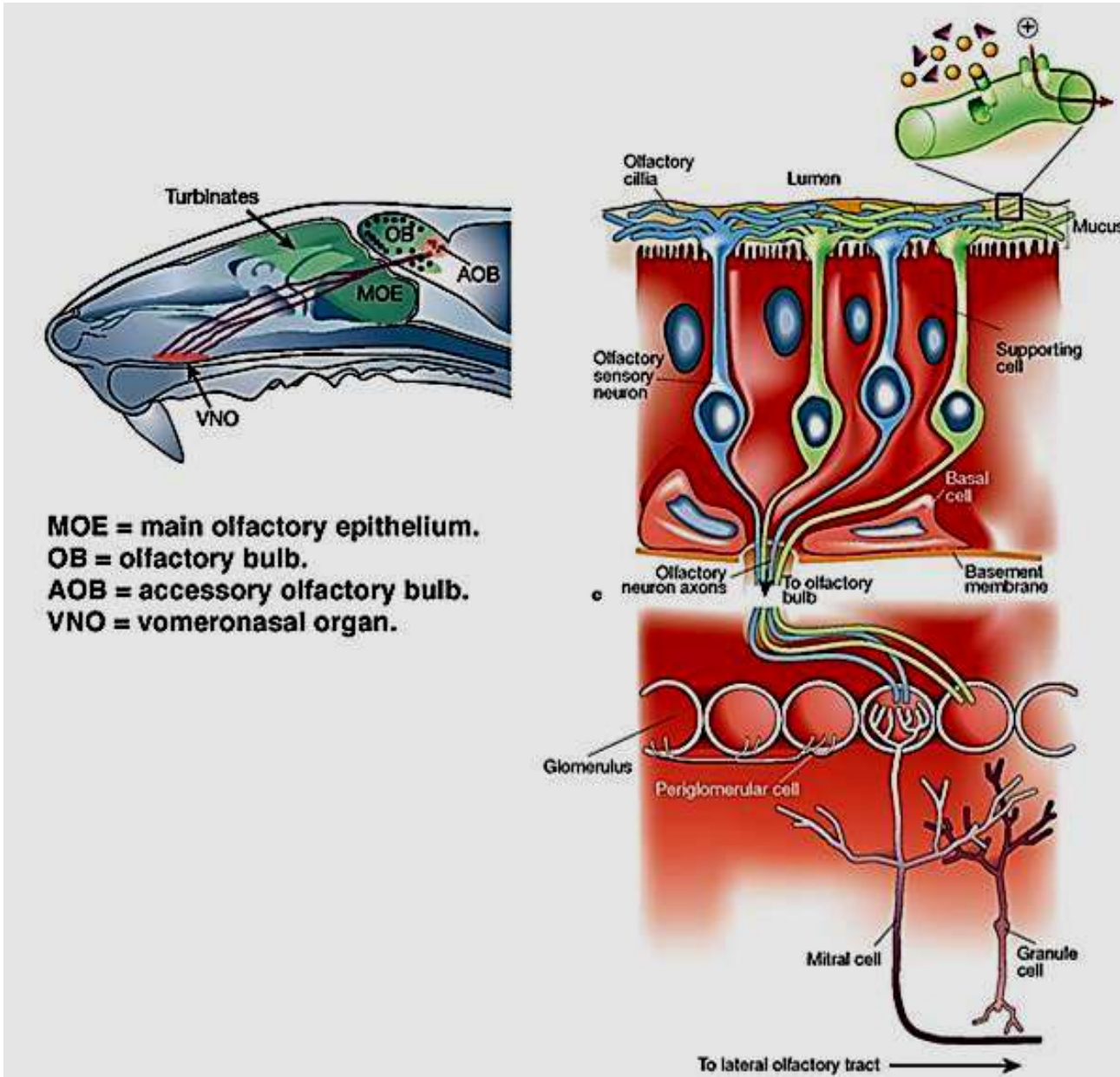
Podobnost architektury sensorických obvodů a drah



Comparison between simplified basic circuit diagrams of the vertebrate retina and olfactory bulb. (After Shepherd, 1978)



Konvergence na příslušný glomerulus (100 - 1000/1)



Může tak vzniknout „mapa vůní“ – vzorec aktivovaných glomerulů čichového laloku. Specifická „mozaika“ aktivace pro konkrétní vůni

Jde tak o konvergenci neprostorového parametru na prostorový

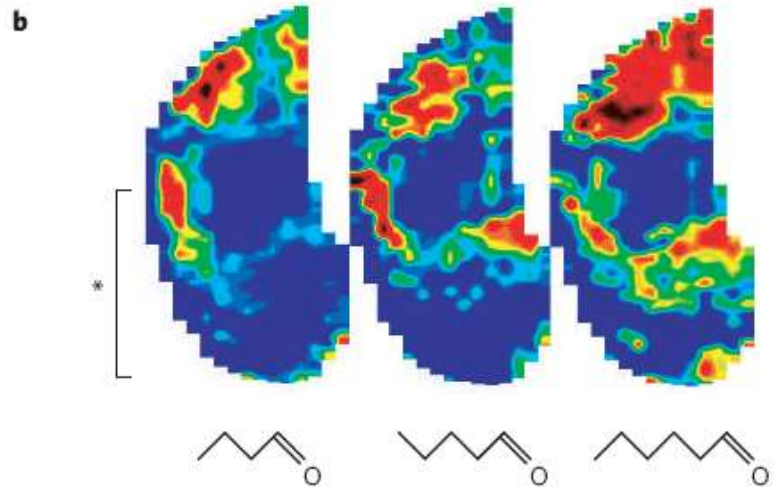
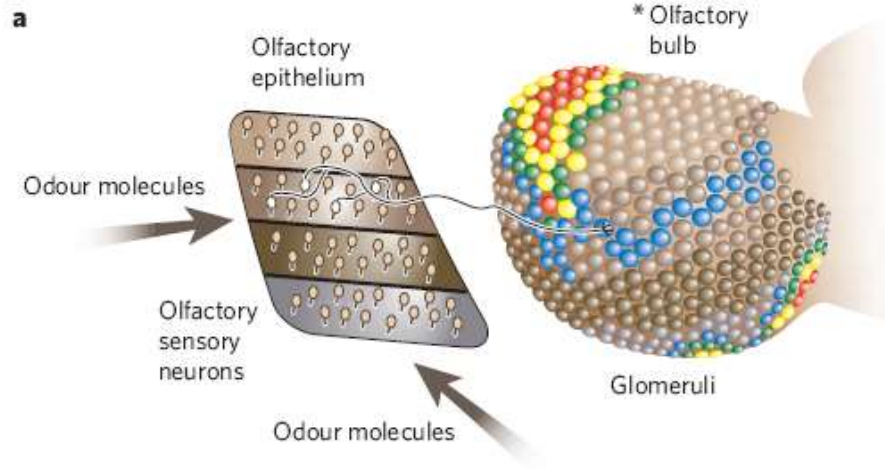
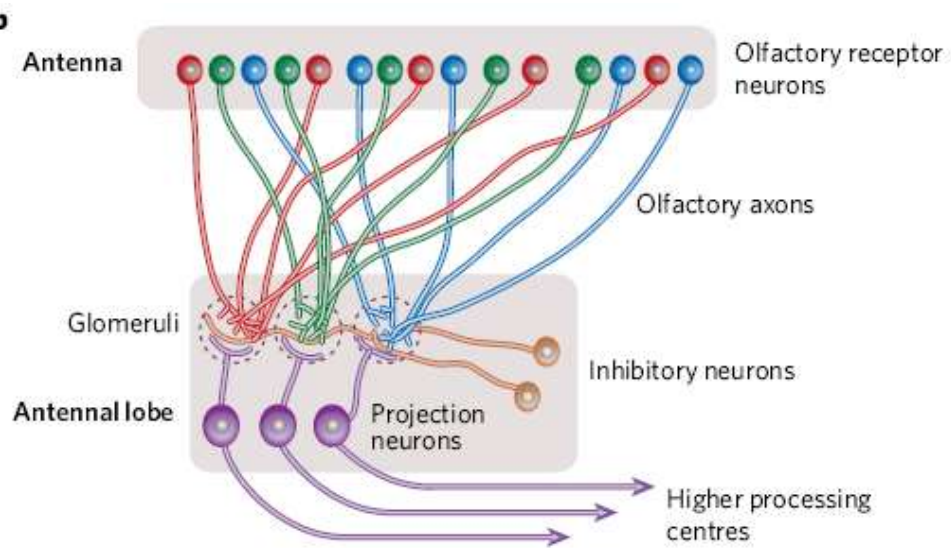


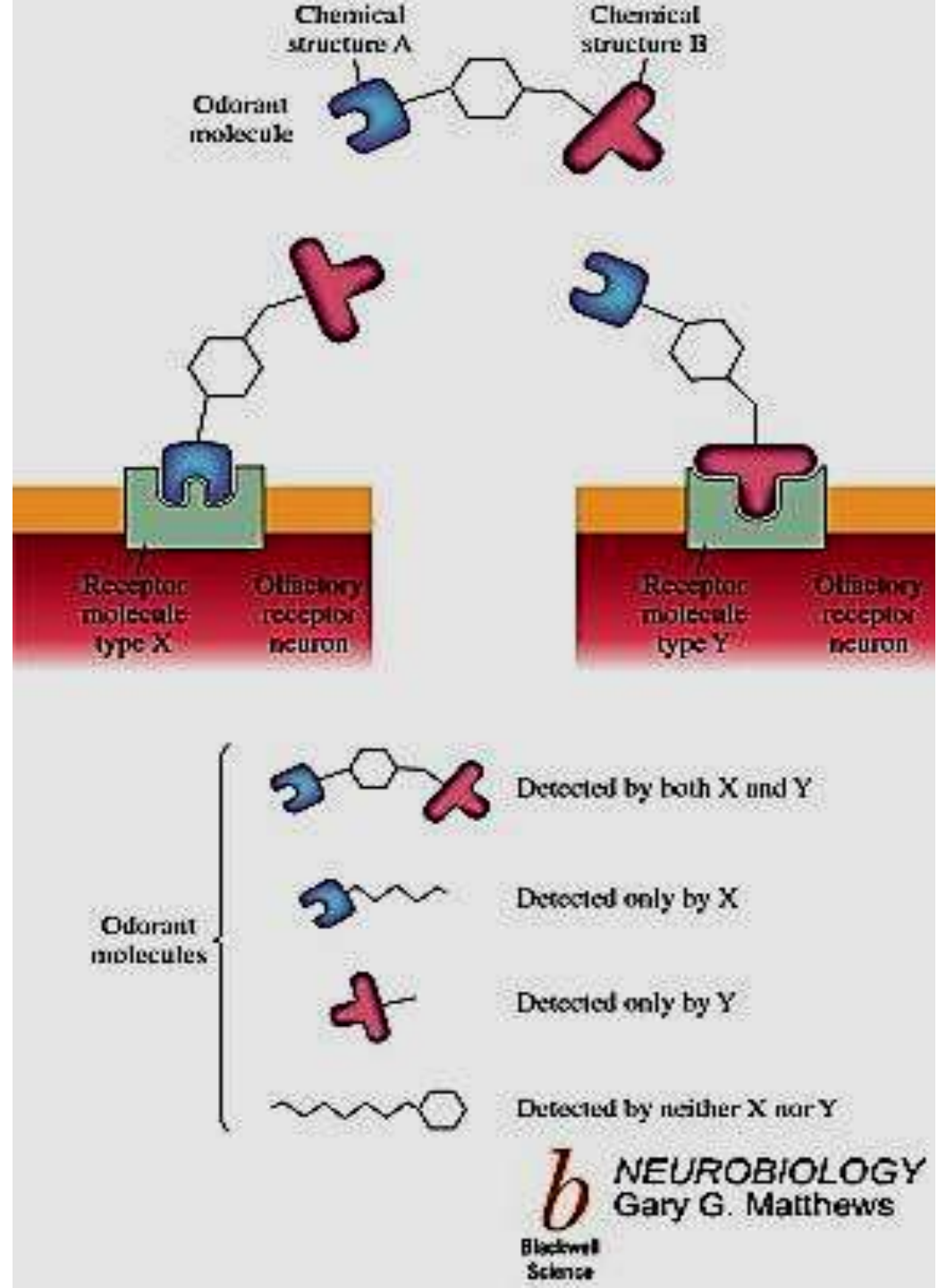
Figure 1 | Odour images in the olfactory glomerular layer. **a**, Diagram showing the relationship between the olfactory receptor cell sheet in the nose and the glomeruli of the olfactory bulb⁵³. **b**, fMRI images of the different but overlapping activity patterns seen in the glomerular layer of the olfactory bulb of a mouse exposed to members of the straight-chain aldehyde series, varying from four to six carbon atoms. The lower part of the image in the left panel corresponds to the image on the medial side of the olfactory glomerular layer as shown in **a** (see asterisk). (Image in **a** adapted, with permission, from ref. 53; image in **b** adapted, with permission, from ref. 10.)

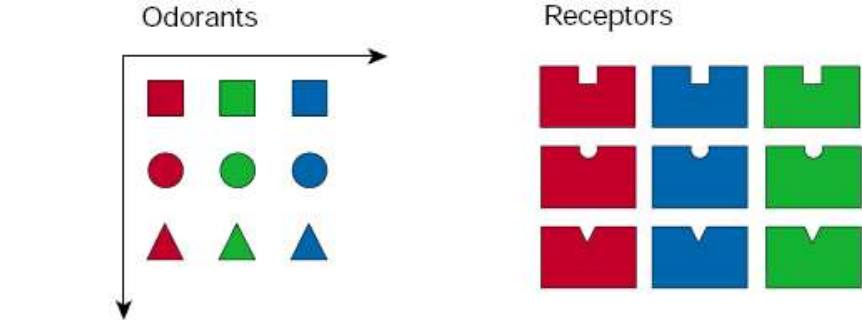


Specializace receptorů
Kombinace cca 350
receptorů
3.000-100.000 vůní (?)

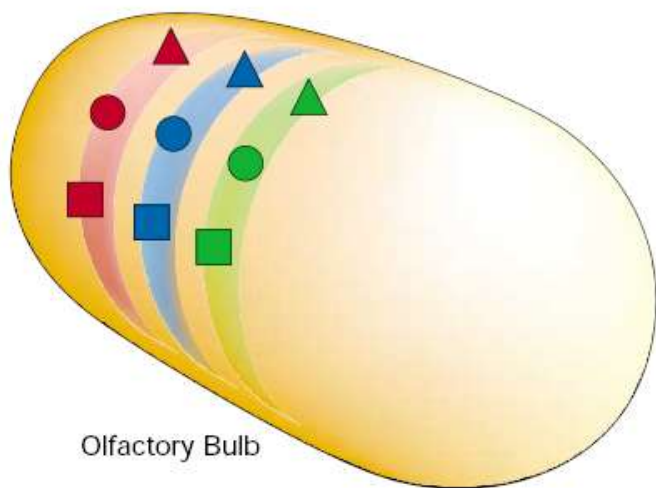
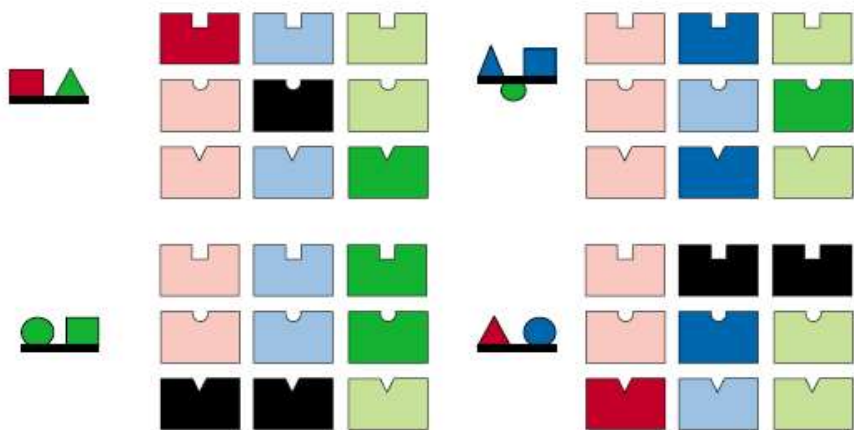
Ale: 21 MARCH 2014 VOL
343 SCIENCE
10¹² - trilion vůní

Rozeznává tisíce hlavně
nízkomolekulárních organických
látek, kterým říkáme pachy nebo
vůně. Jsou to alifatické nebo
aromatické molekuly s různými
uhlovodíkovými bočními větvemi a
vazebnými skupinami., aldehydy,
estery, ketony, alkoholy, aminy,
karboxylové kyseliny, atd.



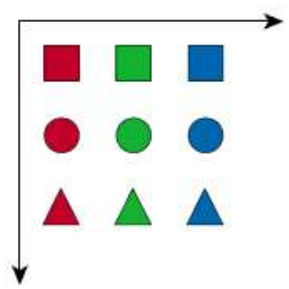


Pattern of peripheral activation

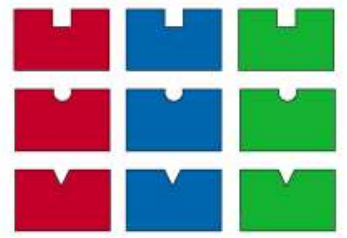


Although there are some 1,000 ORs, detecting the enormous repertoire of odours requires a combinatorial strategy. Most odour molecules are recognized by more than one receptor (perhaps by dozens) and most receptors recognize several odours, probably related by chemical property. The scheme in the figure represents a current consensus model. There are numerous molecular features, two of which are represented here by colour and shape. Receptors are able to recognize different features of molecules, and a particular odour compound may also consist of a number of these 'epitopes' or 'determinants' that possess some of these features. Thus the recognition of an odour molecule depends on which receptors are activated and to what extent, as shown by the shade of colour (black represents no colour or shape match and thus no activation). Four odour compounds are depicted with the specific array of receptors each would activate. Note that there are best receptors (for example, red square), but also other receptors that are able to recognize some feature of the molecule (for example, any square) and would participate in the discrimination of that compound. In the olfactory bulb there seem to be wide areas of sensitivity to different features (for example, functional group or molecular length). This model is based on current experimental evidence, but is likely to undergo considerable revision as more data become available.

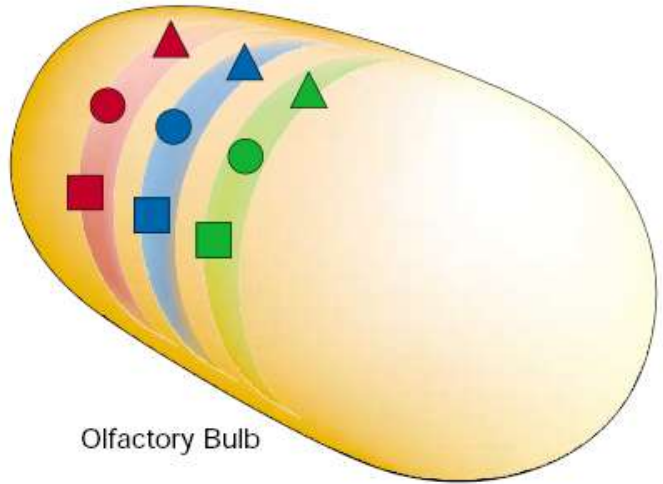
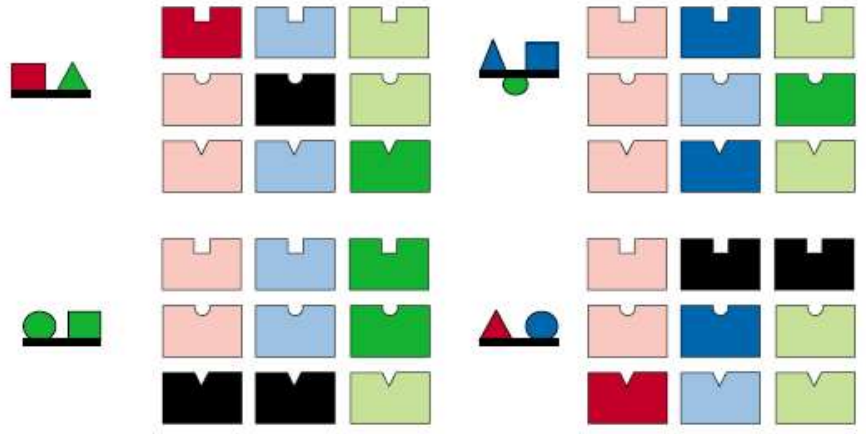
Odorants



Receptors



Pattern of peripheral activation



Olfactory Bulb

Podobnost architektury sensorických obvodů a drah zraku a čichu nebude náhodná

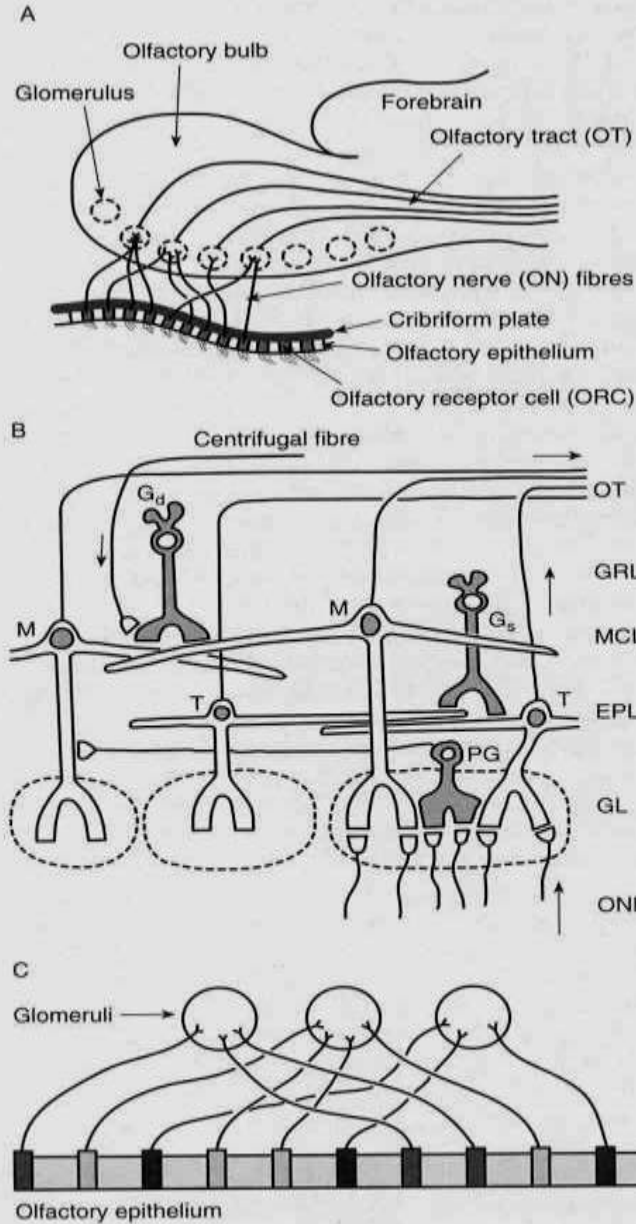
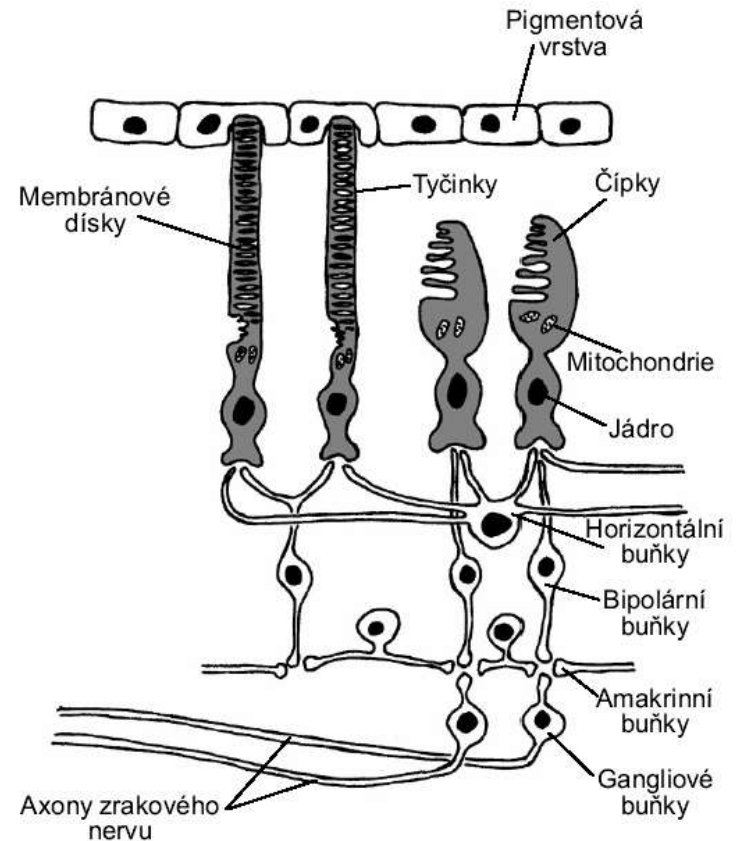


Figure 13.7 Olfactory bulb. (a) The figure shows olfactory axons passing through the cribriform plate to end in glomeruli in the olfactory bulb. (b) Basic circuit of the mammalian olfactory bulb. Layers: EPL = external plexiform layer; GL = glomerular layer; GRL = granule cell layer; OT = olfactory tract; MCL = mitral cell layer. Cells: G_d = deep granule cell; G_s = superficial granule cell; M = mitral cell; PG = periglomerular cell; T = tufted cell. Inhibitory cells stippled. Simplified from



Podobnost architektury sensorických obvodů a drah zraku a čichu nebude náhodná

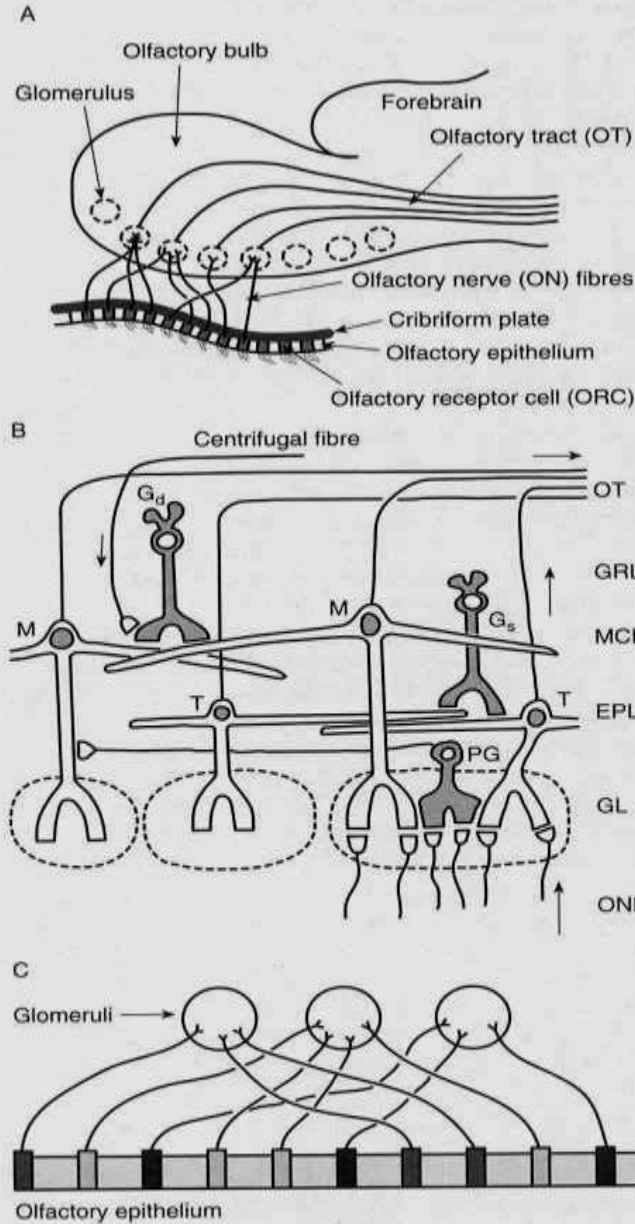
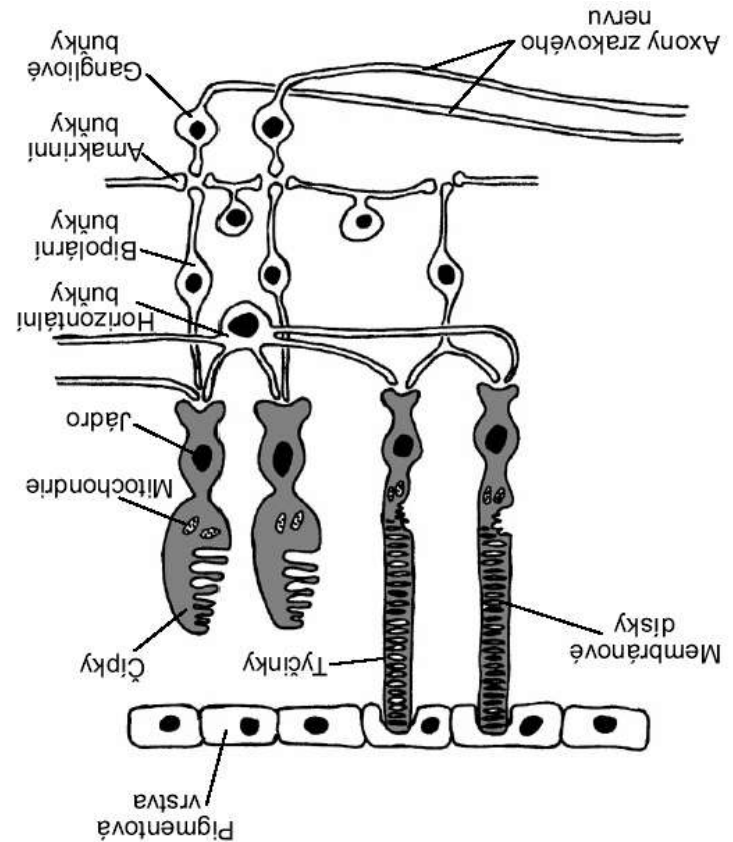
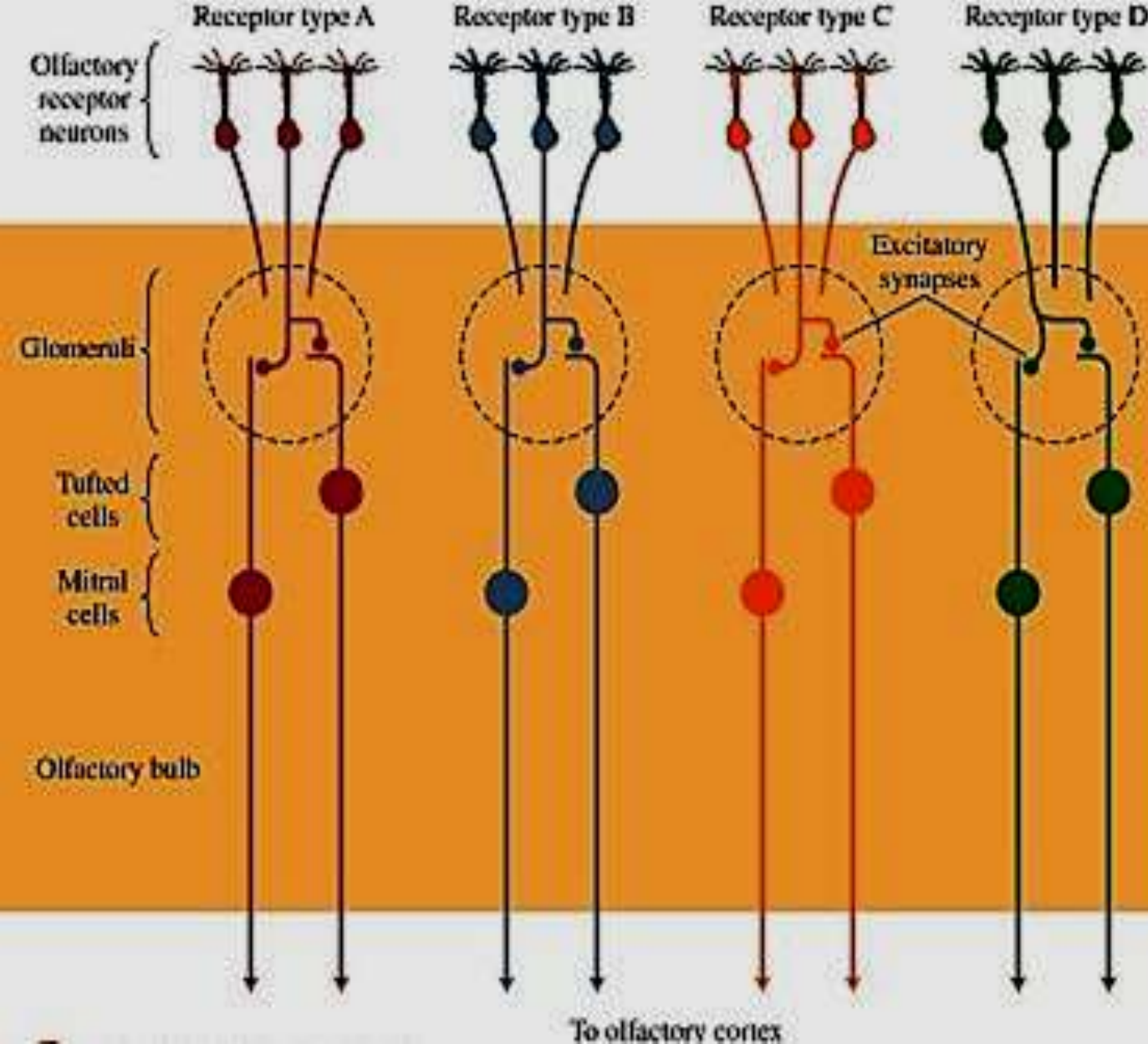
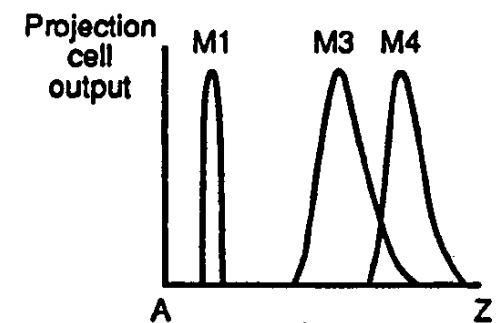
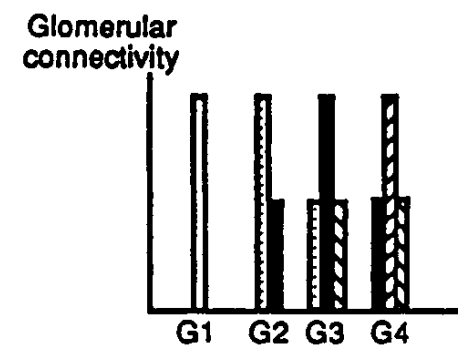
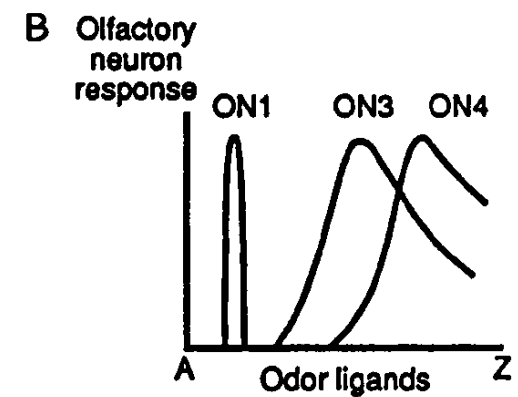


Figure 13.7 Olfactory bulb. (a) The figure shows olfactory axons passing through the cribriform plate to end in glomeruli in the olfactory bulb. (b) Basic circuit of the mammalian olfactory bulb. Layers: EPL = external plexiform layer; GL = glomerular layer; GRL = granule cell layer; OT = olfactory tract; MCL = mitral cell layer. Cells: G_d = deep granule cell; G_s = superficial granule cell; M = mitral cell; PG = periglomerular cell; T = tufted cell. Inhibitory cells stippled. Simplified from





Překryv



Laterální inhibice: „Zostření“ ladění ve vyšších patrech dráhy

Adaptace a habituace: Některé receptorové buňky reagují trvale nebo jen s malou adaptací na trvalé dráždění. To je ale v kontrastu se zkušeností velmi rychlé adaptace nebo i inhibice subjektivního počítku. Příčina je ve vyšších neurálních obvodech čichové dráhy.

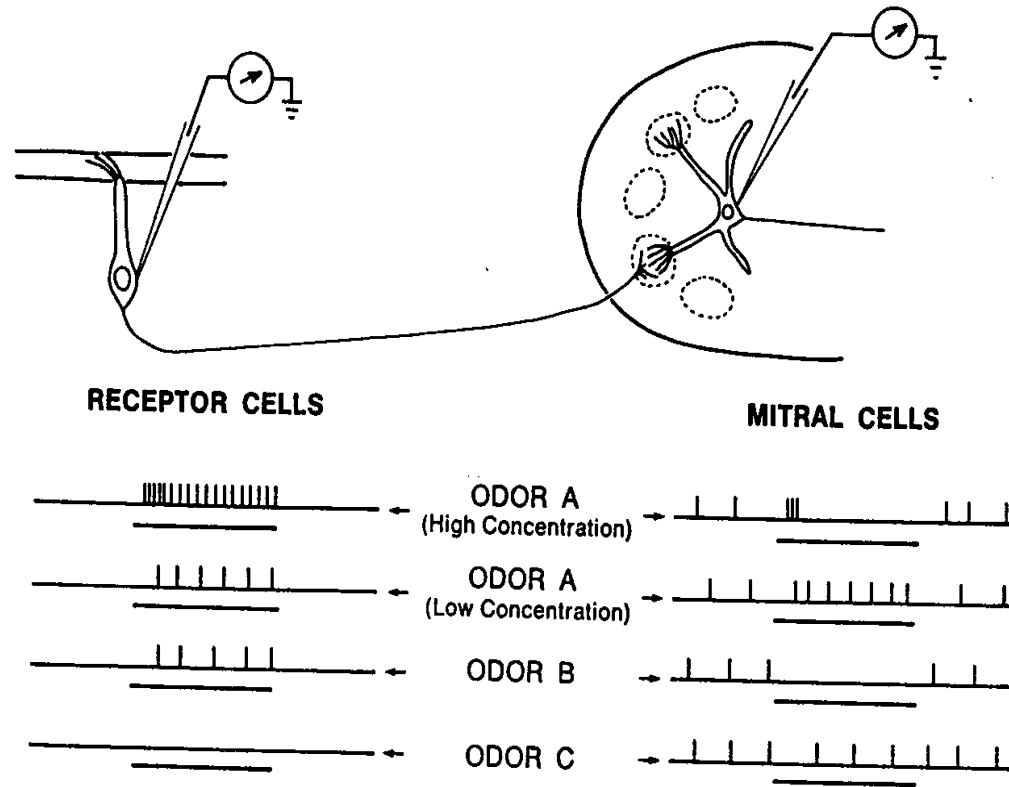


Fig. 11.11 Extracellular single-unit recordings of responses to odors of receptor cells (*left*) and mitral cells (*right*) in the salamander, showing different types of responses and different temporal patterns of activity. (After Kauer, 1974, and Getchell and Shepherd, 1978)

Citlivost: Práh čichové citlivosti může být u živočichů podle behaviorálních pokusů dokonce nižší než u jednotlivých receptorů elektrofyziologicky měřený. Jedním důvodem je právě konvergence na glomerulární buňky, dovolující mitrálním buňkám sbírat vstupy z velké populace identicky naladěných primárních neuronů a posílajících tak i velmi slabé signály do mozku. Systém také někdy zvyšuje citlivost na úkor rychlosti (časového rozlišení), která u čichu nehraje tak životně důležitou roli jako u zraku nebo sluchu.

Časové parametry čichání – řešení problému identity a koncentrace?

At the level of the olfactory bulb (OB) odor information is contained in the spike patterns of mitral/tufted (M/T) cells. Today it is generally assumed that in addition to the identity of the activated M/T cells, the temporal patterns of their responses are important for olfactory coding.

In mammals, every sniff evokes a precise, odour-specific sequence of activity across olfactory neurons.

Distributed representations reflecting different features of a stimulus can therefore occur in the same circuit at different epochs of a response.

Spatial coding and temporal coding are not mutually exclusive, and may instead exhibit synergy in numerous ways. We speculate that time comparisons across *glomeruli* give a concentration-invariant readout for odour *identity*, whereas temporal comparison to an *internal representation* of the sniff yields information about odour *concentration*. Such a coding scheme can rapidly resolve ambiguities that arise as odour identity and intensity change. Extracting both parameters on a sniff-by-sniff basis may help animals locate and identify odour sources in natural olfactory scenes.

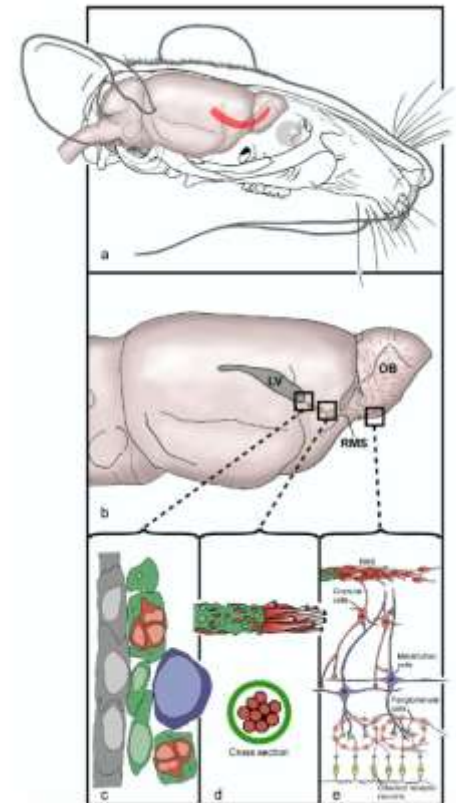
Smear, M., Shusterman, R., O'connor, R., Bozza, T., & Rinberg, D. (2011). Perception of sniff phase in mouse olfaction. *Nature*, 479(7373), 397.

Lateralizace čichu

- With the smells that were either neutral or ones that dogs liked (food, lemon, vaginal secretion and cotton swab), **the first time dogs sniffed them, they did so with their right nostrils. However, as time went on and they encountered the smells more, they then switched to their left nostrils**
- The fact that dogs smell with their right nostril first implies that the right side of the brain is involved first. This is thought to be because the **right-hand side of the brain deals with novel information** (in this case, a new smell), and then once the dog has become accustomed to the smell the left side of the brain takes over more, as this side handles more familiar stimuli.
- However, for the other two smells (the vet's sweat and adrenaline), that perhaps may not be quite as welcome to a dog, the dogs always smelled them with their right nostril. Even though the smell of the vet would be as familiar to the dogs as perhaps dog food or the smell from a female dog, it must have been more stressful to the dogs (as any person who owns a dog knows, taking it to the vet's generally isn't a relaxing event for anyone involved). **The fight-or-flight response is mainly dealt with by the right side of the brain.** Therefore, even though these smells became as familiar as the other ones did, they elicited enough strong emotions like **fear to continue being processed by the right-side of the brain (and therefore the right nostril).**
- doi:10.1016/j.anbehav.2011.05.020

Rostral migratory stream

- The **rostral migratory stream** (RMS) is a specialized migratory route found in the [brain](#) of some animals along which neuronal precursors that originated in the [subventricular zone](#) (SVZ) of the brain migrate to reach the main [olfactory bulb](#)(OB). The importance of the RMS lies in its ability to refine and even change an animal's sensitivity to smells, which explains its importance and larger size in the rodent brain as compared to the human brain, as our olfactory sense is not as developed. When the neurons reach the OB they differentiate into [GABAergic interneurons](#) as they are integrated into either the granule cell layer or periglomerular layer.
- Although it was originally believed that neurons could not regenerate in the adult brain, [neurogenesis](#) has been shown to occur in mammalian brains, including those of primates. However, neurogenesis is limited to the [hippocampus](#) and SVZ, and the RMS is one mechanism neurons use to relocate from these areas.

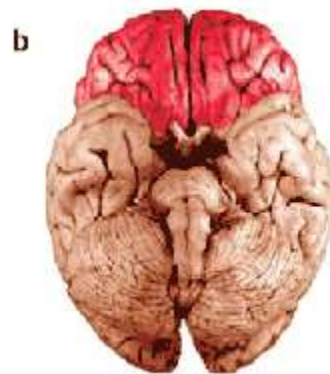
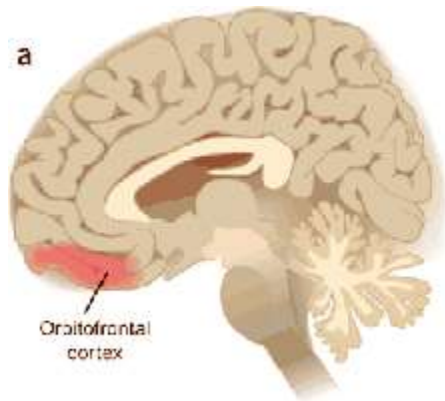




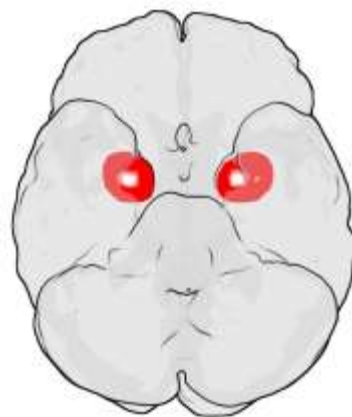
Centrální části čichové dráhy

1. Čichový lalok
2. Piriformní kůra
3. Orbitofrontální kůra

Figure 1. Schematic overview of the basic steps of the central processing of odorous stimuli. Odorants are first detected by receptors at the top of the nasal cavity, and from there, the signal travels to the olfactory bulb (1). This signal is then routed to the piriform cortex (2) and subsequently to the orbitofrontal cortex (3), among other structures. Note the dual route that odorants can take to reach the receptors at the top of the nasal cavity. The route via the nostrils is known as orthonasal olfaction, whereas the route via the back of the throat is known as retronasal olfaction. See the text for

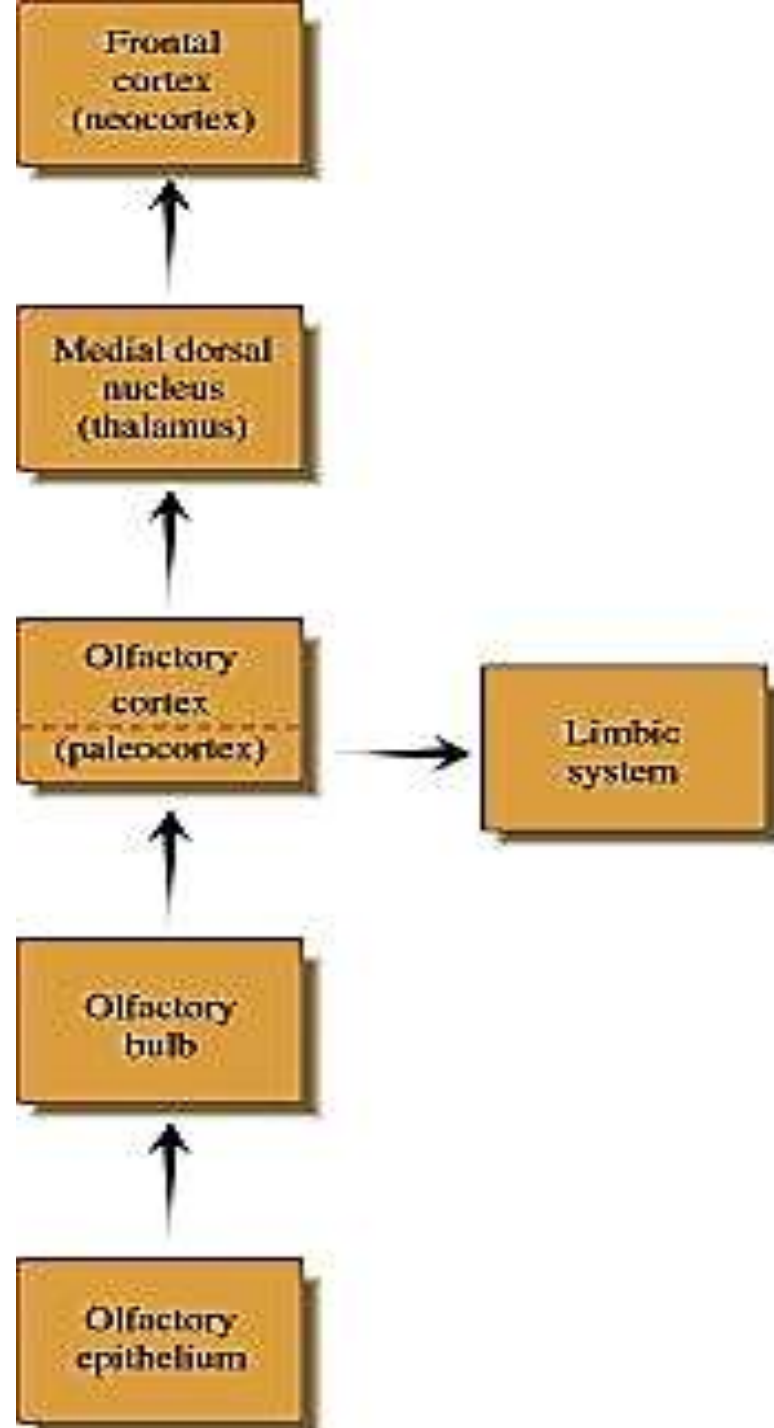


Orbitofrontální kůra neokortexu



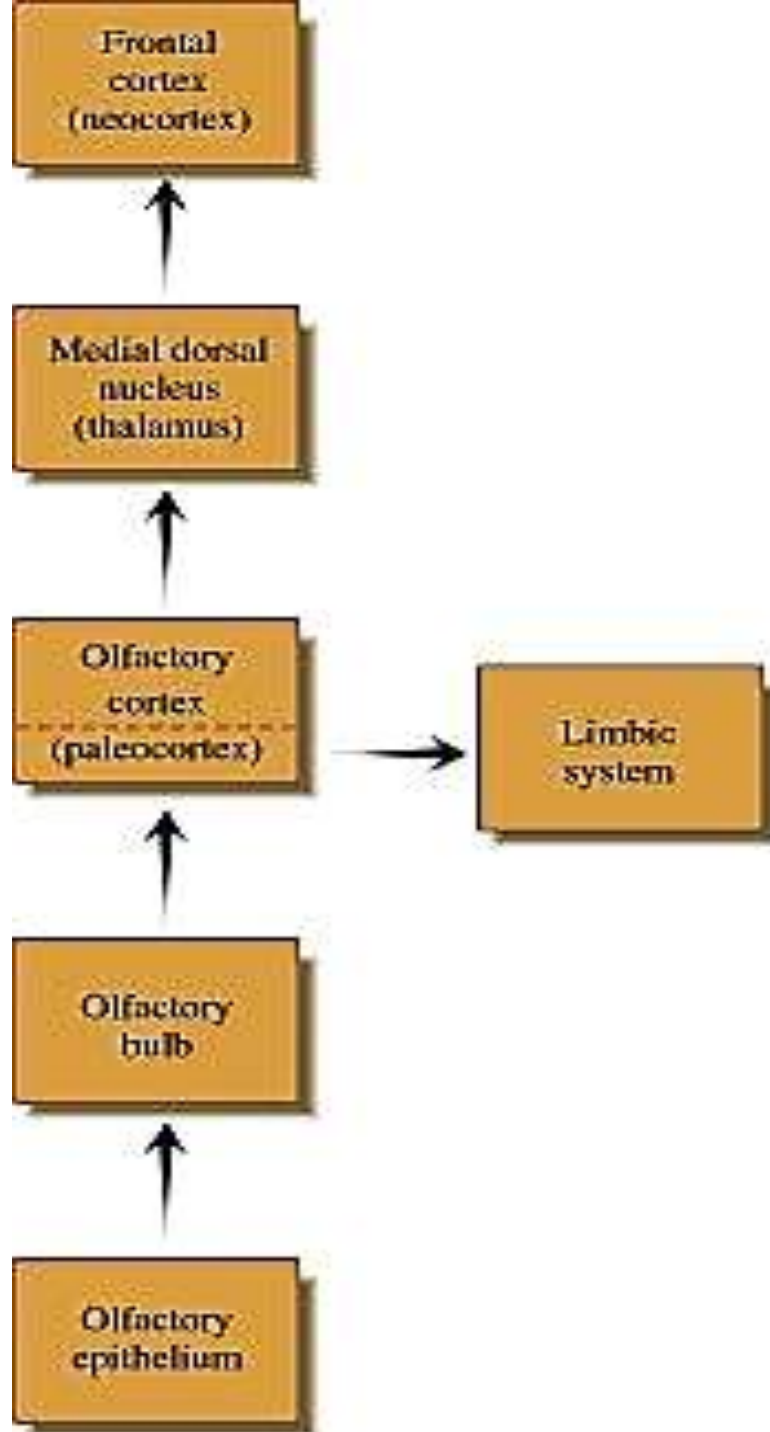
Piriformní kůra zahrnuje kortikální amygdalu (paleokortex)

Anosmie doprovází úrazy hlavy či neurodegeneraci ve stáří.



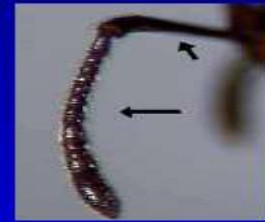
Lingvistické, deklarativní schopnosti jsou odděleny od čichu – je těžké pojmenovat a popsat čichové počítky.

Má vztah k silné emocionální složce čichových vjemů a ukládání paměťových stop. Antabus. Aromaterapie. Vzpomínky. Emoční, hedonická hodnota vždy automaticky přítomná. Je většinou naučená, ne vrozená.

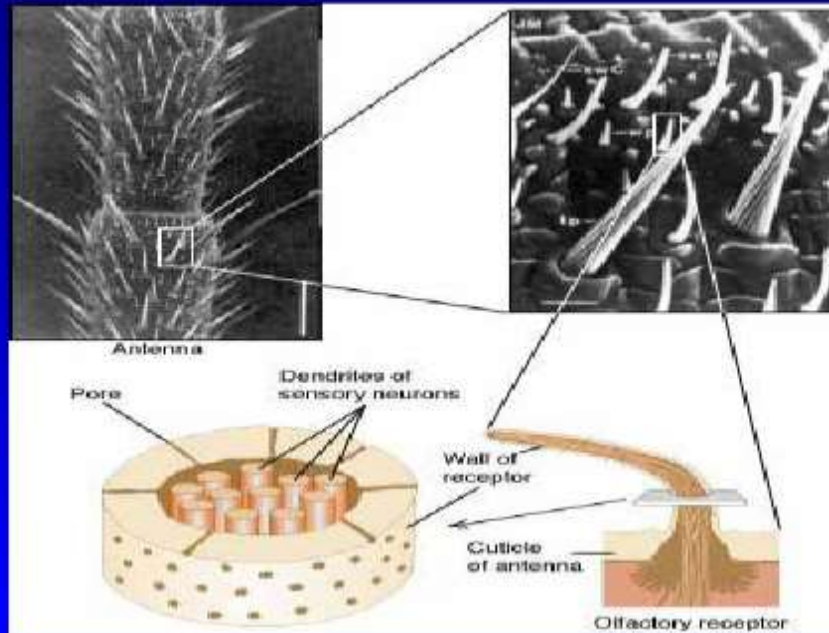


A co hmyz ?

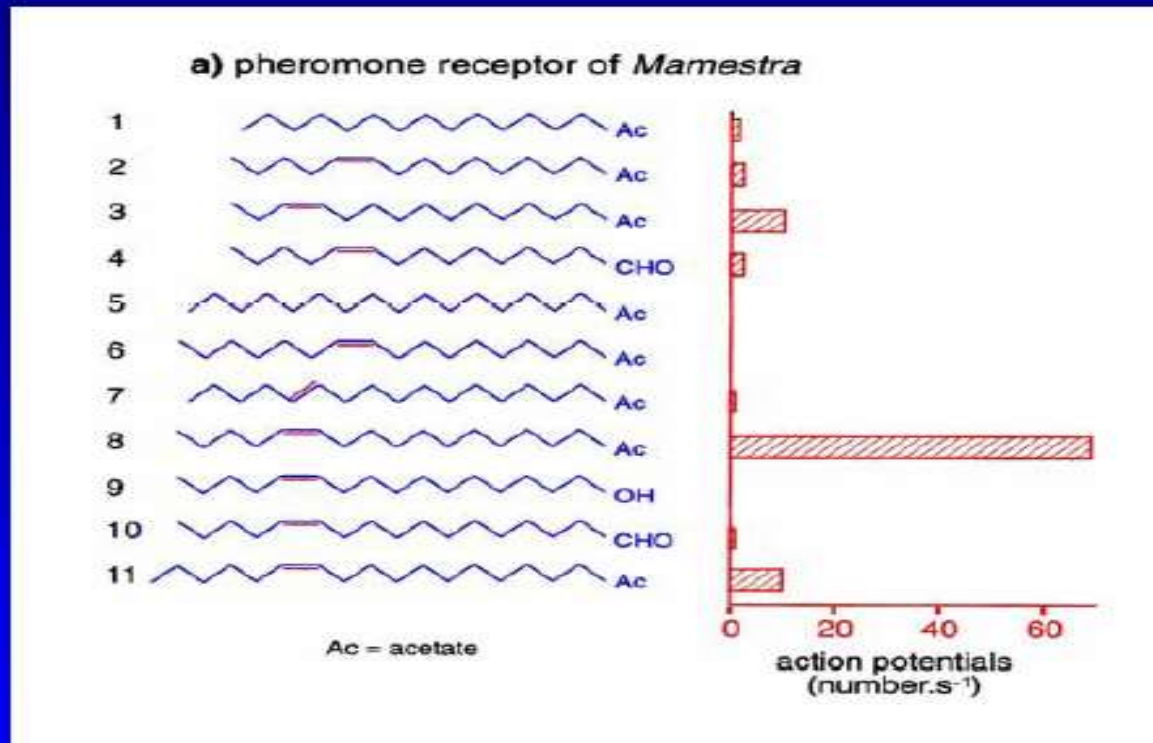
Antennal morphology diversity



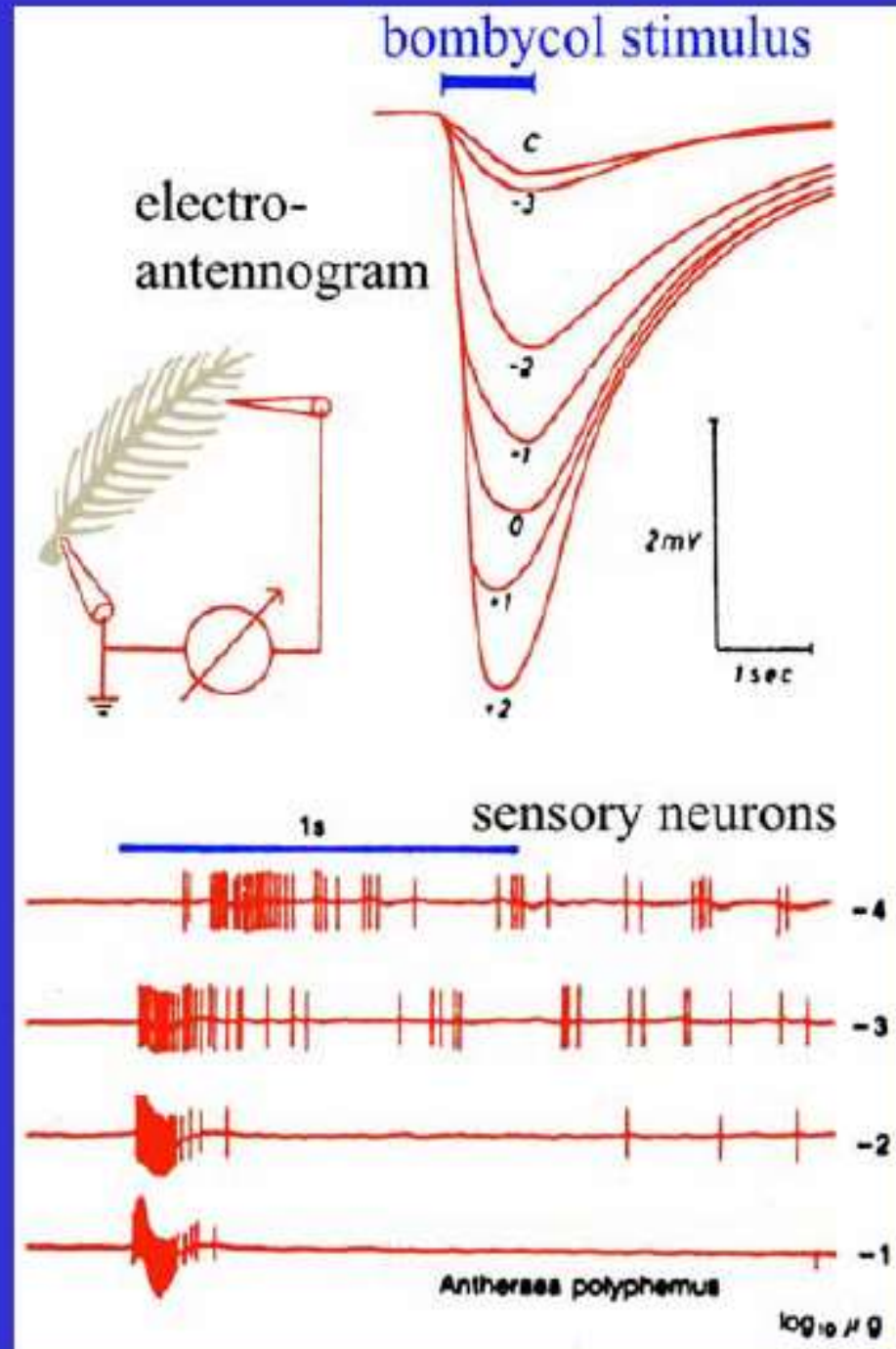
Anatomy of an antennal sensilla



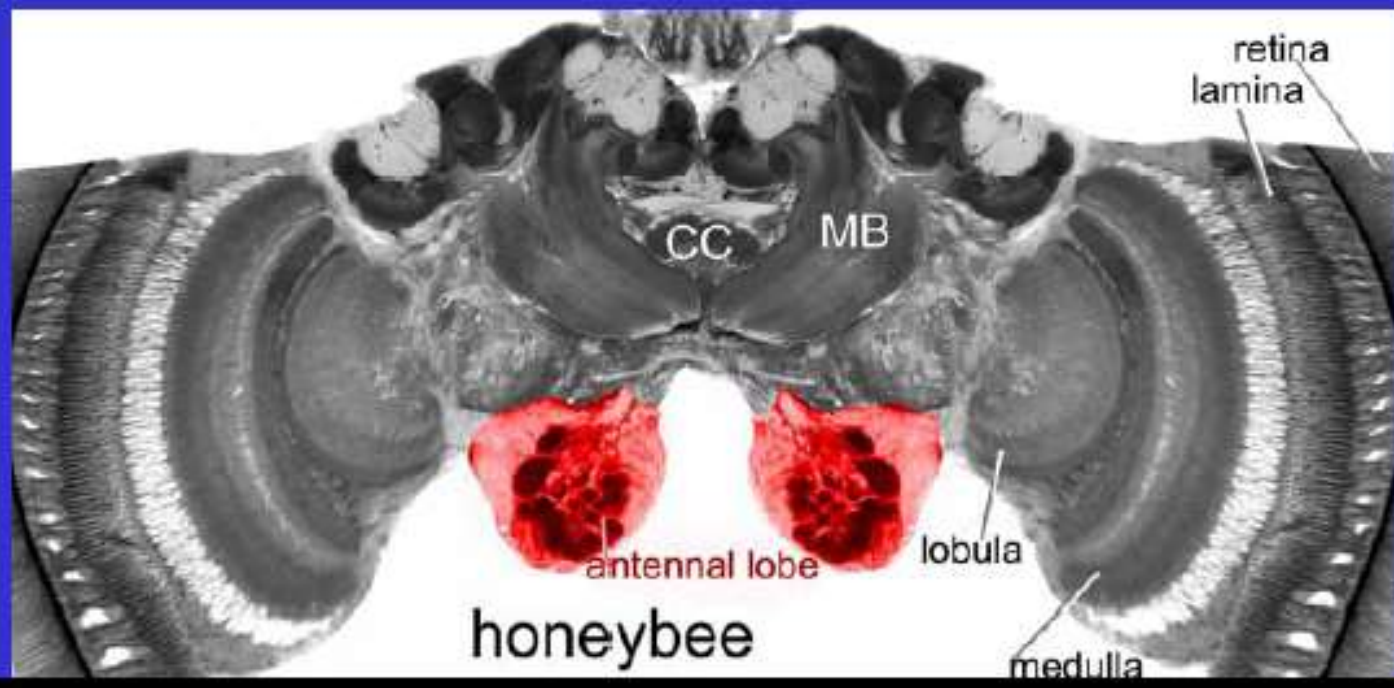
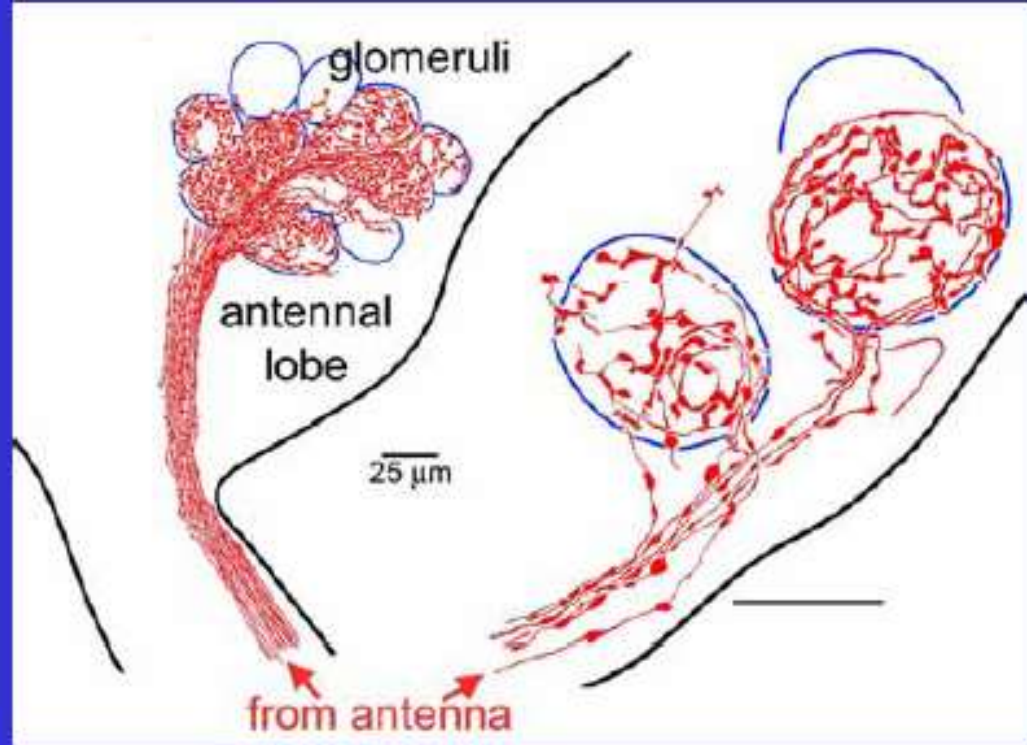
Response specificity to size and composition of odorant molecule



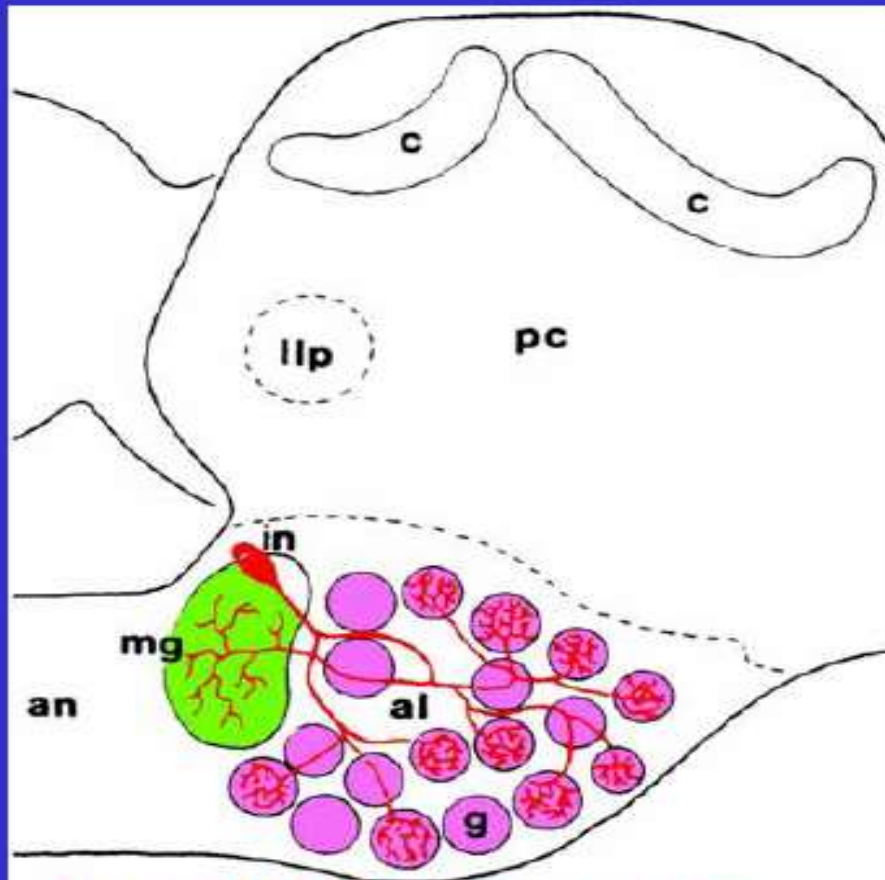
Olfactory receptor neurons respond to odorants



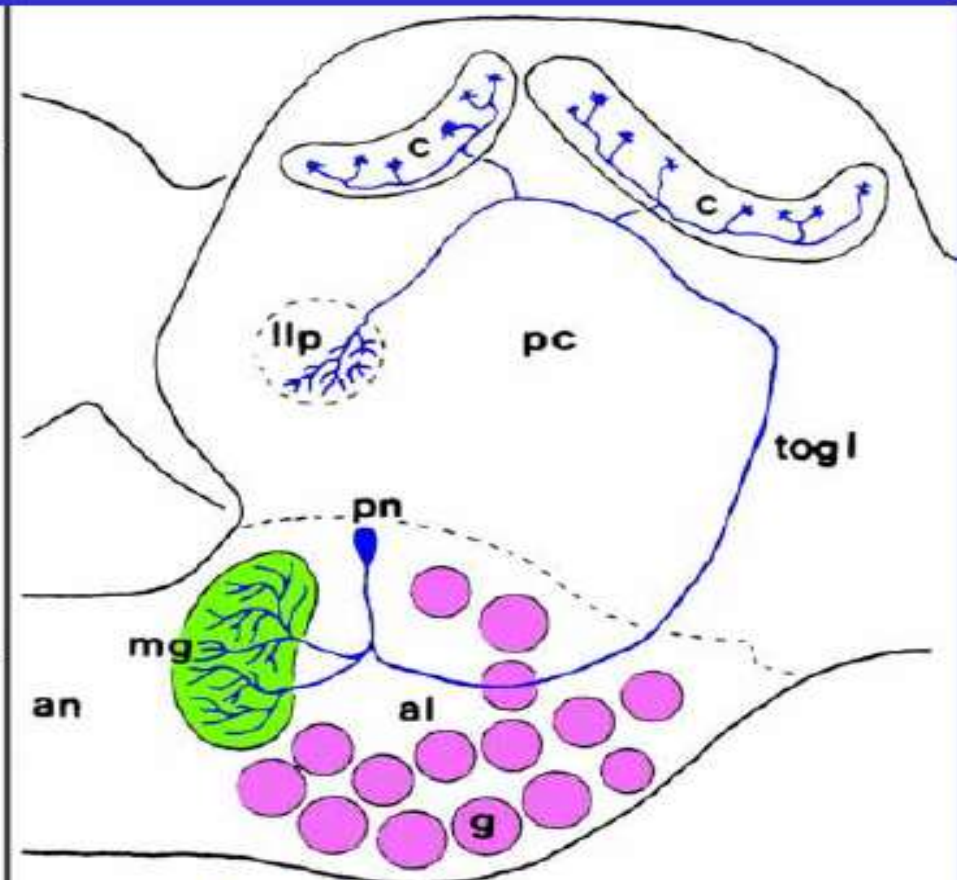
Antennal
olfactory receptor
neurons terminate
in antennal lobe
glomeruli



Antennal lobe: two major classes of neurons



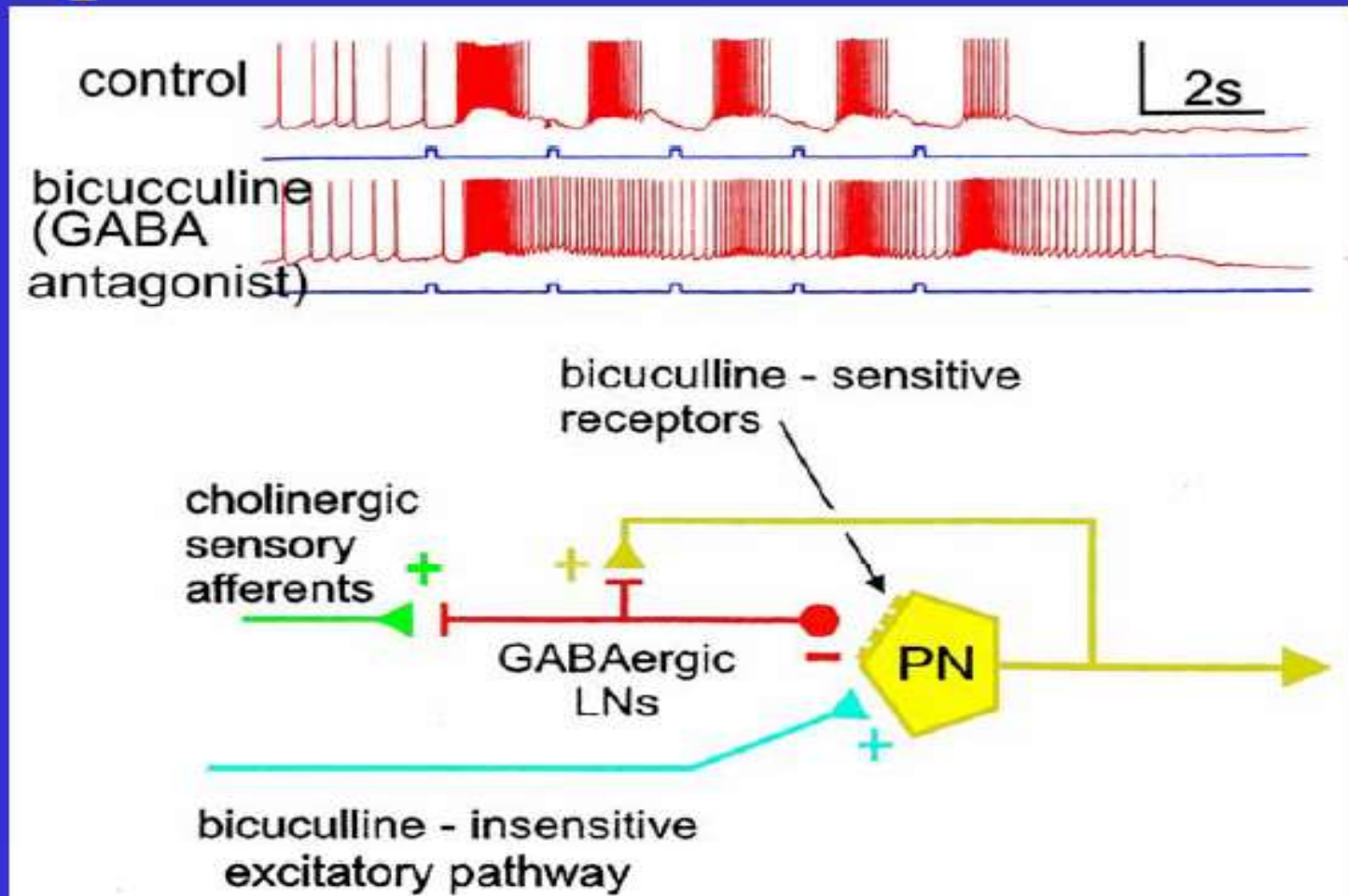
local interneuron



projection neuron

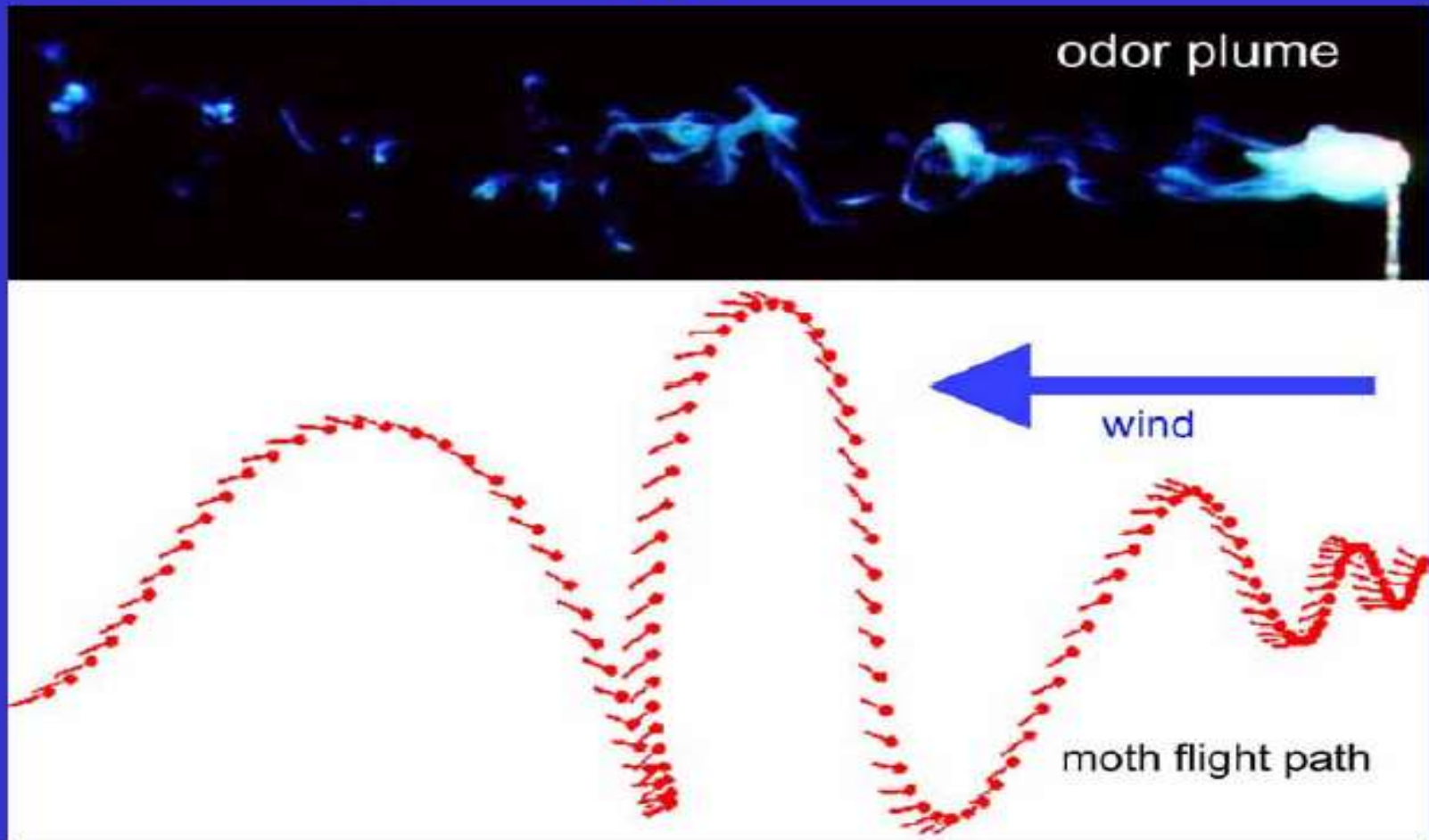
Projekce do tzv. houbových tělísek, ty zajišťují paměť a naučené chování

Inhibition 'sharpens' the PN response (temporal and odor discrimination)



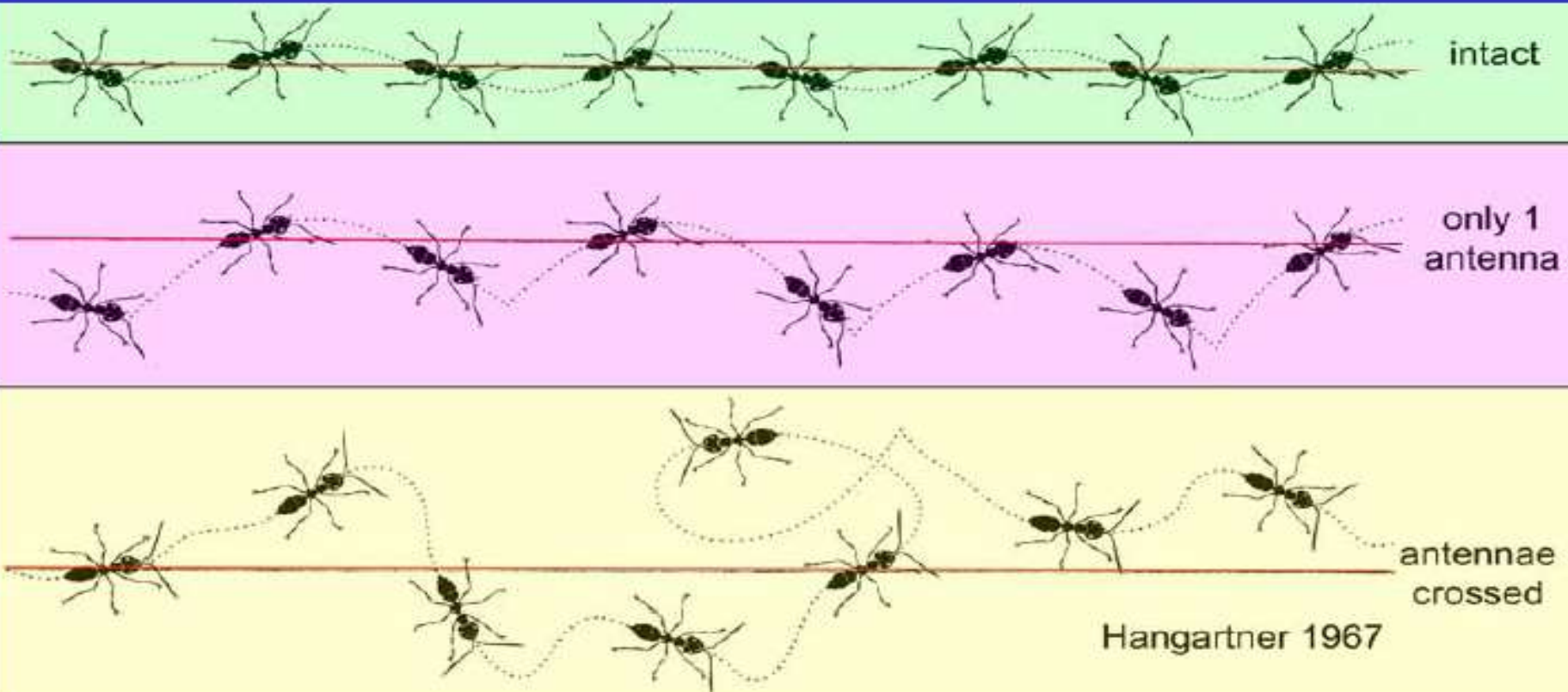
Terminace odpovědi nezbytná pro časovou rozlišitelnost signálů. Ta je nezbytná pro sledování pachové stopy. Inhibice GABAergním neuronem nutná pro časové rozlišení. Při vyřazení splývají časově oddělené podněty do jednoho.

Odor is discontinuously distributed in air

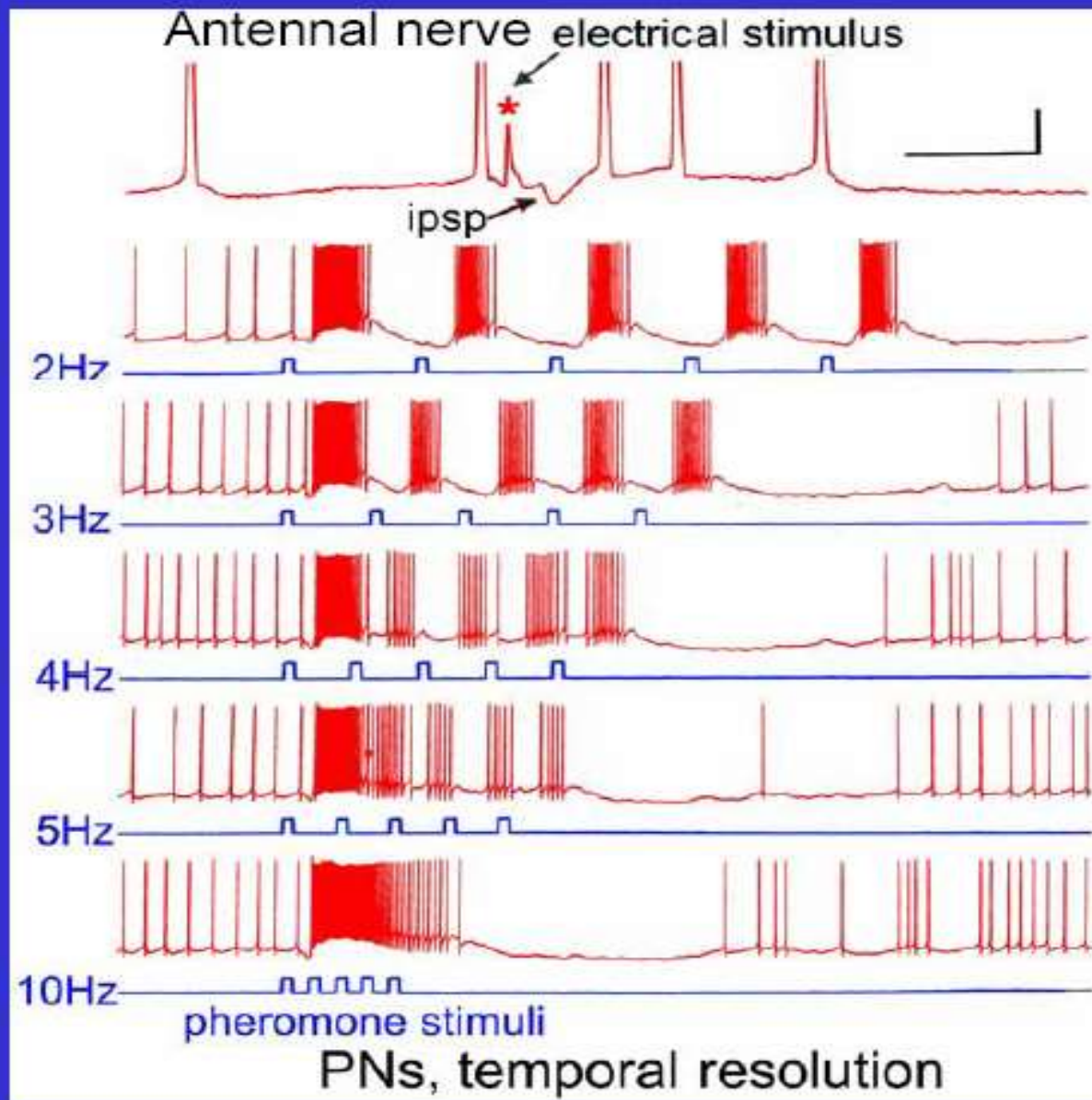


Časové parametry čichu jsou pro sledování voňavé stopy důležité. Pach netvoří kontinuálním gradient, ale sérií obláčků.

Even when following an odor trace, perception is discontinuous

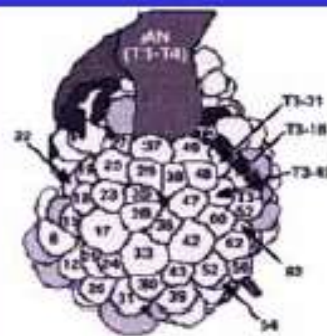


Temporal resolution is limited

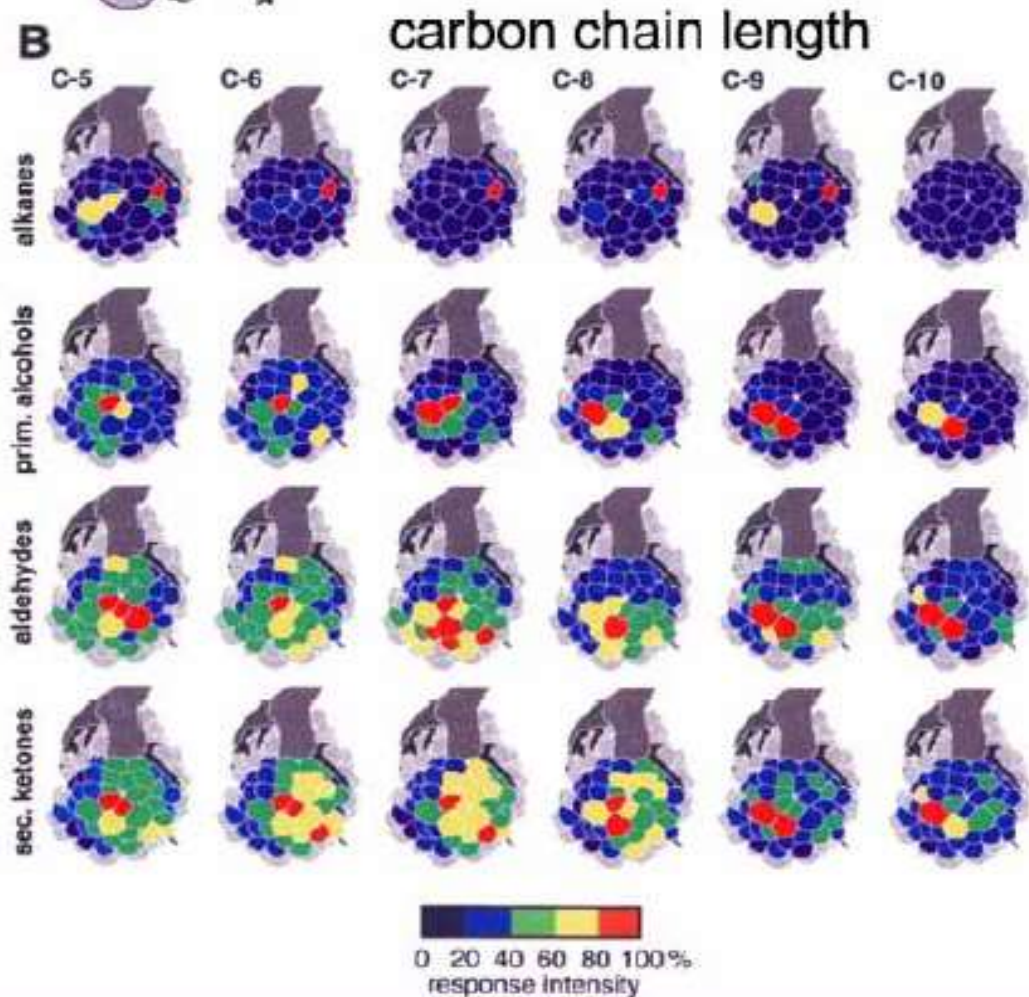


Časové rozlišení má hranici mezi 5 a 10 Hz.

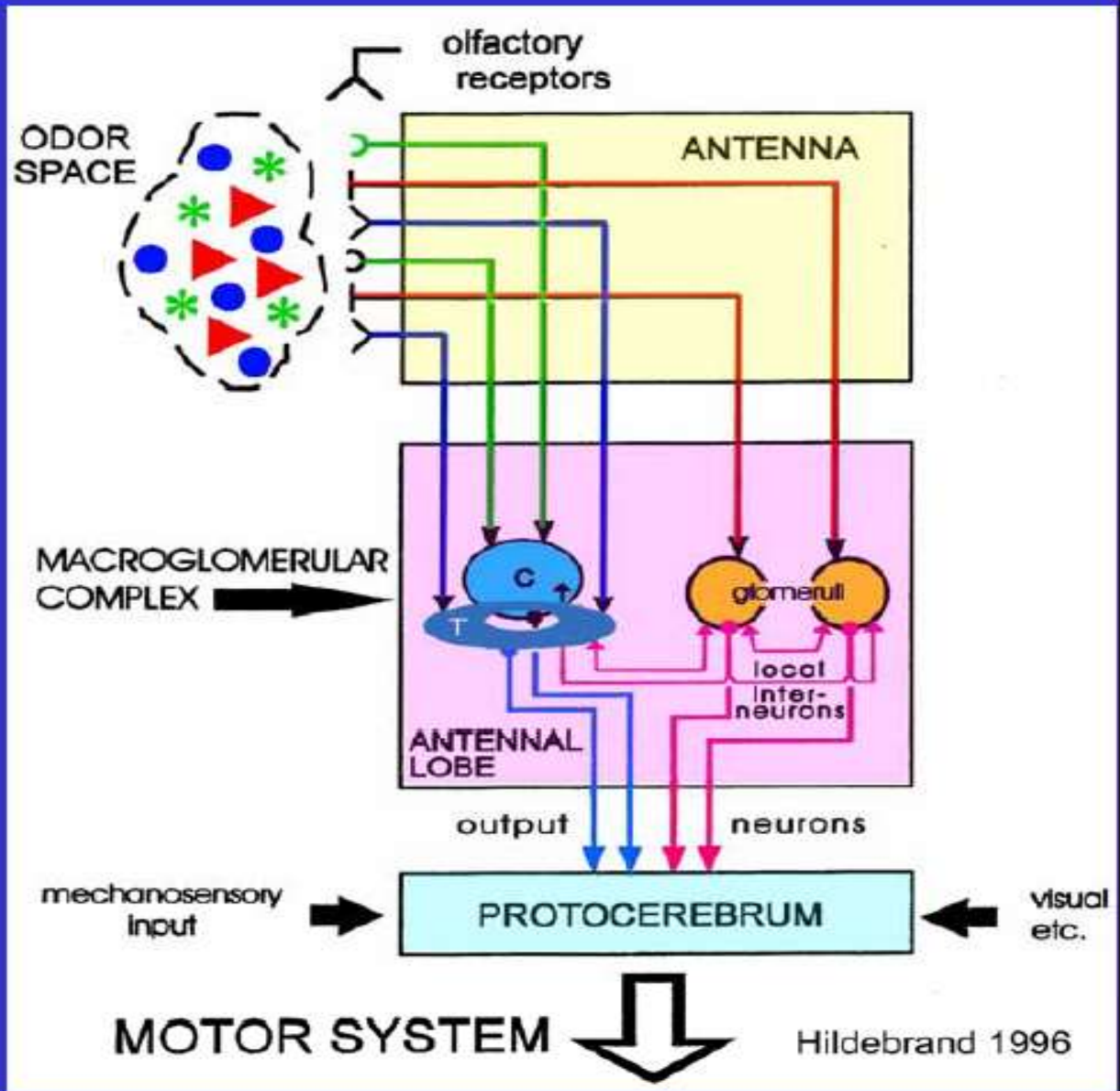
Glomeruli responses reflect odorants' structural properties (chain length, residues, polarity etc.):
odor map



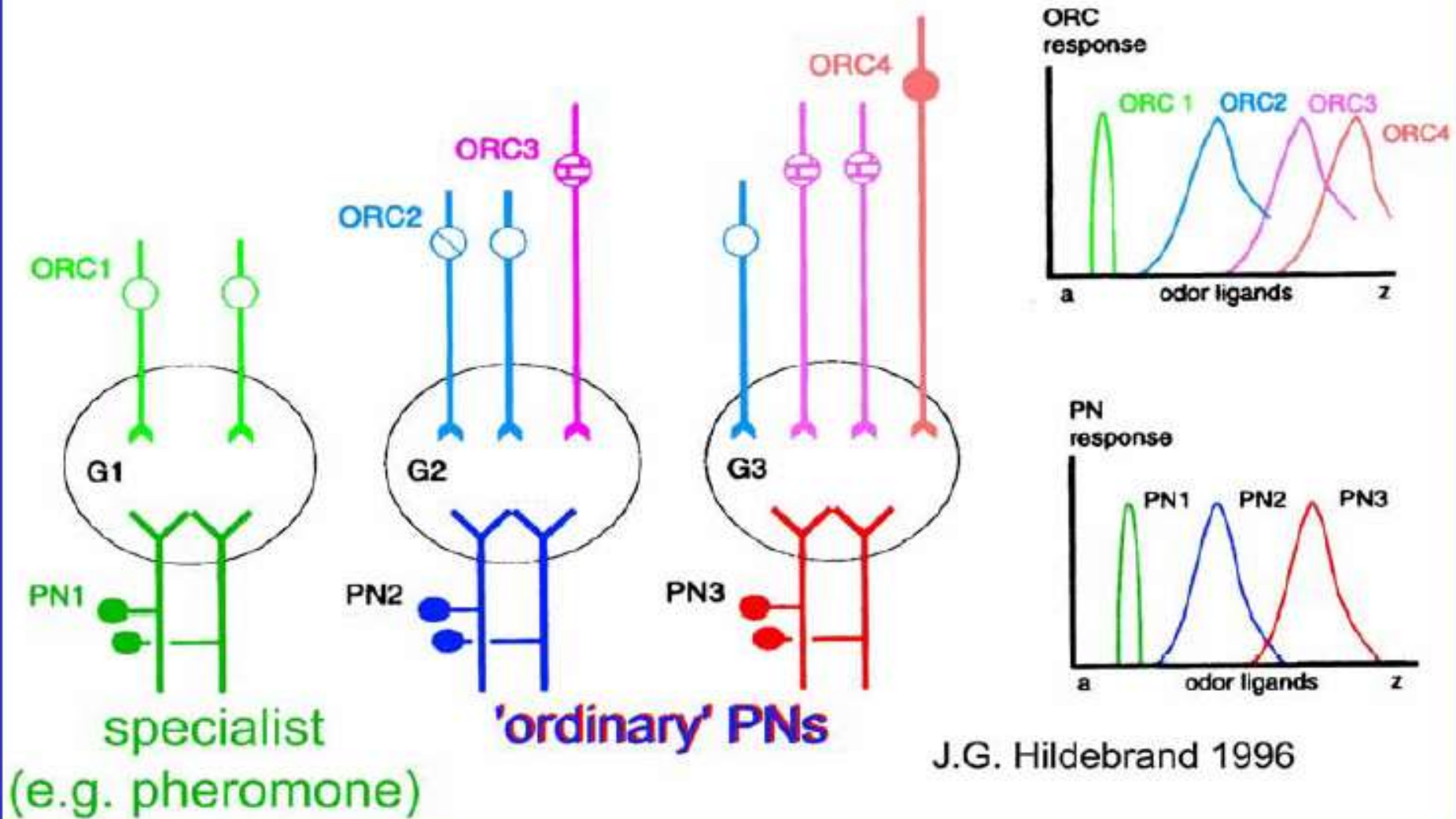
Apis mellifera,
antennal lobe



(sex)
pheromones
and
'ordinary'
odors are
processed by
two different
pathways



PNs may have narrower response spectra than receptor neurons



J.G. Hildebrand 1996

Podobnost mezi hmyzem a obratlovci jen omezená

Table 2 | **Commonalities and differences of olfactory receptors in vertebrates and insects**

Characteristic	Vertebrates	Insects
Class	GPCR	Non-GPCR
Repertoire	Large, variable	Smaller, constant
Topology	Heptahelical	Inverse heptahelical
Activation	Metabotropic	Ionotropic
Pseudogene fraction	High	None to low
Stoichiometry	Monomers	Heteromers
One receptor–one neuron rule	Yes	Yes*
Gene selection	Stochastic	Deterministic
Expression pattern	Zonal and random	Zonal and random
Instructive role	Yes	Unknown
Ectopic expression	Yes	Unknown
Inhibitory action of odorants	Rare	Common
Convergence of axons to glomeruli	Yes	Yes
Glomeruli per receptor type	Variable, ≤ 2 up to 20	~1

GPCR, G protein-coupled receptor. *There are notable exceptions to this rule, which have been excluded from this table for clarity.

Vertebrates

In general, G protein-coupled receptor (GPCR) signalling, such as that mediated by photoreceptors, amplifies a signal¹³⁸. However, the principles governing olfactory signalling are quite different. Owing to the relatively low binding affinity of many odorants (micromolar range), the lifetime of the receptor–ligand complex is brief. Consequently, the probability that a receptor–ligand complex will meet a G protein and catalyse GDP–GTP exchange is low⁷². Why do most olfactory neurons not require high amplification at the receptor level? At micromolar odorant concentrations, more than 20 million odorant molecules arrive at a cilium every second¹³⁹. Thus, although the probability that a single odorant molecule will activate the signalling pathway is minuscule, it is likely that a few odorant molecules will successfully evoke a response. By contrast, at low light levels, at which only a few photons reach the eye, amplification allows rod photoreceptors to detect and respond to single photons.

In the vomeronasal organ, concentrations of pheromone molecules above 0.1 pM can elicit a response^{140,141}. At these low concentrations, only a few molecules per second are captured by a cilium. What are the biophysical requirements for such exquisite sensitivity? Receptors must bind the ligand with high affinity, increasing the lifetime of the ligand–receptor complex (seconds to minutes). During this time, the receptor may activate many hundreds of G proteins. However, active mechanisms are required to disable such stable ligand–receptor complexes. Receptor phosphorylation and β -arrestin capping may be an important route for response termination. In other cases, there may be no need for rapid inactivation, because temporal coding of successive stimuli does not matter.

Insects

Similar to vertebrate neurons, insect olfactory receptor neurons (ORNs) can be very sensitive, responding to the binding of a single molecule of a sex pheromone¹⁴². Insect ORNs, which have an ionotropic mechanism of action, also lack the amplification provided at the receptor and G protein level. How then can a single pheromone molecule activate an insect neuron? The open probability (P_o) of a ligand-gated channel is determined by its affinity for the ligand and, for nanomolar binding affinities, may reach unity on a timescale of seconds. Depending on the single-channel conductance, a single channel may readily carry currents in the order of a few picoamperes. The input resistance of vertebrate ORNs is high (2–8 G Ω) and a few picoamperes of inward current produce a voltage response that is sufficient to reach the threshold for triggering an action potential¹⁴³. Similar mechanisms are seen in rod photoreceptors and sperm, which detect single photons and single molecules, respectively^{108,144,145}.

Feromony u obratlovců

Interindividuální komunikace

- Spouštěče: vyvolávají okamžitý behaviorální projev
- Primery: pomalejší změny vývoje nebo metabolismu
- Modulátory (?): ovlivňující emoce, náladu (u lidí)

Chemické složení: velikost, polarita, těkavost:

Atraktanty nebo poplachové feromony – malé a těkavé (alkoholy)

Individuální feromony – netěkavé (proteiny)

Dva chemosensitivní systémy savců

Hlavní čichový epitel (MOE):

Těkavé látky, ciliární čichové buňky

Projekce do čichového laloku

Každá buňka exprimuje jediný typ receptoru (1300 u myši)

Proud vzduchu při nadechování (a vydechování)

Identifikace potravy, kořisti, predátora, značení teritoria

Otevřený systém vybudovaný na předpokladu, že není možné předvídat, se kterou molekulou se potká.

Vomeronasální orgán (VNO):

Slepá dutinka pod hlavní čichovou sliznicí

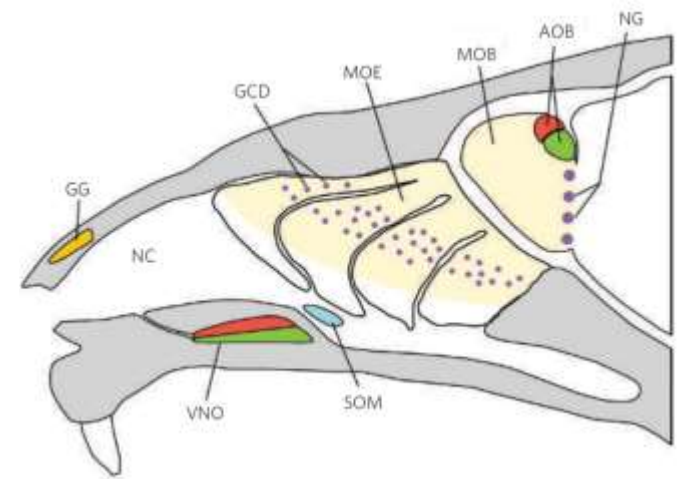
Mikrovilární morfologie

Projekce do přídatného čichového laloku (AOB)

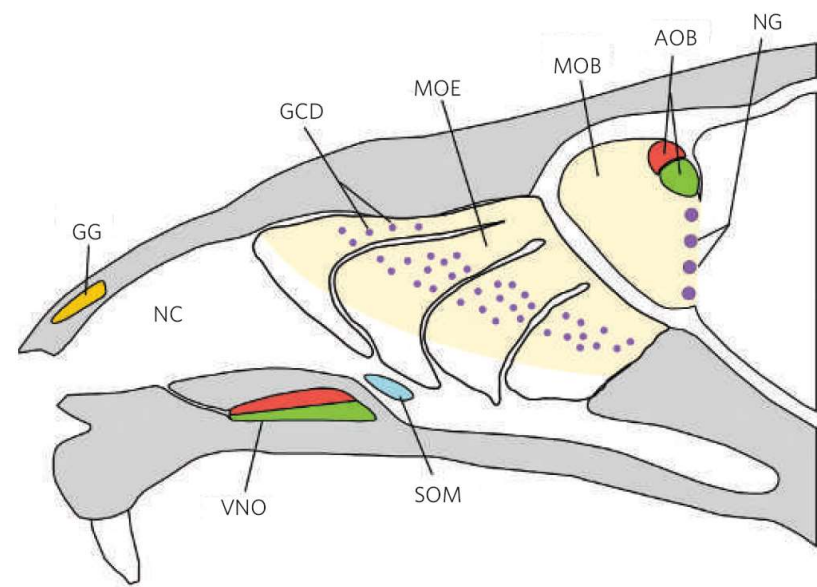
2 třídy receptorů (G protein, ale málo příbuzné čichovým asi 200 celkem), velmi citlivé a specifické

Vzduch přichází „pumpováním“ při vzrušení (také přímým kontaktem)

Nezbytný pro paletu chování spojených s pohlavím a rozmnožováním, výchovou potomstva, nástupu pohl. dospívání, blokování těhotenství, obrany a rozeznávání mláďat, mateřského chování, páření a vnitrodruhové agrese.



Vomeronasální orgán (VNO):



Citlivost je vysoká, pro feromony myši až $10^{-10}M$. Axony jsou mezi čichovými laloky a vstupují do přídatných čichových laloků. Zde najdeme podobně jako v hlavní dráze specificky naladěné glomeruli (přijímají vstupy jen z buněk exprimujících jeden typ receptoru). Projekce pak nevedou ani tak do čichového kortexu, ale spíše do amygdaly a hypotalamu limbického systému, kde vyvolávají nevědomé odpovědi.

U člověka také?

AOB u dospělců nenalezen, ani inervace ne.

Experimentální izolace dvou feromonů:

Mužského z potu, ženského z moči

MRI a PET ukázaly „rozsvícení“ čichové kůry

žen u ženského f. a hypotalamu u mužského f.

Muži reagovali opačně.

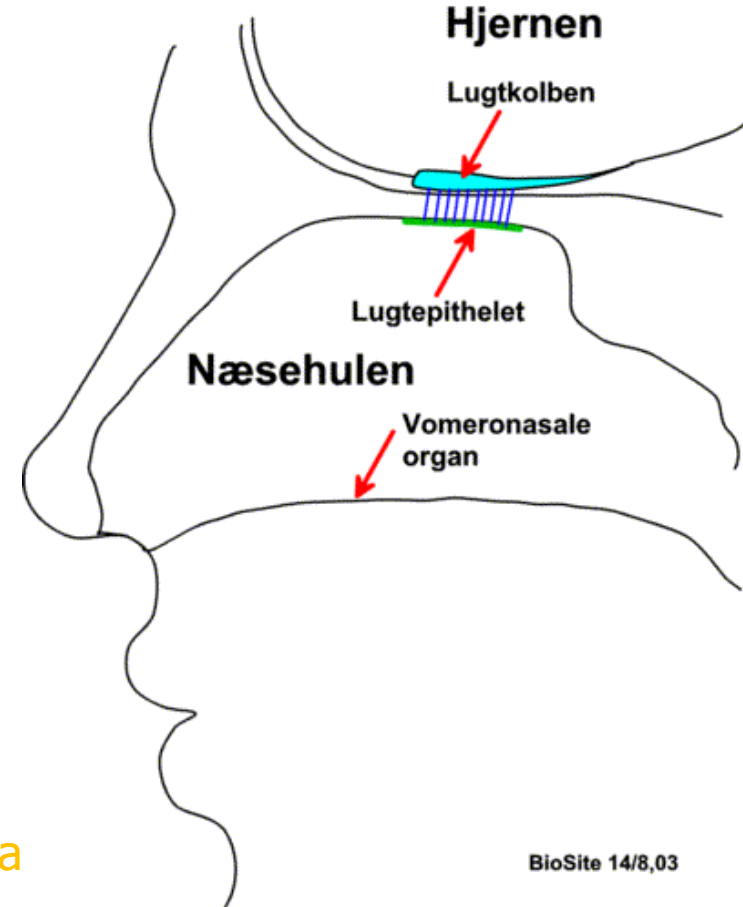
Gayové jako ženy.

MHC nepříbuznost detekovaná čichem?

MHC molekuly ovlivňují složení těkavých látek moči a

Potu = Individualita na dálku

Volba partnera, afrodisiaka, parfémy...



Aroma, příchut' jídla – kromě orthonasálního ještě i retronasální olfaktorický vjem

FIGURE 14.1 Molecules released into the air inside our mouths as we chew and swallow food travel up through the retronasal passage into the nose, where they then move upward and contact the olfactory epithelium.

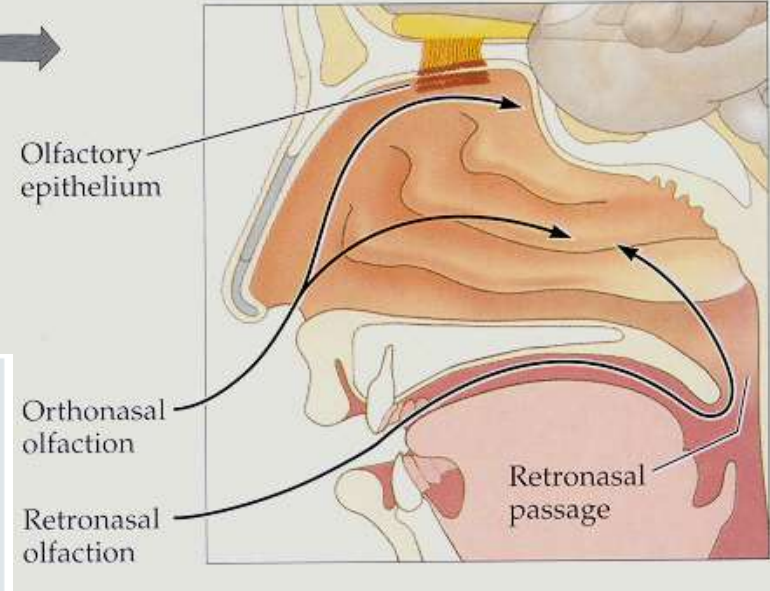
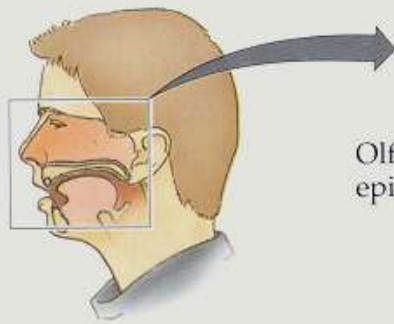
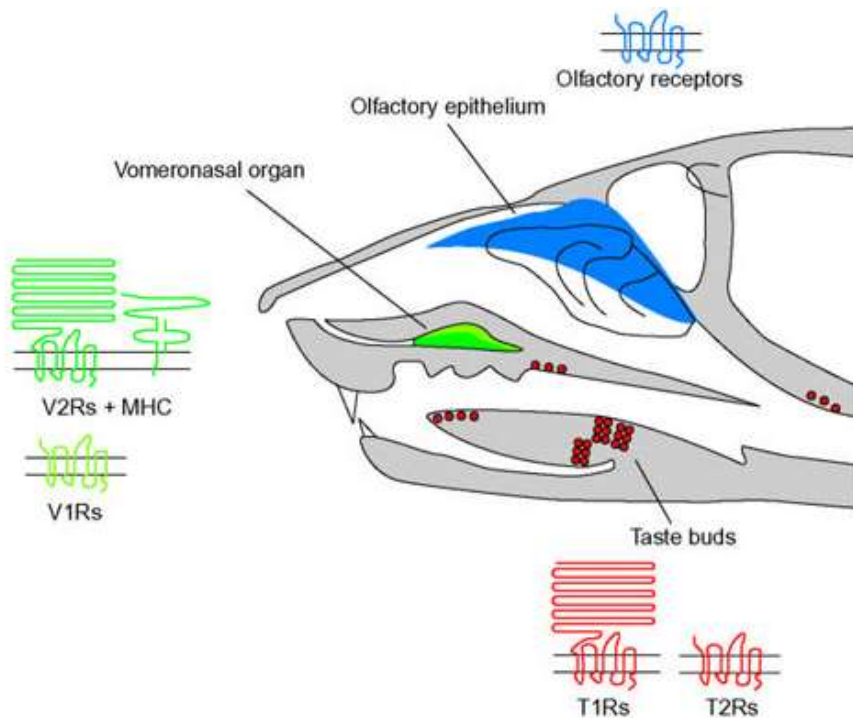


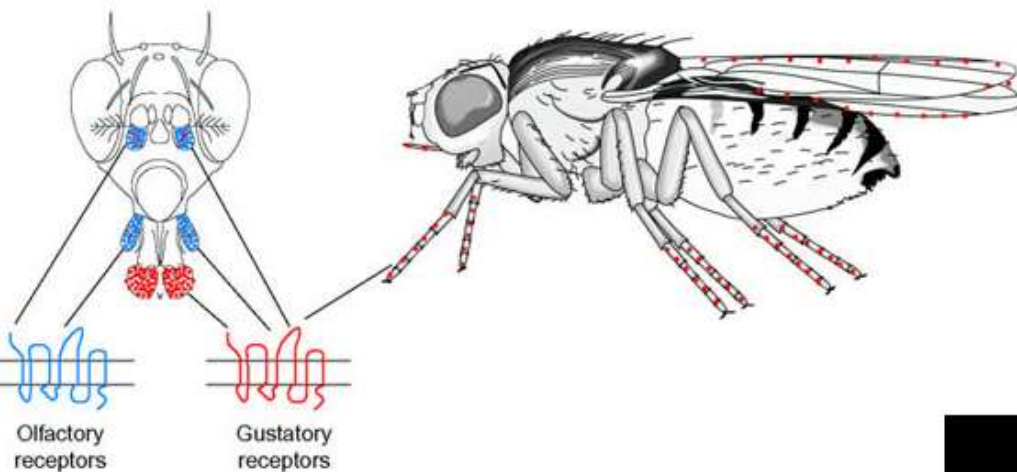
Table 1 The dual olfactory system		
Operations	Orthonasal olfaction	Retronasal olfaction
Stimulation route	Through the external nares	From the back of the mouth through the nasopharynx
Stimuli	Floral scents Perfumes Smoke Food aromas Prey/predator smells Social odors Pheromones MHC molecules	Food volatiles
Processed by	Olfactory pathway influenced by the visual pathway	Olfactory pathway combined with pathways for taste, touch, sound and active sensing by proprioception form a 'flavour system'

Note the interesting contrast, that orthonasal olfactory perception involves a wide range of types of odors processed through only the olfactory pathway, in comparison with retronasal olfactory perception which involves only food volatiles but processed in combination with many brain pathways.

(a)



(b)



The location of chemosensory organs in the mouse and *Drosophila*. **(a)** A sensory neuron in the olfactory epithelium of mice expresses one of about 1,000 olfactory receptors. Neurons in the apical and basal layers of the vomeronasal organ express distinct, unrelated classes of G-protein-coupled pheromone receptors (V1Rs in the apical and V2Rs in the basal layer). In addition, a small family of MHC class I-like molecules is coexpressed with V2Rs in neurons of the basal layer. The taste cells in the tongue, palate and pharynx express other classes of GPCRs, one encoding sweet-taste receptors (T1Rs) and one encoding receptors for bitter compounds (T2Rs). Note that V1Rs and T2Rs are related to each other, as are V2Rs and T1Rs, respectively. **(b)** The olfactory neurons of *Drosophila* are located in two pairs of appendages in the head, the third antennal segment and the maxillary palps, and each neuron expresses very few, possibly just one, of the 61 olfactory receptor genes identified so far. The gustatory or taste sensory neurons are located in numerous organs, including the two labial palps on the head, internal sensory clusters in the pharynx (not shown), all the legs and the anterior wing margin. Each neuron expresses a few, possibly just one, gustatory receptor gene. A few gustatory receptor genes are also expressed in olfactory neurons of the antenna and maxillary palps.

Čich a chuť spolupracují



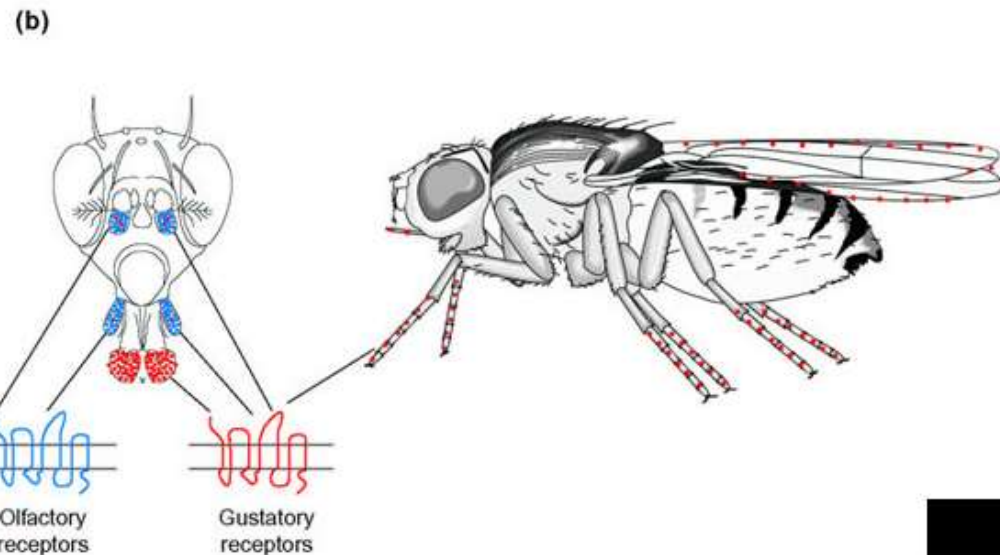
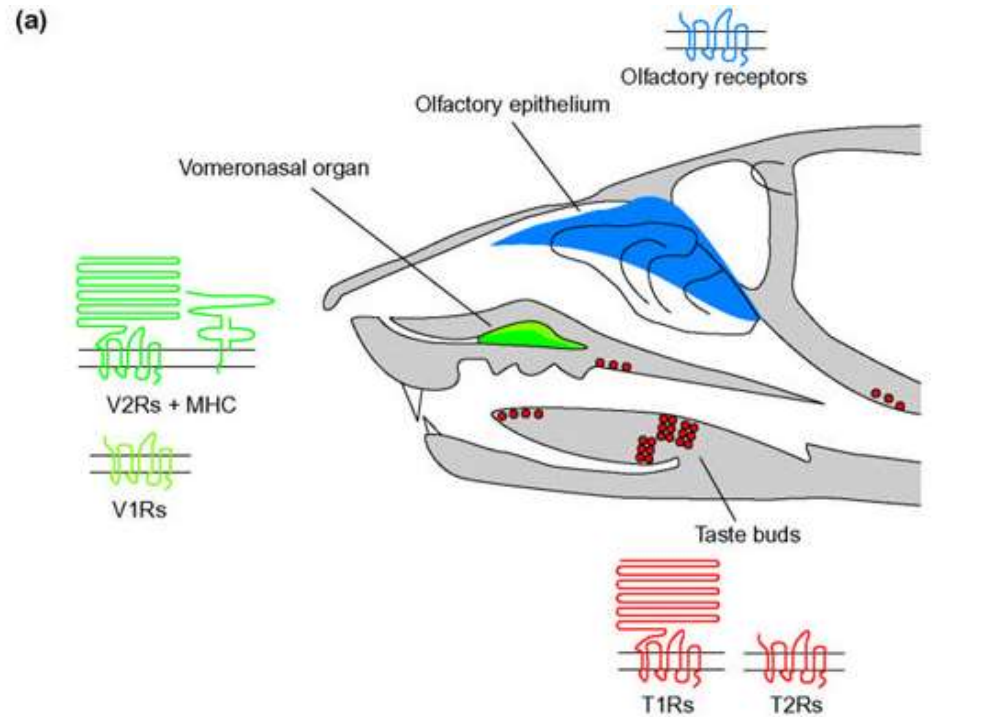
Chut'



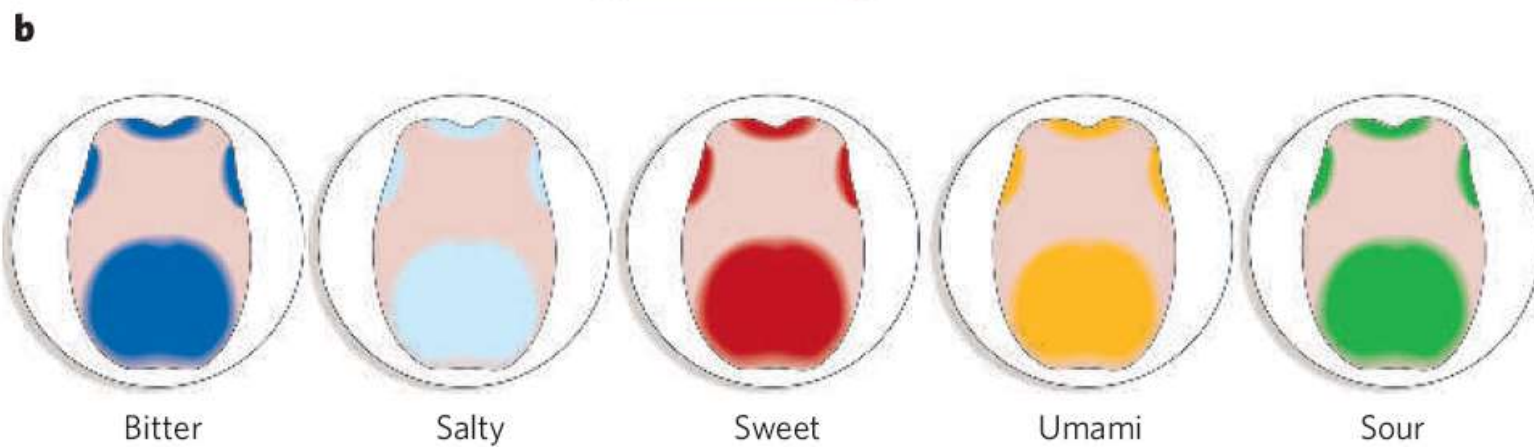
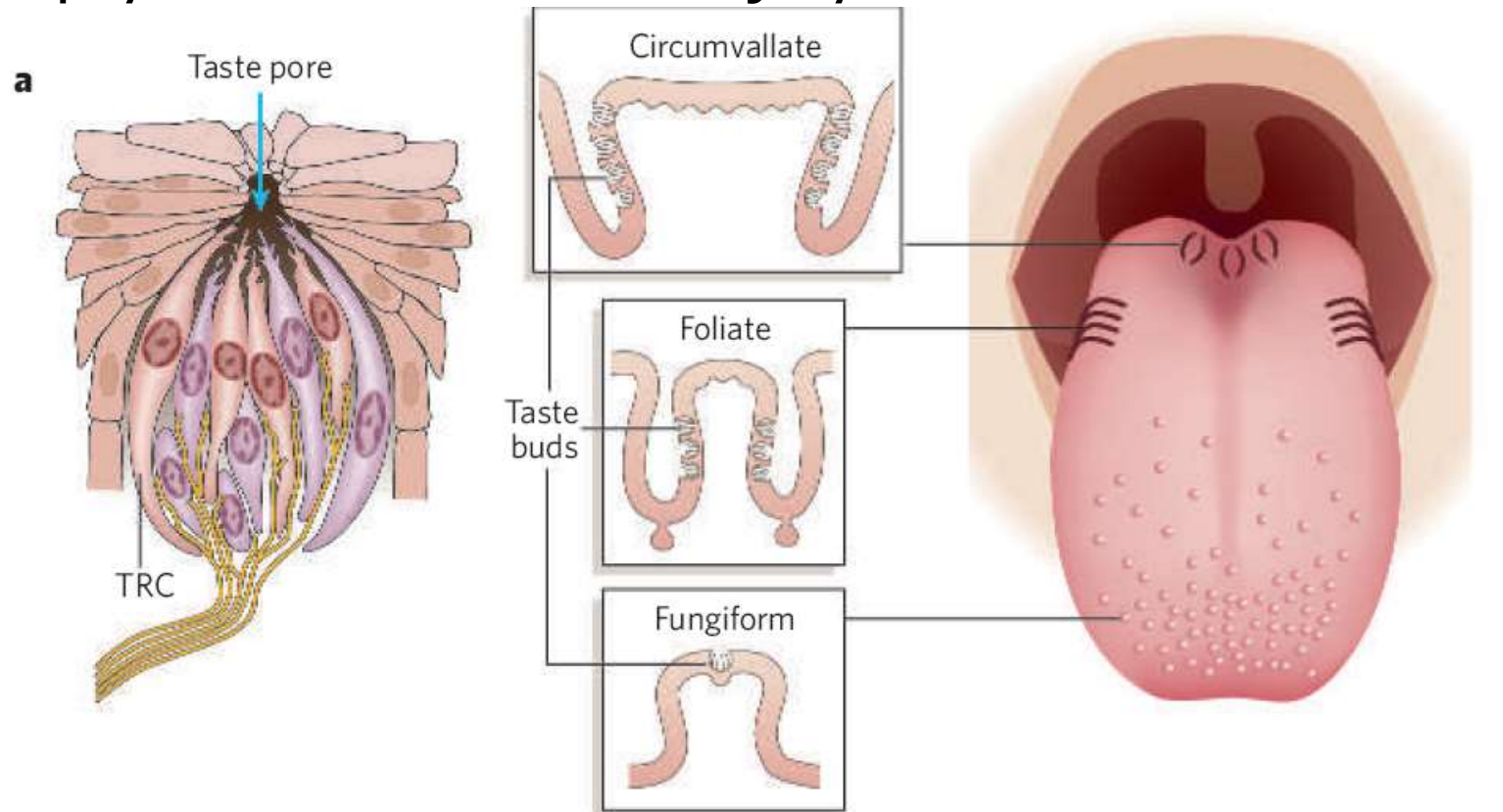
Chuť

Na rozdíl od čichu je to smysl, kontaktní, méně citlivý, má mnohem méně receptorů, ale překvapivě různá transdukční schémata.

Čich často rozeznává plynnou fázi, chuť vždy kapalnou.



Papily a distribuce chutí na jazyku



15.1 Scientific Urban Legend—The Bogus Tongue Map

One of the “facts” that experts have been unable to purge from many textbooks is the notion that sweet is perceived at the tip of the tongue, bitter at the back, sour on the sides, and salty all over. In the case of this myth, we know roughly when it began and we have some idea about what has maintained it in the face of determined efforts by experts to stamp it out.

The origin is most likely a book written by Harvard University’s Edwin Boring in 1942. Boring, in addition to his own work, chronicled the history of sensation and perception. He described a study conducted by Hänig in the laboratory of Wilhelm Wundt in 1901 (Hänig, 1901). Hänig wanted to show that the four basic tastes were mediated by different receptor mechanisms (something we take for granted today). He reasoned that if taste thresholds varied with tongue locus, then one would have to conclude that the receptor mechanisms varied as well. Hänig selected points on the oval distribution of taste buds around the perimeter of the tongue and laboriously measured thresholds for substances representing each of the four basic tastes. The variation in thresholds was small but the patterns across the four tastes were different; Hänig had made his point. Boring apparently misunderstood the concentration units in Hänig’s study and failed to appreciate just how small the variations in thresholds really were. Thus, Hänig’s result that sweet thresholds were slightly lower on the front of the tongue and bitter thresholds were slightly lower on the back was misconstrued and turned into the notion that we taste sweet on the front of our tongues, bitter on the back, etc.

Since the tongue map became a common laboratory demonstration, generations of students have had reason to doubt the map. Asked why they could not observe it, one group of students said that they “must have done the experiment wrong.” It is worth remembering that textbooks are not always correct. But you can believe us here: receptors for all four of the basic tastes are distributed over the entire tongue.

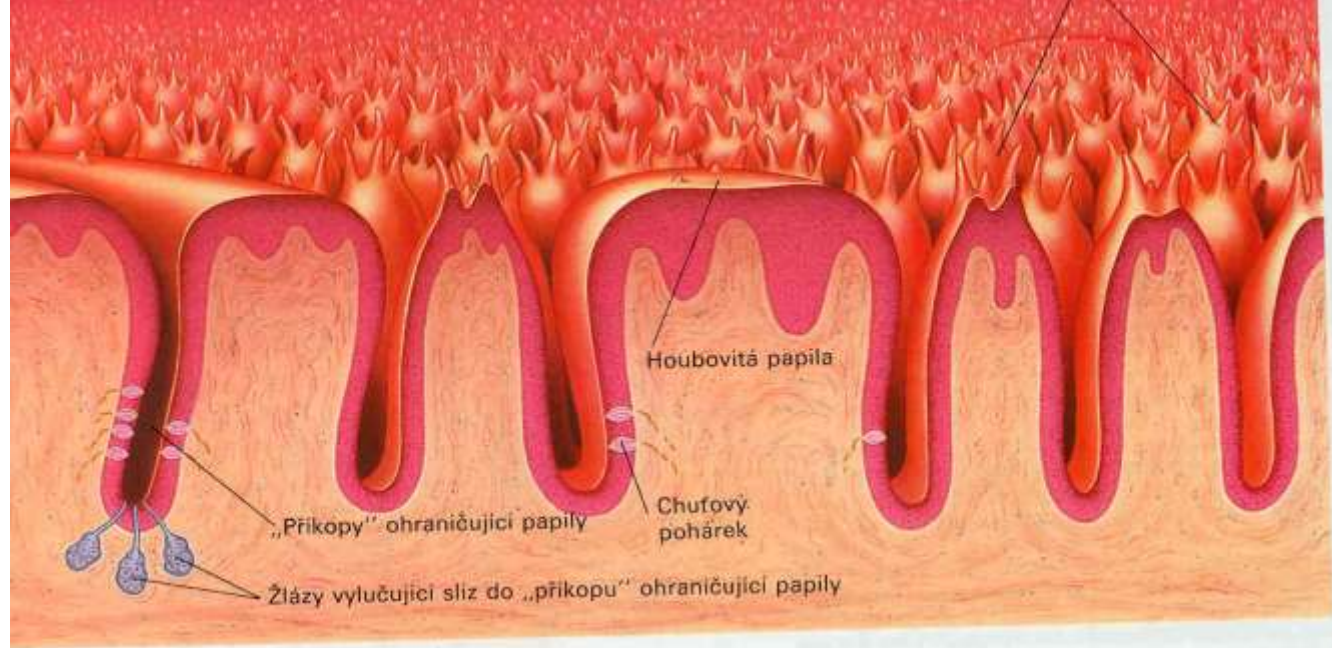
References

Boring, E. G. (1942). *Sensation and Perception in the History of Experimental Psychology*. Appleton-Century-Crofts.

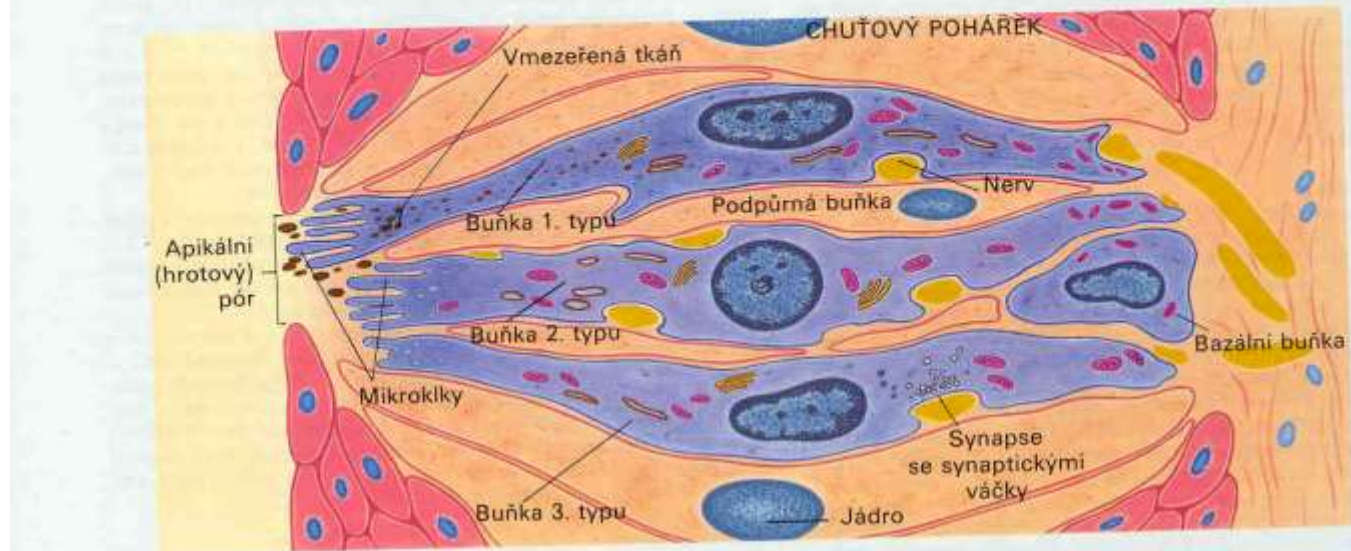
Hänig, D. P. (1901). Zur Psychophysik des Geschmackssinnes. *Philosophische Studien*



Receptory nejsou neurony, vznikají z epitelu pokožky, sekundární. Opatřené mikrovilli.
 Chuťové, podpůrné a bazální .



V „přikopech“ obklopujících jejich centrální val, reagují na chutě hofké. Mezery mezi papilami zvlhčuje sliz, vylučovaný žlázami umístěnými na bázi těchto mezer. Chuťové molekuly se musí v tomto vlhkém prostředí nejprve rozptýlit, a teprve poté je mohou chuťové pohárky detekovat.



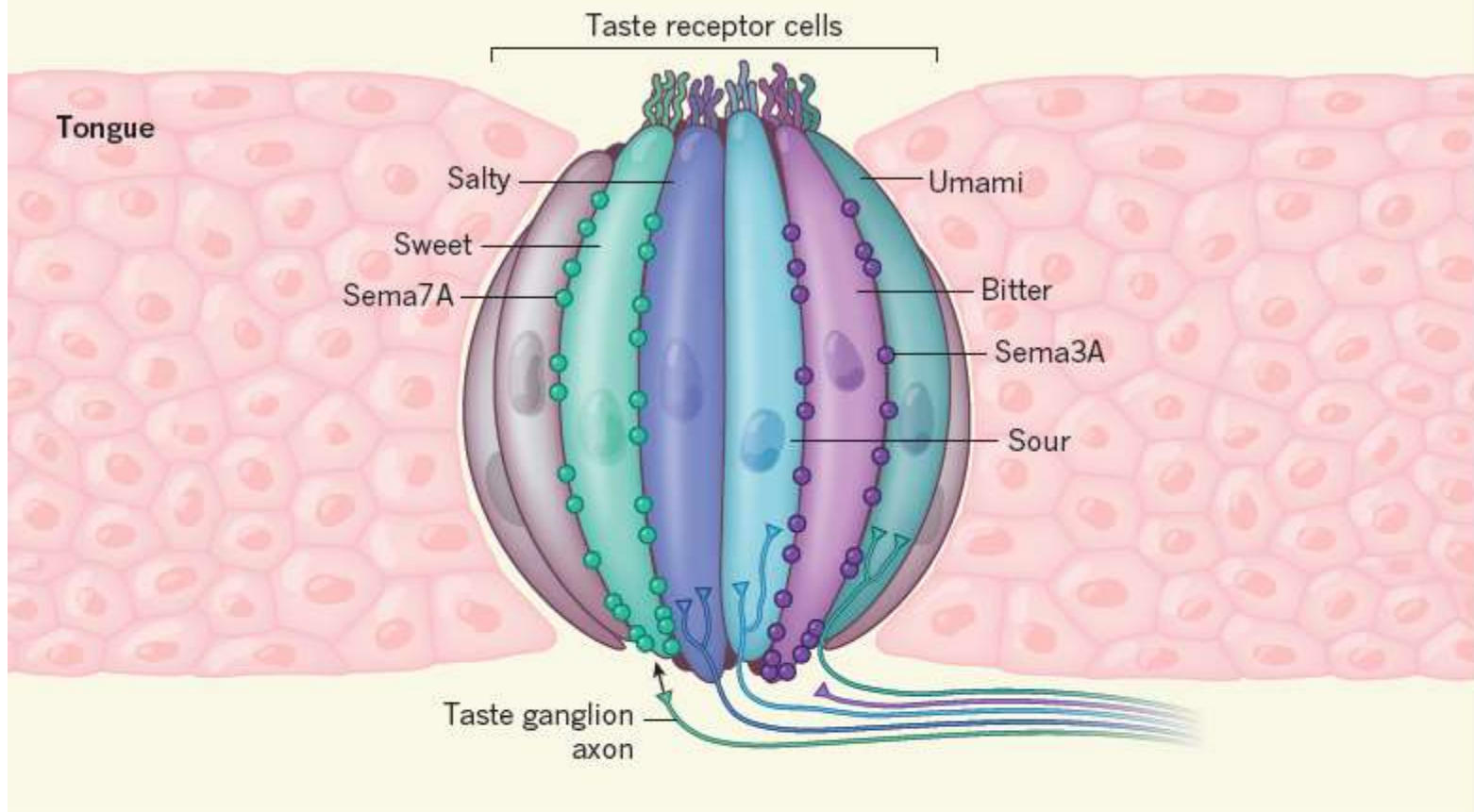
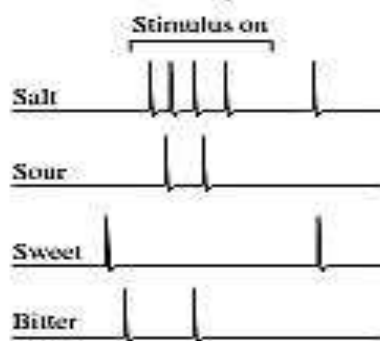
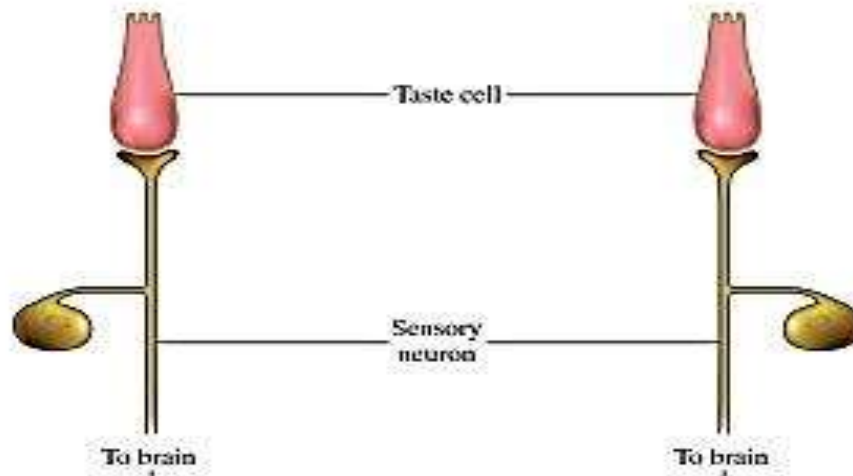
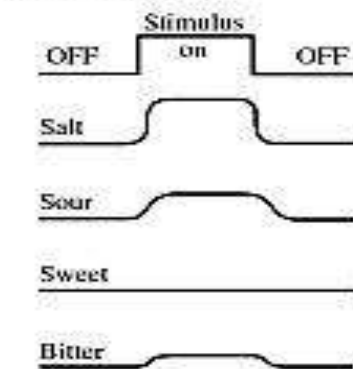


Figure 1 | Wiring the taste system in mice. Each taste bud of the tongue harbours dozens of taste receptor cells (TRCs), most of which are receptive to only one of the five taste qualities — bitter, sweet, sour, salty and umami. In mice, TRCs connect to neuronal projections called axons that originate from clusters of neurons called ganglia in the head that relay taste information, mostly in a type-specific manner (type-specific axons are colour-coded to match TRCs). For example, TRCs that respond to sweet tastes connect to axons from sweet-responsive ganglion neurons. Lee *et al.*¹ have shown that two proteins from the semaphorin family guide this pattern of wiring. Sema3A, produced by bitter TRCs, guides connections with bitter ganglion neurons. Sema7A has the same role but in the sweet taste pathway.

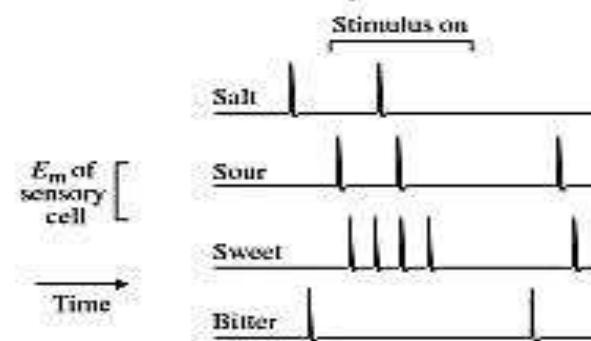
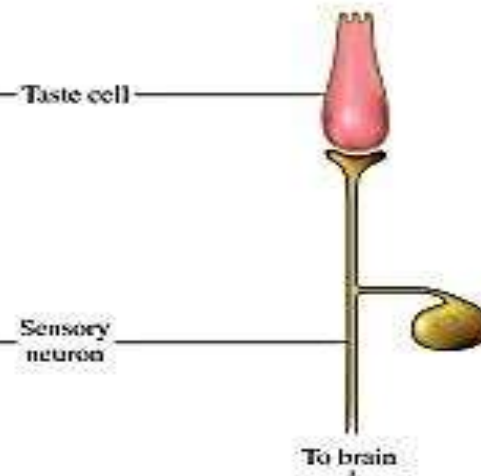
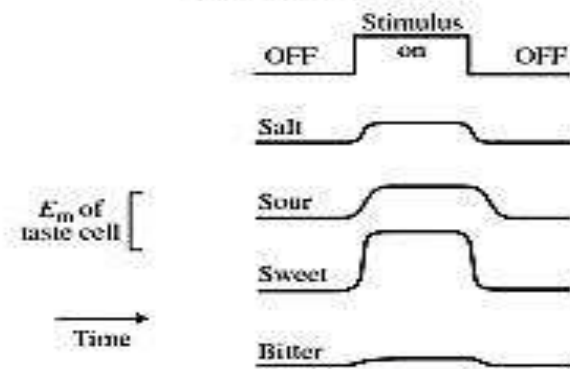
Selektivita omezená.

Člověk může rozlišit asi 100 chuťových kvalit, přičemž jde asi o skládání 5 základních kvalit: sladké, slané, kyselé, hořké a UMAMI. Jedna chuťová buňka může reagovat na všechny čtyři základní chuťové kvality, ale na jeden typ odpovídá maximálním generátorovým potenciálem. Některé jsou více specialisté jiné generalisté.

A. Salt-preferring



B. Sweet-preferring



Transdukční schémata G-prot – gustducin

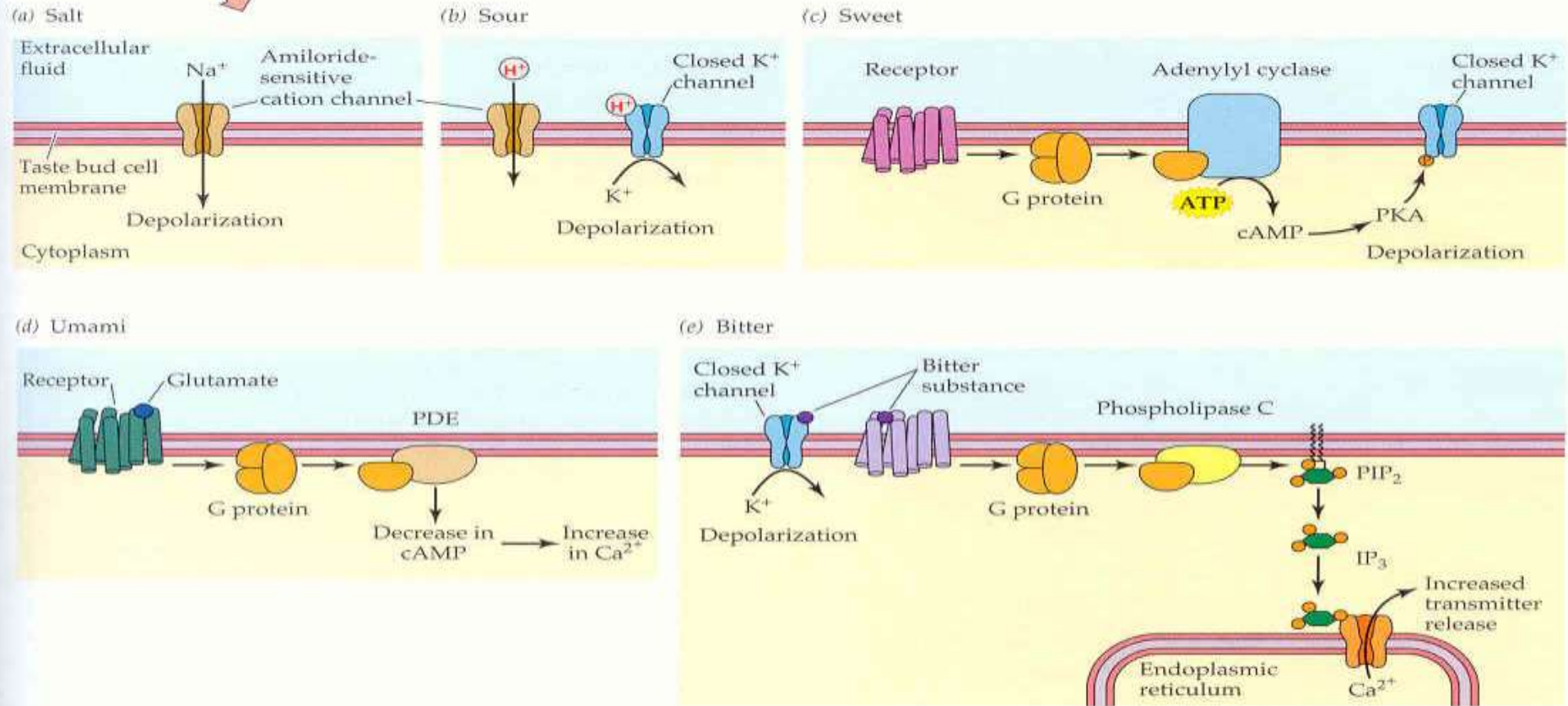
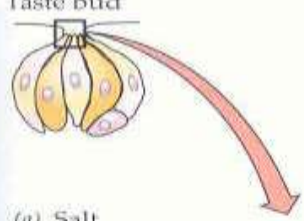


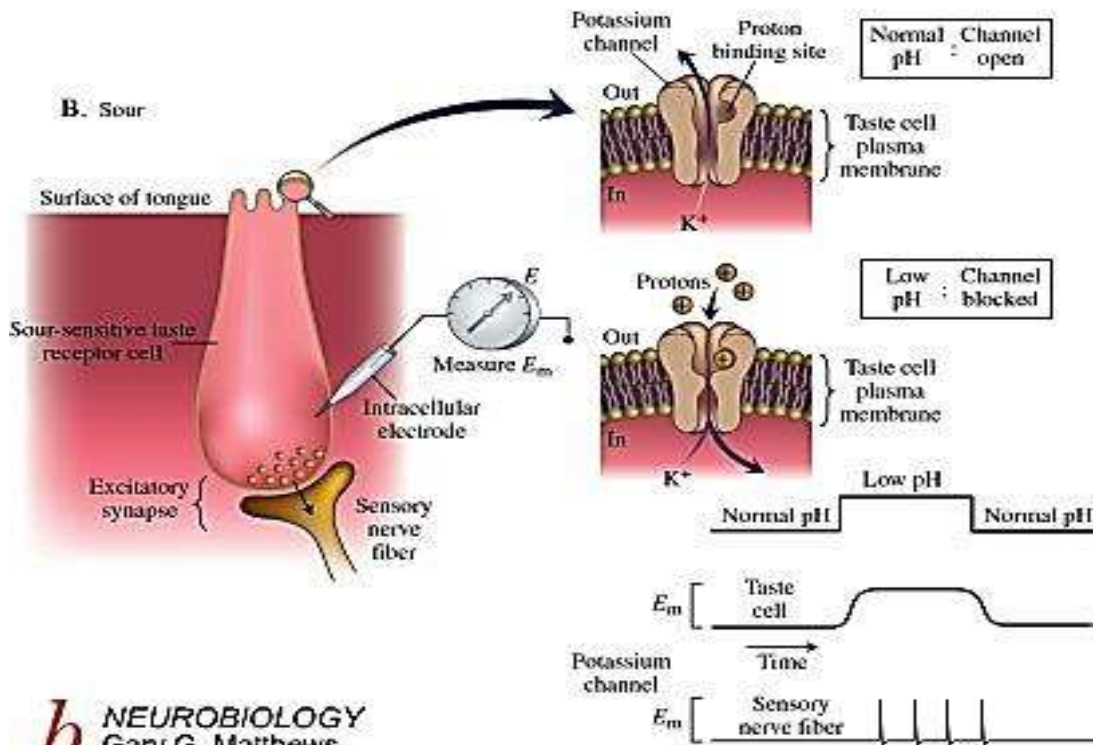
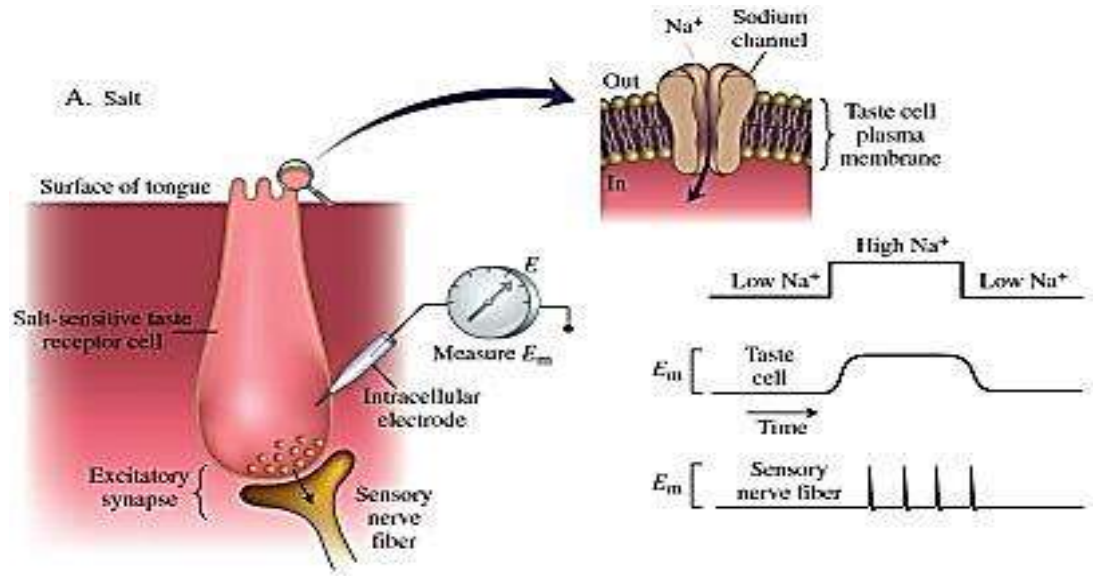
Figure 13.34 Taste-transduction mechanisms differ for different taste qualities All transduction mechanisms except the IP₃ action in (e) lead to *depolarization*, which spreads to the basal end of the cell and opens voltage-gated Ca²⁺ channels to allow Ca²⁺ entry and transmitter release. (a) For salt taste, sodium ions enter a taste bud cell through amiloride-sensitive cation channels, directly depolarizing the cell. (b) In sour taste, either H⁺ ions enter the cell through amiloride-sensitive cation channels, or they close K⁺ channels to produce depolarization. (c) Sweet taste is most commonly mediated by the binding of sugars to a G protein-coupled receptor, which acts via a G protein to activate adenylyl cyclase and produce cyclic AMP. Cyclic AMP then activates protein kinase A (PKA) to close a K⁺ channel (by phosphorylating

it), producing depolarization. (d) The amino acid glutamate (monosodium glutamate, MSG) stimulates the taste quality umami (a savory or meaty quality). Glutamate binds to a G protein-coupled receptor (related to synaptic metabotropic glutamate receptors) to activate a phosphodiesterase (PDE) and decrease the concentration of cAMP. The decrease in cAMP leads to an increase in intracellular Ca²⁺ concentration. (e) Bitter taste mechanisms can involve a G protein-coupled receptor for bitter substances that acts via a G protein and phospholipase C to produce IP₃. IP₃ liberates Ca²⁺ ions from intracellular stores, eliciting transmitter release without requiring depolarization. Other bitter substances bind to K⁺ channels and close them to depolarize the cell.

Transdukční schémata

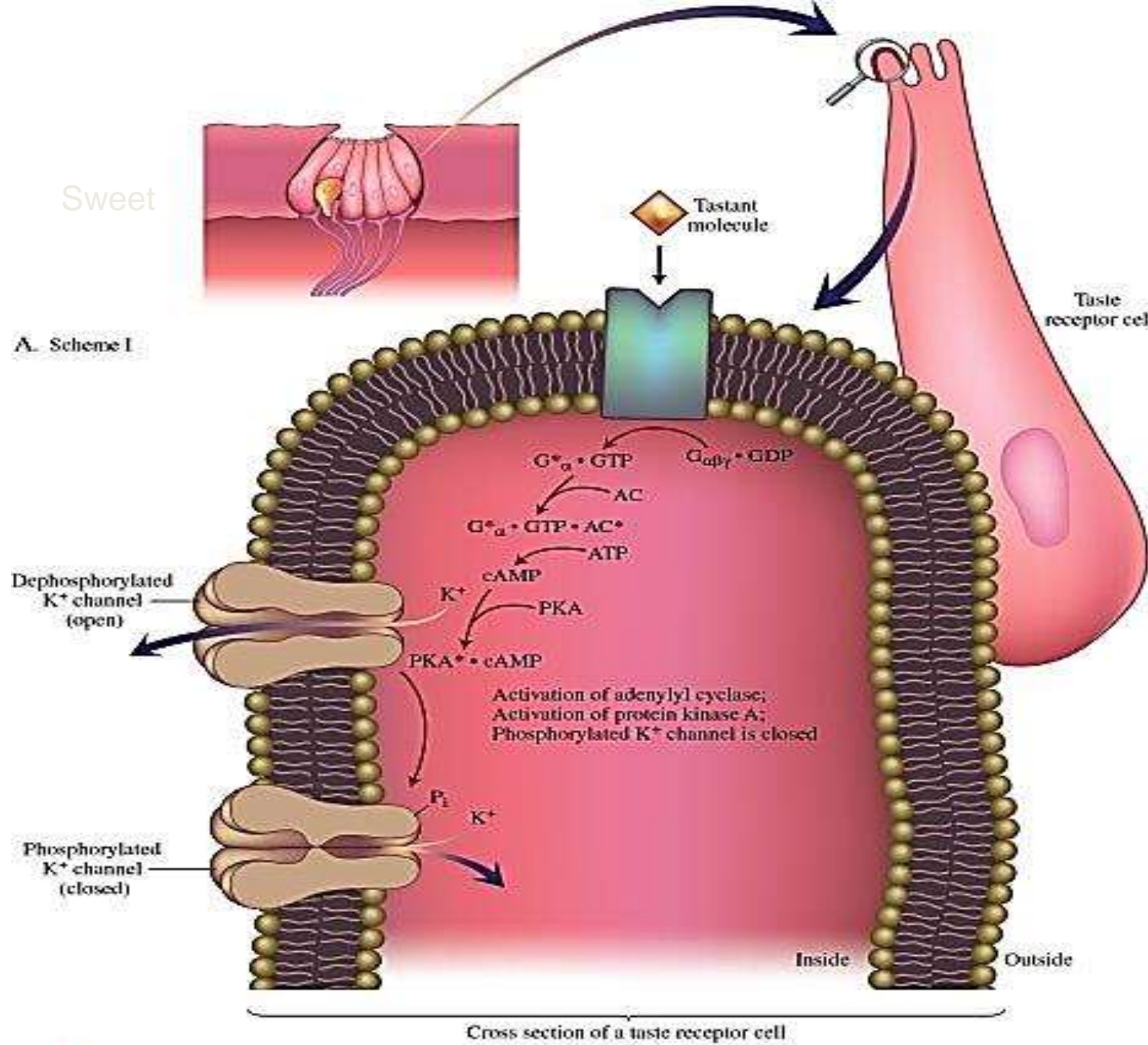
Kanál vůbec nemusí měnit propustnost – slané

Nebo je citlivý na pH - kyselé



Transdukční schémata pro sladké Varianta I

Uzavření K kanálu fosforylací

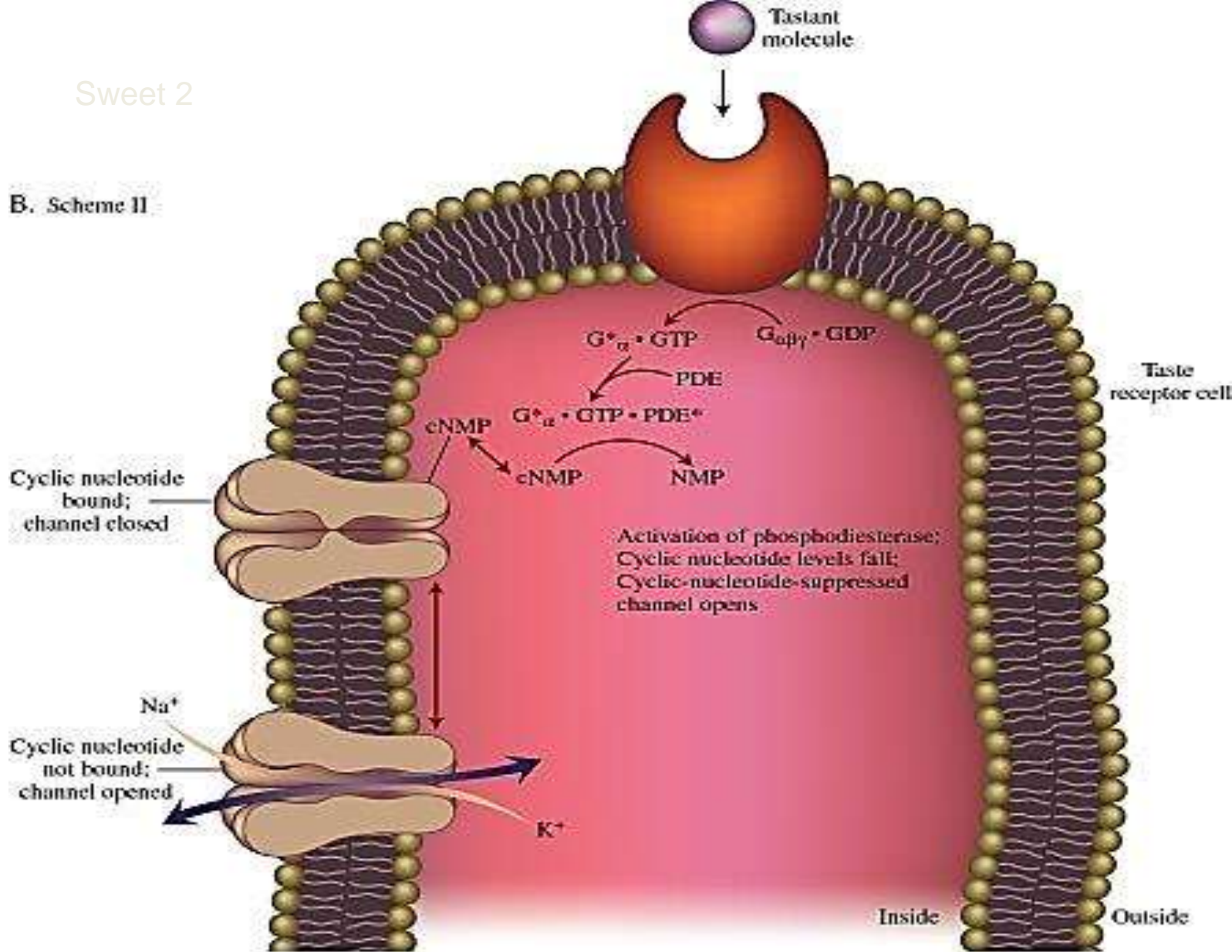


Sweet 2

Transdukční schémata pro sladké Varianta II

Neselektivní kationtový kanál se otevírá

B. Scheme II



Hořká chuť

Velká řada ligandů
Různí druzí poslové

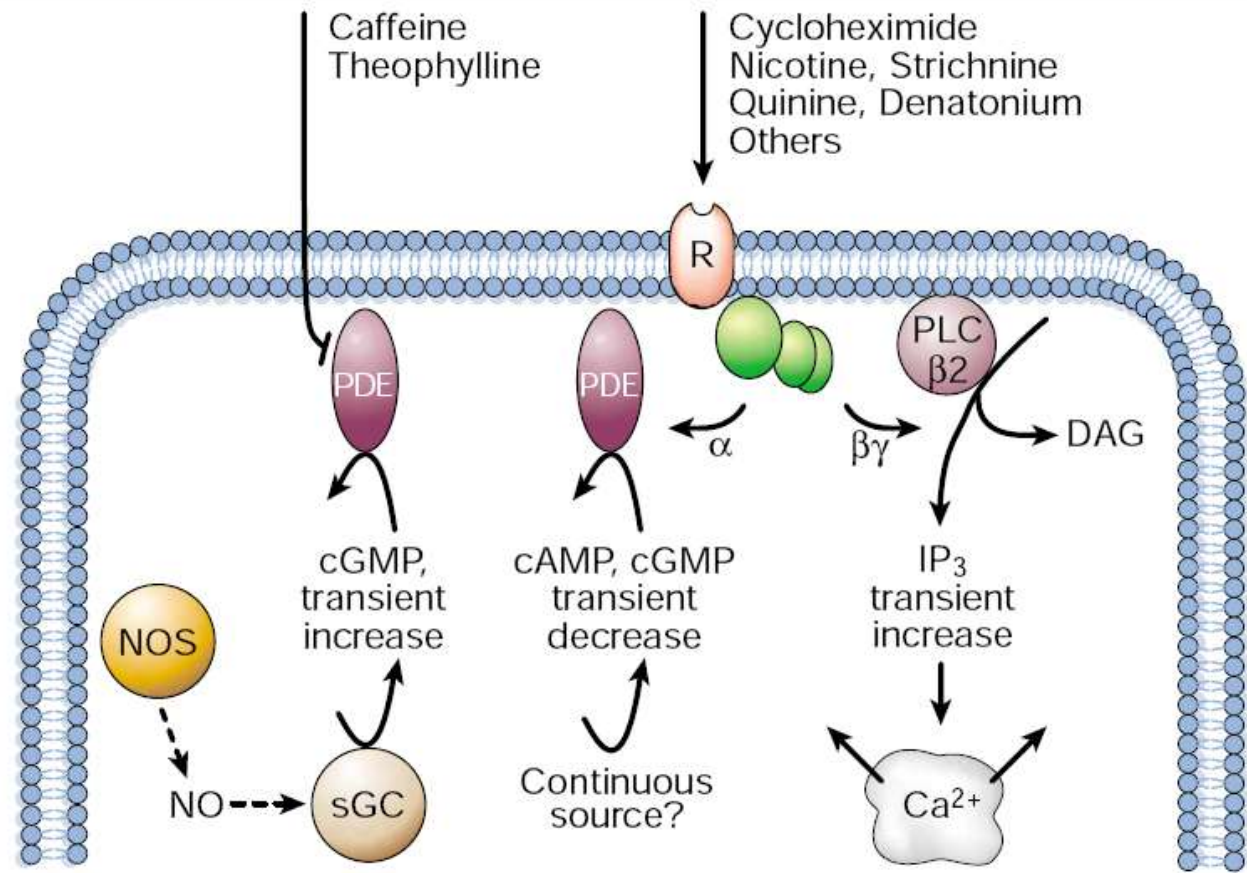


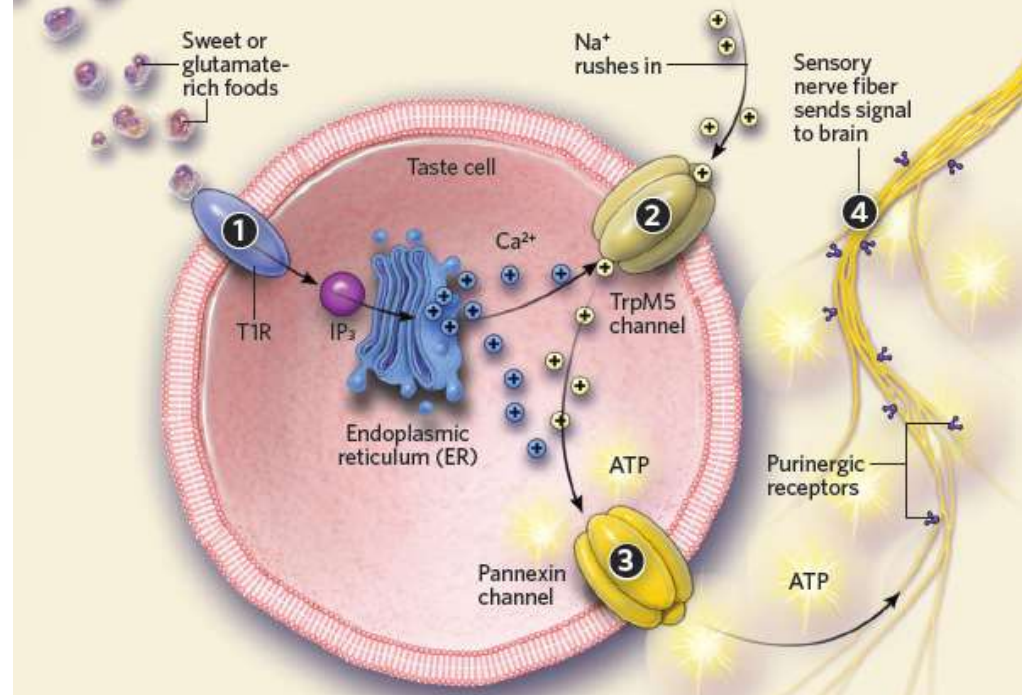
Figure 3 Transduction of bitter taste as elicited by a variety of ligands. Rs, multiple GPCRs of the T2R family, coupled to the G protein gustducin^{47–49}; α , α -subunit of gustducin^{6,57}; $\beta\gamma$, G-protein subunits $\beta 3$ and $\gamma 13$ (refs 60–62); PLC $\beta 2$, phospholipase C subtype⁶¹; Ins(1,4,5)P₃, inositol-1,4,5-trisphosphate⁵⁹; PDE, taste-specific phosphodiesterase⁵⁸; cAMP, cyclic adenosine monophosphate⁵⁹; cGMP, cyclic guanosine monophosphate⁵⁹; sGC, soluble guanylate cyclase⁵⁵; NO, nitric oxide⁵⁵; NOS, NO synthase⁵⁶. For second-messenger kinetics, see refs 55,59,63,64.

Zatímco sladká, umami, slaná (a tučná) chuť poskytují příjemné vjemy, hořká a kyselá chrání před příjmem potenciálně toxických látek a silných kyselin.

ATP jako mediátor purinergní signalizace.

TASTE IN THE MOUTH

Taste-bud receptors, primarily on the tongue, sense the qualities of salty, sour, bitter, sweet, and umami (the taste of glutamate). While sweet, umami, and salty foods provide pleasurable sensations that drive the intake of carbohydrates, amino acids, and sodium, the tastes of bitter and sour inhibit intake of potentially toxic substances and strong acids.



THE TASTE SIGNALING CASCADE IN THE MOUTH

The binding of molecular components of sweet or glutamate-rich foods to T1R-class receptors and bitter substances to T2R receptors stimulates the release of Ca^{2+} into the cytosol from the endoplasmic reticulum (ER) via G protein signaling and the second messenger molecule inositol trisphosphate (IP_3) ①. The Ca^{2+} activates the TrpM5 channel to allow the entry of sodium ions (Na^+), depolarizing the cell ②. The combination of depolarization resulting from the influx of Na^+ and rise in intracellular Ca^{2+} opens pannexin channels in the taste-cell membrane, releasing ATP from the cell ③. This in turn activates purinergic receptors on the sensory nerve fibers innervating the taste buds, thereby sending a signal to the brain ④.

Chuť ve střevě?

Stejně
receptory a
podobné dráhy
řídí reflexní
reakce na
potravu

TASTE IN THE GUT

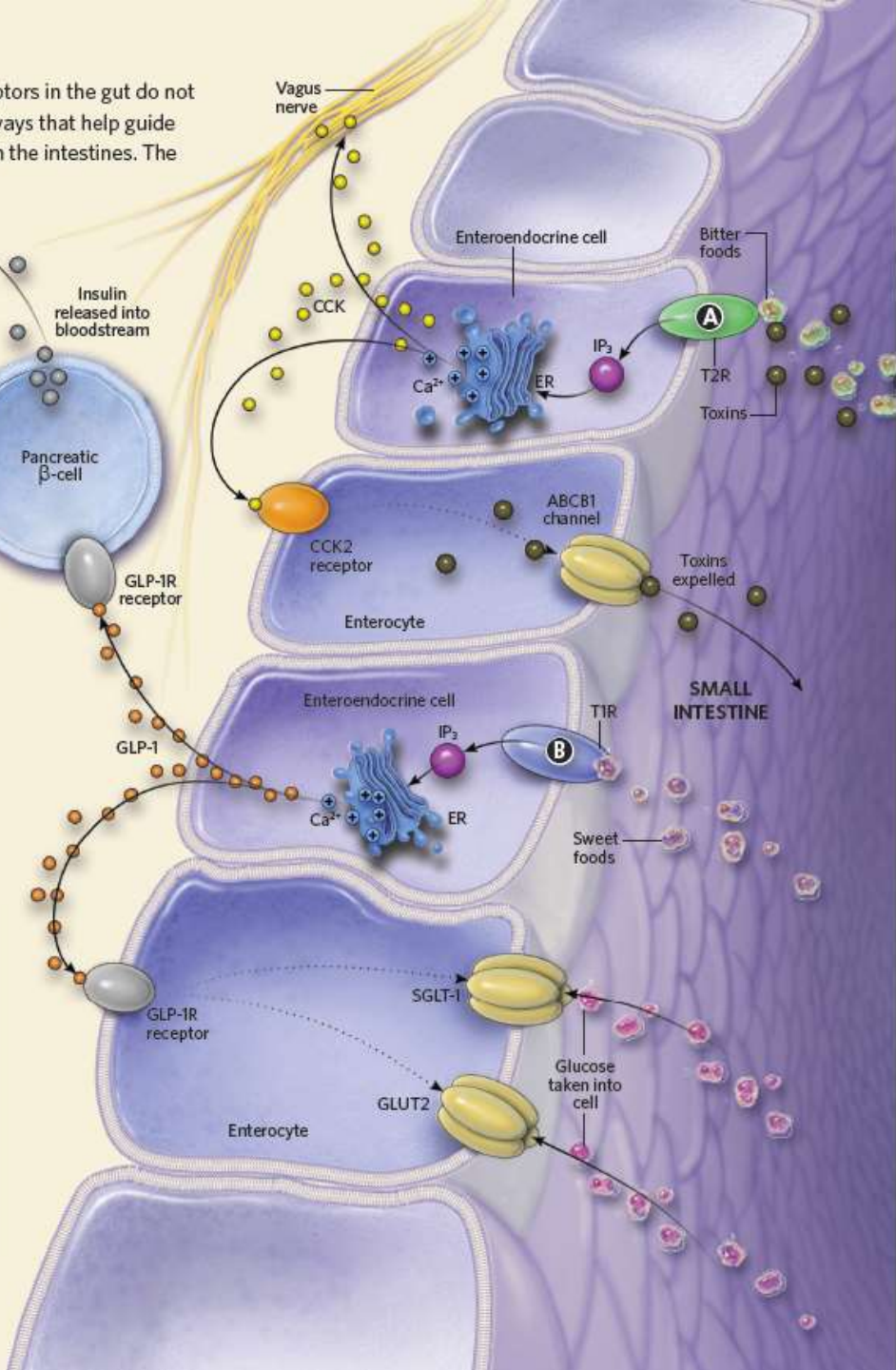
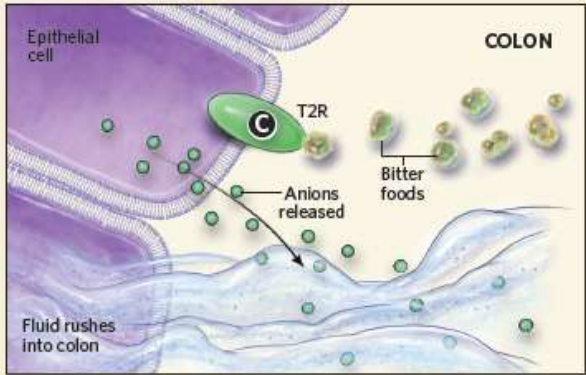
In contrast to taste receptors in the mouth, T1R and T2R receptors in the gut do not induce sensations of taste, but rather initiate molecular pathways that help guide the digestion or rejection of food substances traveling through the intestines. The underlying pathways, however, have many similarities.

FOODS IN THE GUT

A Specialized endocrine cells of the small intestine, known as enteroendocrine cells, display T2R bitter receptors on their cell membranes. When bitter compounds bind to the T2R receptors, the cells release the peptide hormone cholecystokinin (CCK), which acts on CCK2 receptors located on enterocytes, or intestinal absorptive cells. This increases the expression of the transporter ABCB1, which pumps toxins or unwanted substances out of the cell and back into the intestinal lumen. CCK also binds to CCK1 receptors on sensory fibers of the vagus nerve, sending signals to the brain to cease food intake.

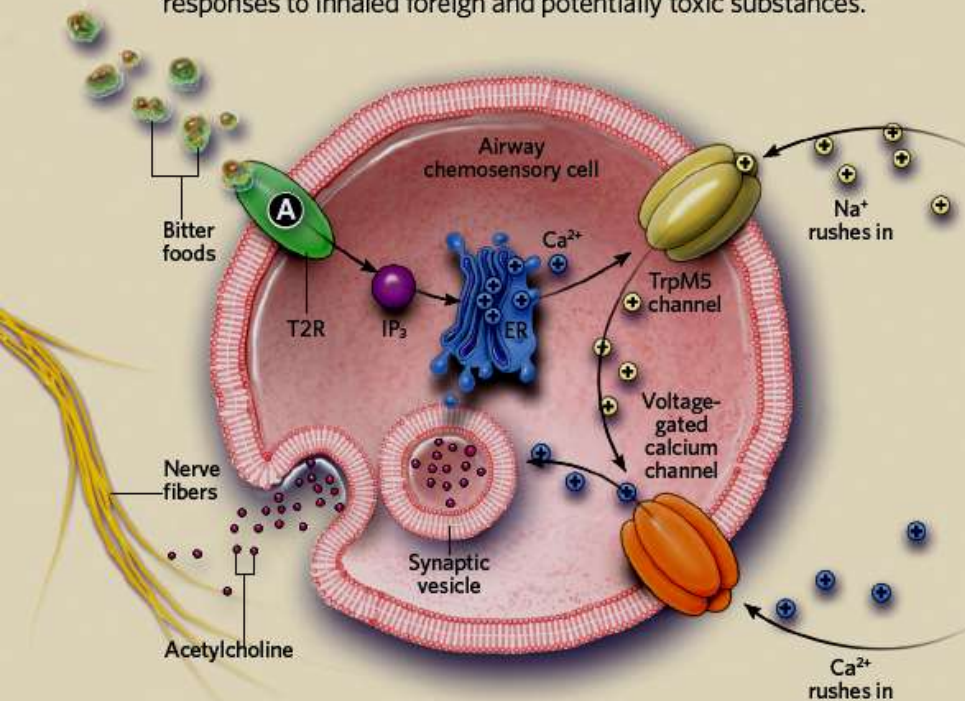
B T1R-class receptors on enteroendocrine cells lining the small intestine detect sweet substances and respond by secreting the glucagon-like peptide GLP-1. GLP-1 then travels to the pancreas via the bloodstream, where it boosts the release of insulin from pancreatic β -cells, promoting the uptake of glucose by diverse tissues. Additionally, GLP-1 diffuses to neighboring enterocyte cells in the small intestine, driving the insertion of the glucose transporters SGLT-1 and GLUT2, which facilitates the uptake of glucose from the intestines.

C In the colon, bitter ligands bind to T2R receptors on epithelial cells, where they induce the secretion of anions and water, which leads to fluid rushing into the intestine, resulting in diarrhea that flushes out the colon.



TASTE IN THE AIRWAYS

Scientists have also recently identified the existence of taste pathways in human airway cells, where they likely mediate defensive responses to inhaled foreign and potentially toxic substances.

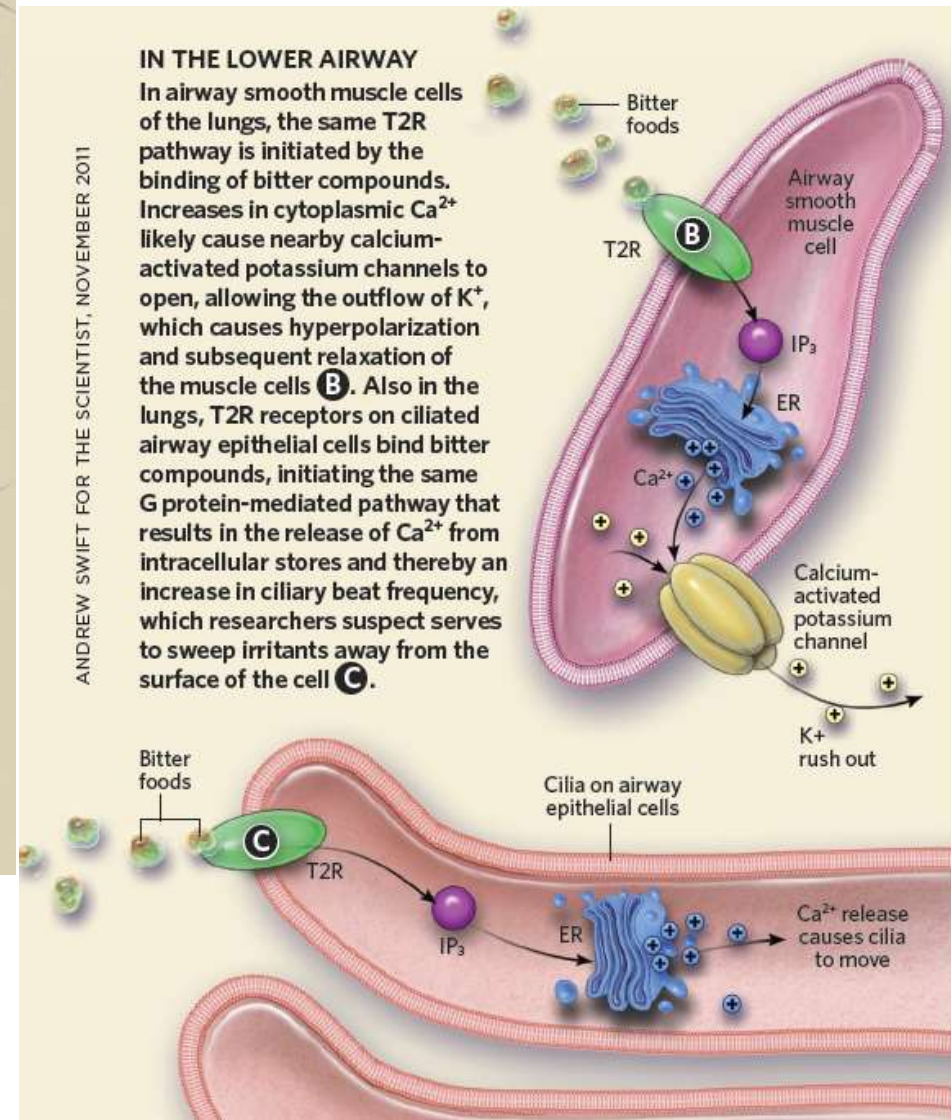


IN THE UPPER AIRWAY

In the upper airways (nasal passages and trachea), T2R receptors on chemosensory cells sense bitter compounds, releasing secondary messengers that spur the release of Ca^{2+} from the ER. The increase in cytoplasmic Ca^{2+} activates the TrpM5 transduction channel, allowing the influx of Na^+ and the depolarization of the cell. This in turn activates voltage-gated Ca^{2+} channels, which permit even more Ca^{2+} to flood into the cell. This initiates the fusion of synaptic vesicles with the plasma membrane, releasing the neurotransmitter acetylcholine to activate nearby nerve fibers and induce protective reflexes such as sneezing **A**.

Nosohltan a trachea – horní c.d.

Potenciálně toxické (hořké) substance
T2R receptor
Kýchání, relaxace dých. cest, pohyb řasinek
Plíce – dolní c.d.



ANDREW SWIFT FOR THE SCIENTIST, NOVEMBER 2011

IN THE LOWER AIRWAY

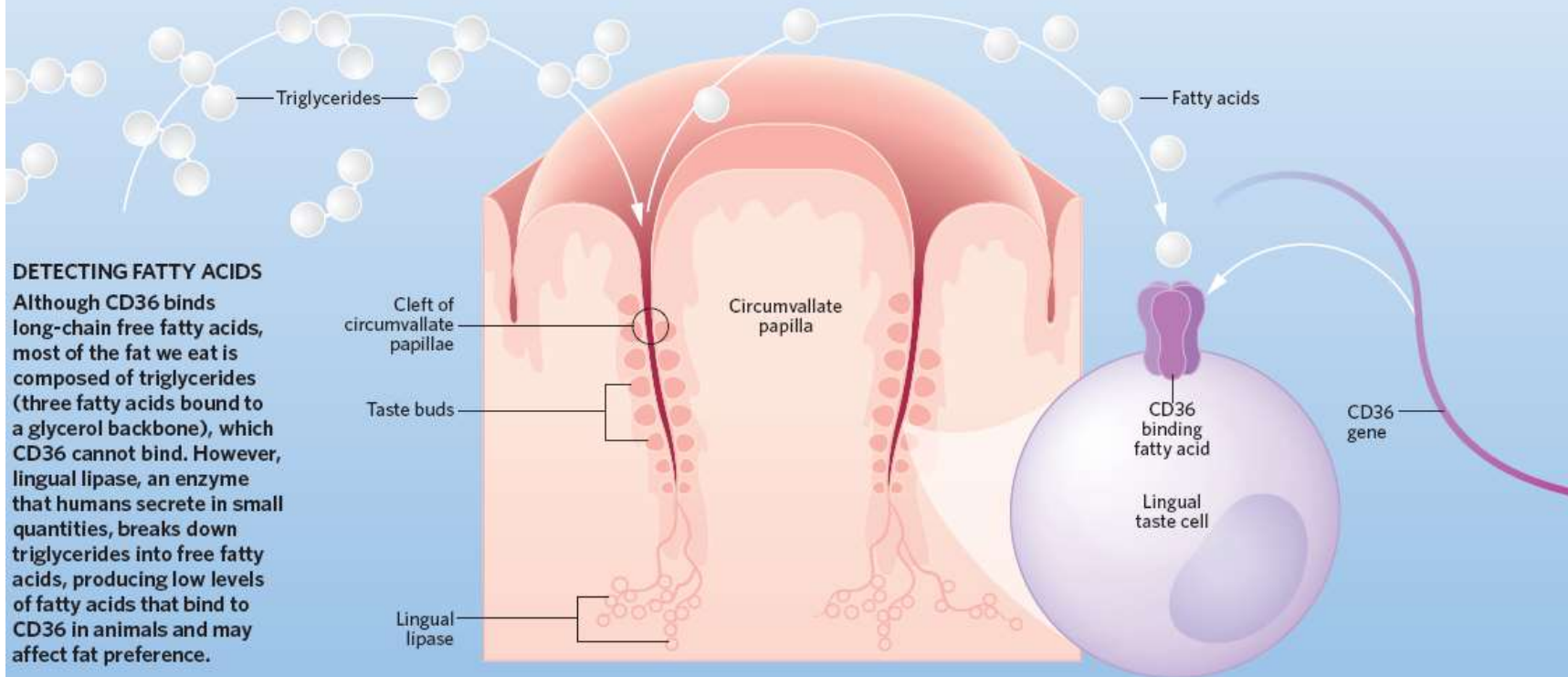
In airway smooth muscle cells of the lungs, the same T2R pathway is initiated by the binding of bitter compounds. Increases in cytoplasmic Ca^{2+} likely cause nearby calcium-activated potassium channels to open, allowing the outflow of K^+ , which causes hyperpolarization and subsequent relaxation of the muscle cells **B**. Also in the lungs, T2R receptors on ciliated airway epithelial cells bind bitter compounds, initiating the same G protein-mediated pathway that results in the release of Ca^{2+} from intracellular stores and thereby an increase in ciliary beat frequency, which researchers suspect serves to sweep irritants away from the surface of the cell **C**.

Ca^{2+} release causes cilia to move

Sensing fat?

CAN WE TASTE FATS?

Although *gustin* and *TAS2R38* contribute to the supertaster phenotype and may contribute to the perception of fat texture, researchers are still looking for a receptor directly triggered by fat. One promising candidate is the protein CD36, which binds long-chain fatty acids in mice, and is expressed on taste buds. The mechanism by which the CD36 carrier protein initiates a neural signal is poorly understood. CD36 may serve as a carrier protein that transfers the fatty acid to another receptor or it may activate an ion channel that alters the excitability of taste cells.



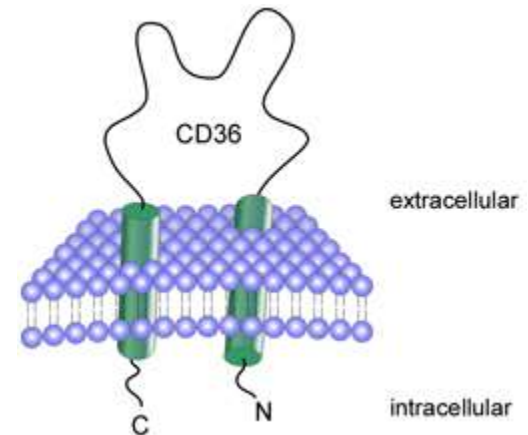
HOW DOES THIS LEAD TO OBESITY?

Recent work has shown that people who had a particular single nucleotide difference in their CD36 gene perceived high levels of creaminess in foods regardless of the fat level. These individuals, showed high preferences for creamy, usually fattier, foods. Although the mechanism remains unclear, this finding raises the possibility that disruptions in this gene lead to both persistently high responsiveness to the oral sensation of fat and an elevated preference for fat which could lead to obesity over time.



Chuť na tučné

- CD36 – receptor na lipidy (?), scavenger receptor, uplatňuje se v metabolismu lipidů, zánětu, hemostáze, ateroskleróze, řízení tlaku, při malárii sekvestrace Ery ve slezině



2 názory na kódování chutí:

A) labeled lines (analogie sluchu) – jeden nerv, jedna nemíchaná chuť, nepřekrývají se ani buňky ani dráhy, nebo:

B) specifické vzorce aktivity (analogie b.vidění nebo čichu – jeden receptor o výsledné kvalitě nic neříká a až směs dvou dává třetí kvalitu)

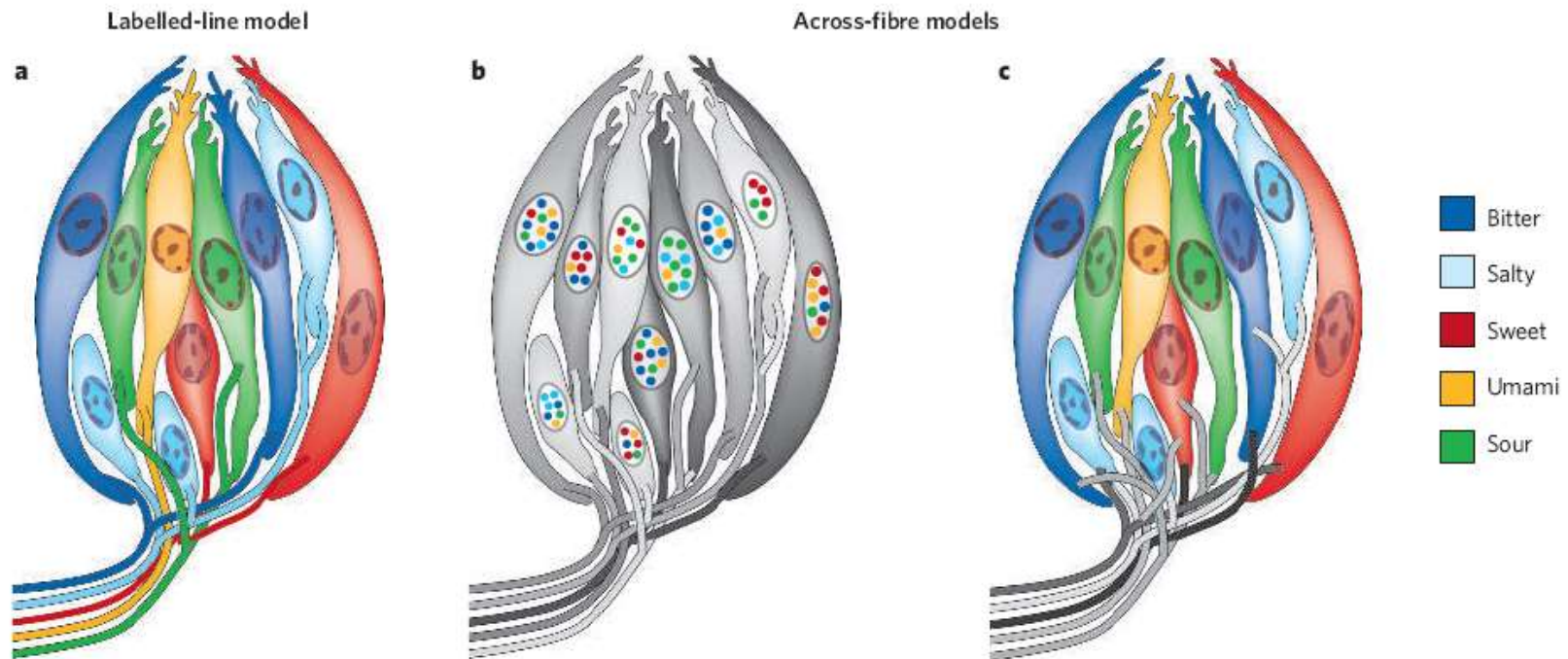
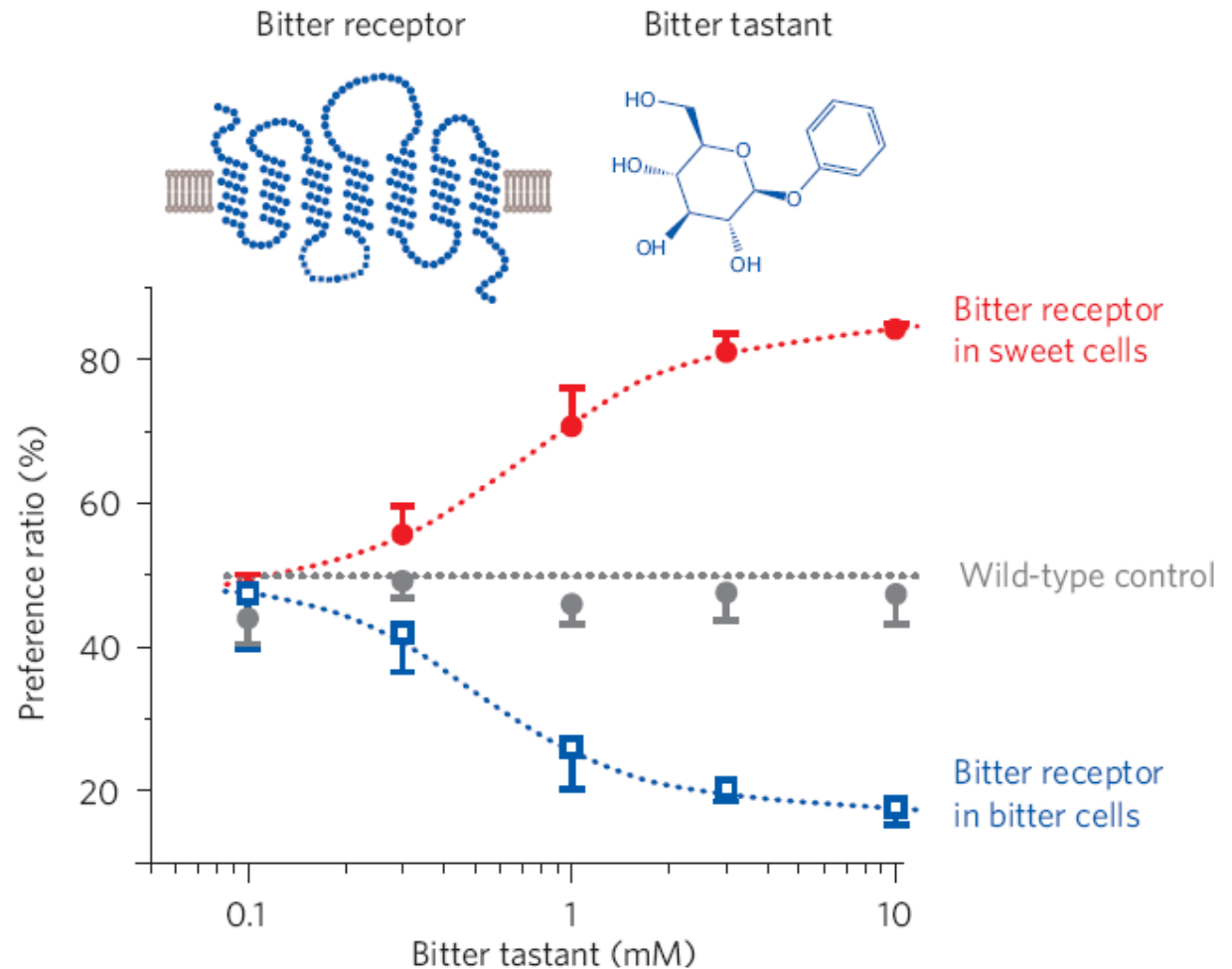


Figure 2 | Encoding of taste qualities at the periphery. There are two opposing views of how taste qualities are encoded in the periphery. **a**, In the labelled-line model, receptor cells are tuned to respond to single taste modalities — sweet, bitter, sour, salty or umami — and are innervated by individually tuned nerve fibres. In this case, each taste quality is specified by the activity of non-overlapping cells and fibres. **b, c**, Two contrasting models of what is known as the ‘across-fibre pattern’. This states that either individual TRCs are tuned to multiple taste qualities (indicated by various tones of grey and multicoloured stippled nuclei), and consequently the same afferent fibre carries information for more than one taste modality (**b**), or that TRCs are still tuned to single taste qualities but the same afferent fibre carries information for more than one taste modality (**c**). In these two models, the specification of any one taste quality is embedded in a complex pattern of activity across various lines. 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.

Transgenní myši s přehozenými receptory



Vnímání sladkého nebo hořkého odráží aktivaci jen určitých receptorových buněk bez ohledu na vlastnosti receptoru nebo chuťových molekul

Závěr: Každou jednotlivou chuť rozeznáme i ve směsi chutí – ochrana. Mícháním chutí se tedy nevytváří chuť (kvalita) zcela nová. Chuť je analytickým smyslem.

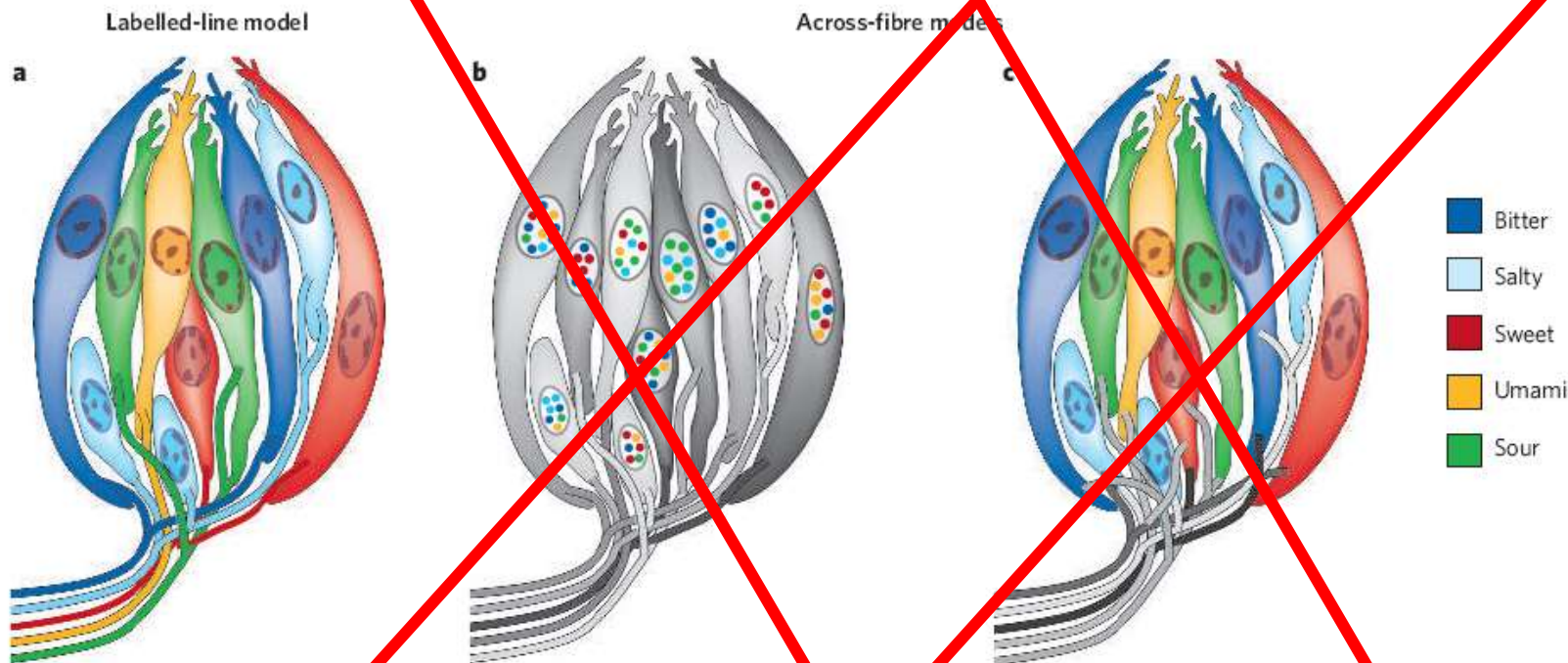
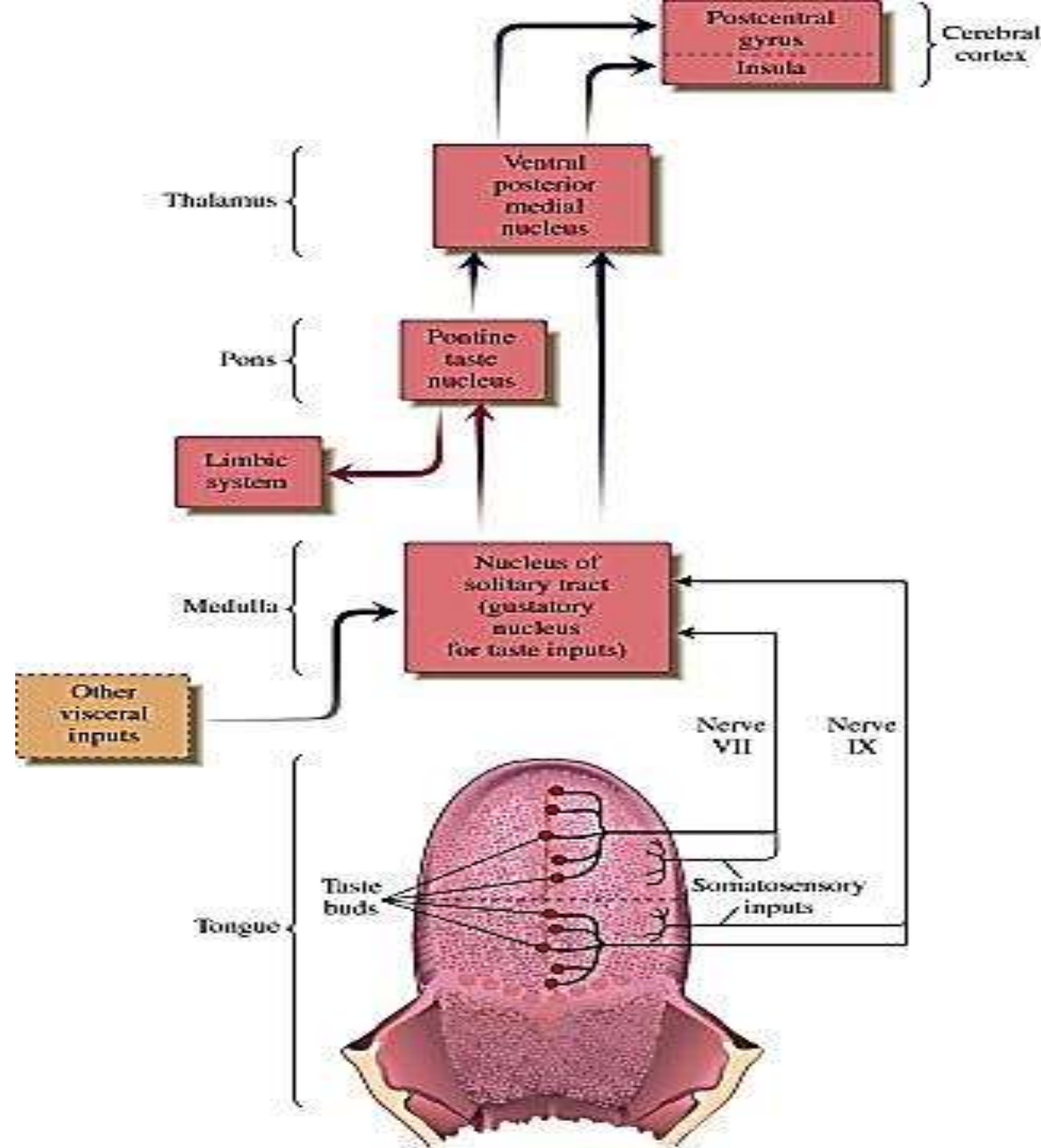
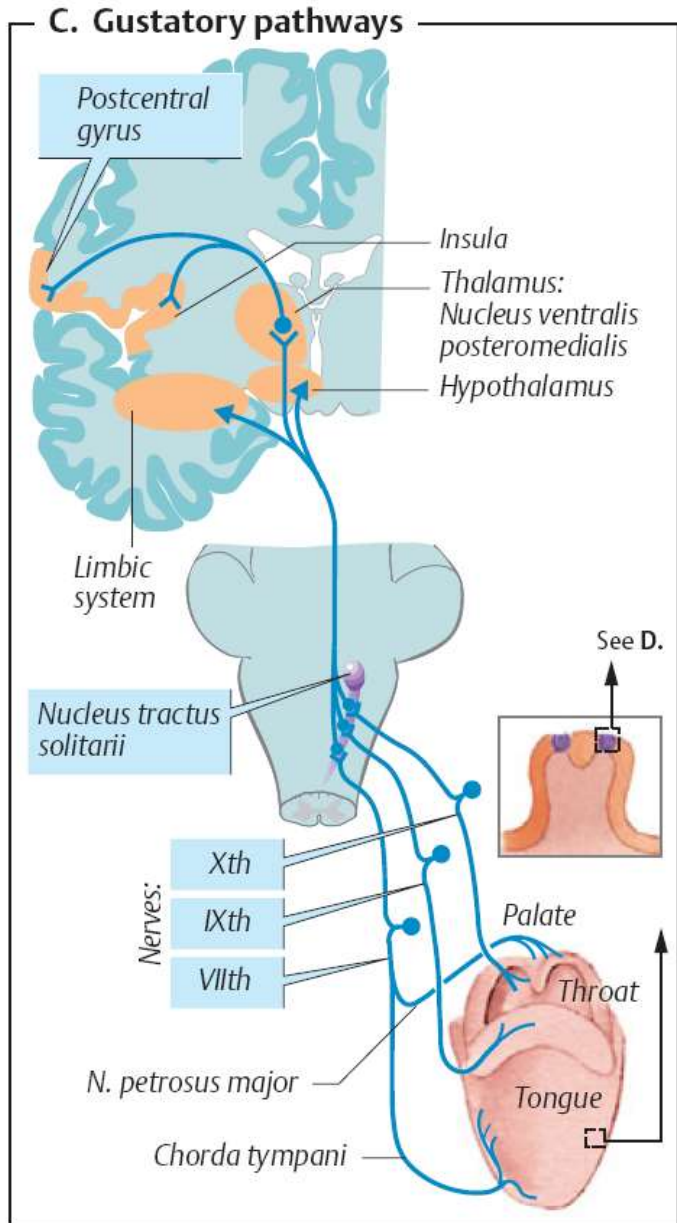


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Chuťová dráha



Chuťová dráha

Axony patří pseudounipolárním neuronům, jejichž těla leží v gangliích VII., IX. a X. hlavového nervu. Přes nižší mozková centra (hypotalamus, talamus) můžeme sledovat cestu chuťové informace ke dvěma korovým chuťovým oblastem (postcentrální závit a insula).

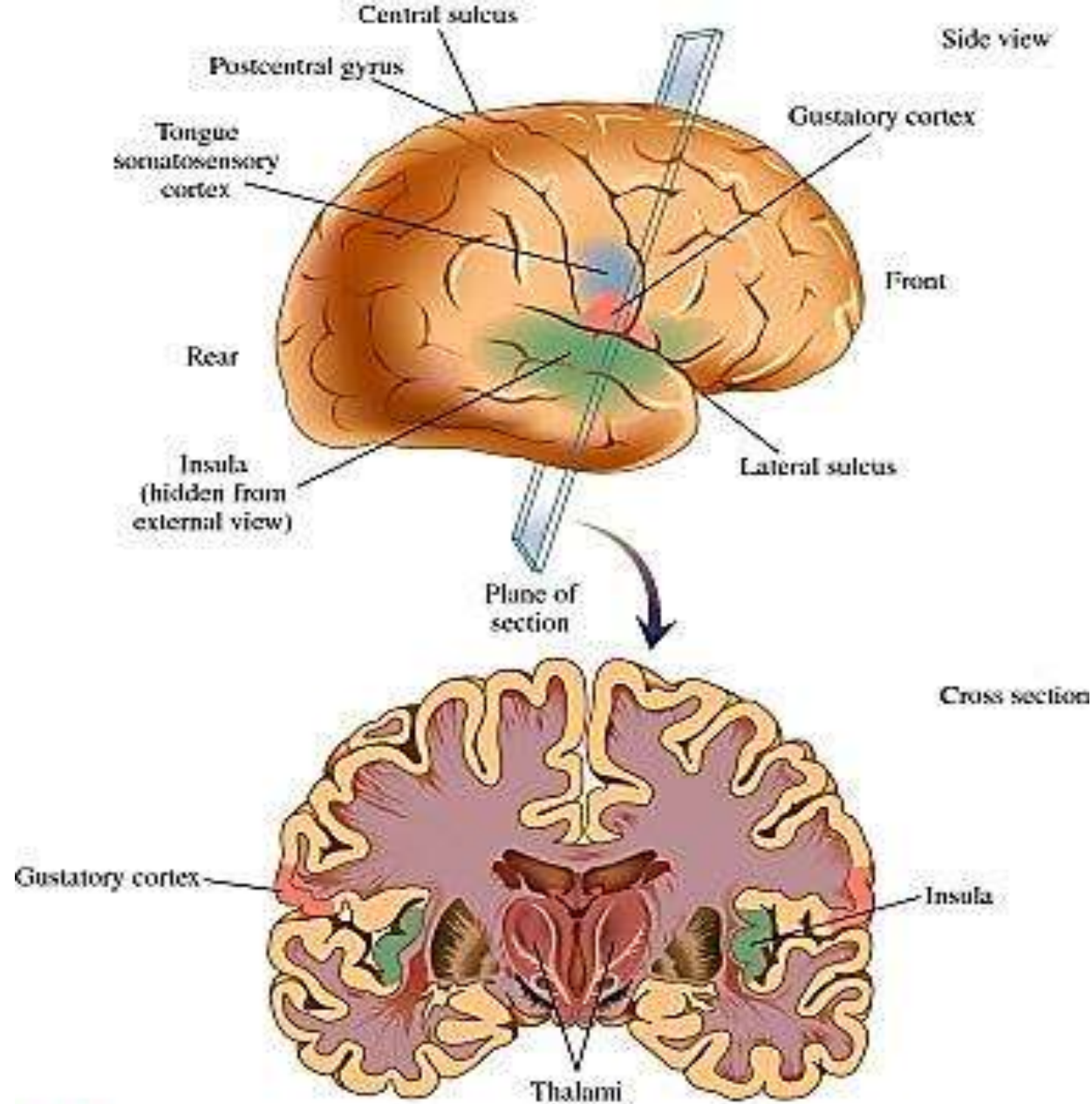
První asi hraje roli při vnímání prostorového rozmístění chuťových počitků na jazyku a druhá je zodpovědná za vnímání vlastní kvality chuti.

Najdeme také významnou projekci do limbického systému a hypotalamu.

Uvedené spoje jsou morfologickým substrátem významné emocionální komponenty, která vždy doprovází určitý chuťový vjem a pojí se paměťovými stopami – rozlišování vhodné a nevhodné potravy už od mládí. Zřejmě také zprostředkovávají autonomní reflexní reakce při příjmu potravy (sekrece slin, žaludeční šťávy apod.).

Chuťová kůra

Insula – lat. část mozkové kůry ležící v hloubi postranní brázdy mozkové sulcus lateralis, je překrytá čelním, temenním a spánkovým lalokem.
lat. ostrov



(a)



(b)



Potěšení z chutí - vrozené prospěšné reflexy. Zvýšená chuť na chybějící složku.

Příjemné tóny sladkého a umami signalizují kalorické stravitelné jídlo. Hořká chuť má nízký práh při vyvolávání dávivého reflexu, jde o varování před obvykle jedovatými látkami.

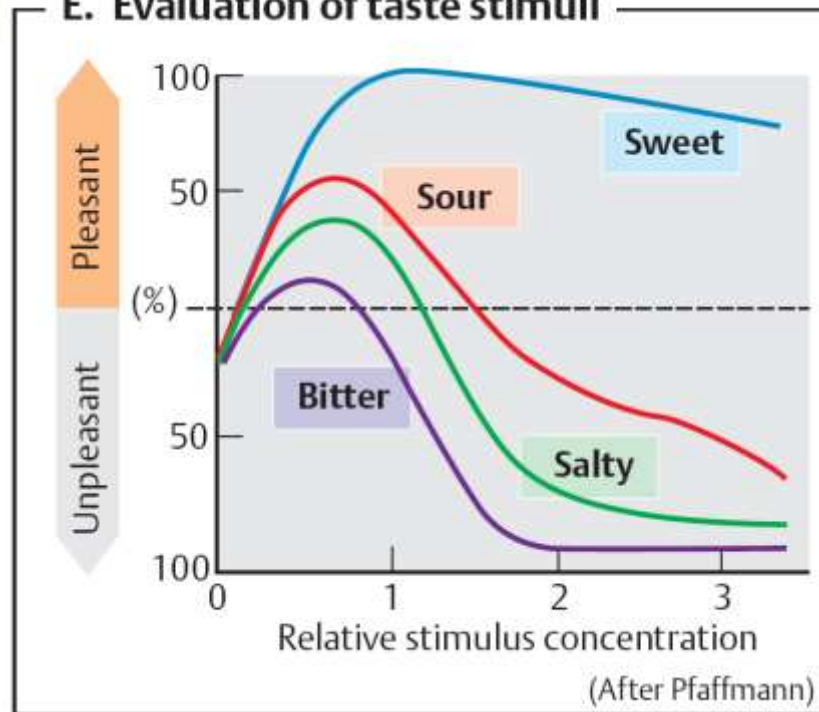
(a)



(b)

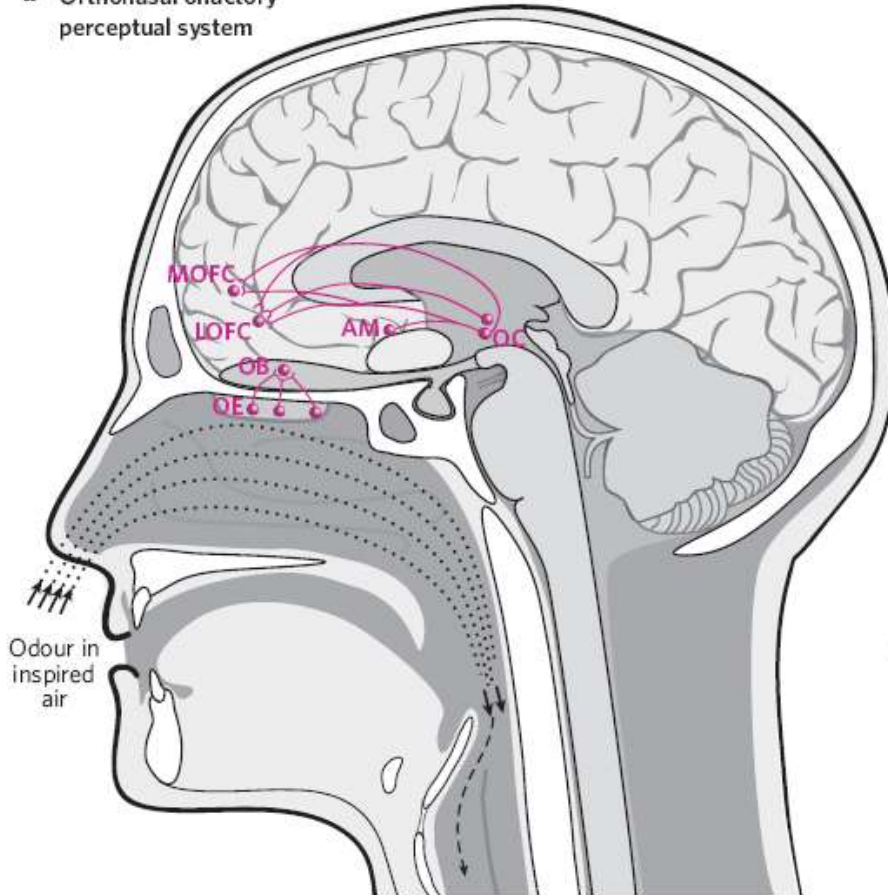


E. Evaluation of taste stimuli



Spolupráce s čichem a dalšími smysly při kontrole příjmu potravy.

a Orthonasal olfactory perceptual system



b Retronasal olfactory flavour system

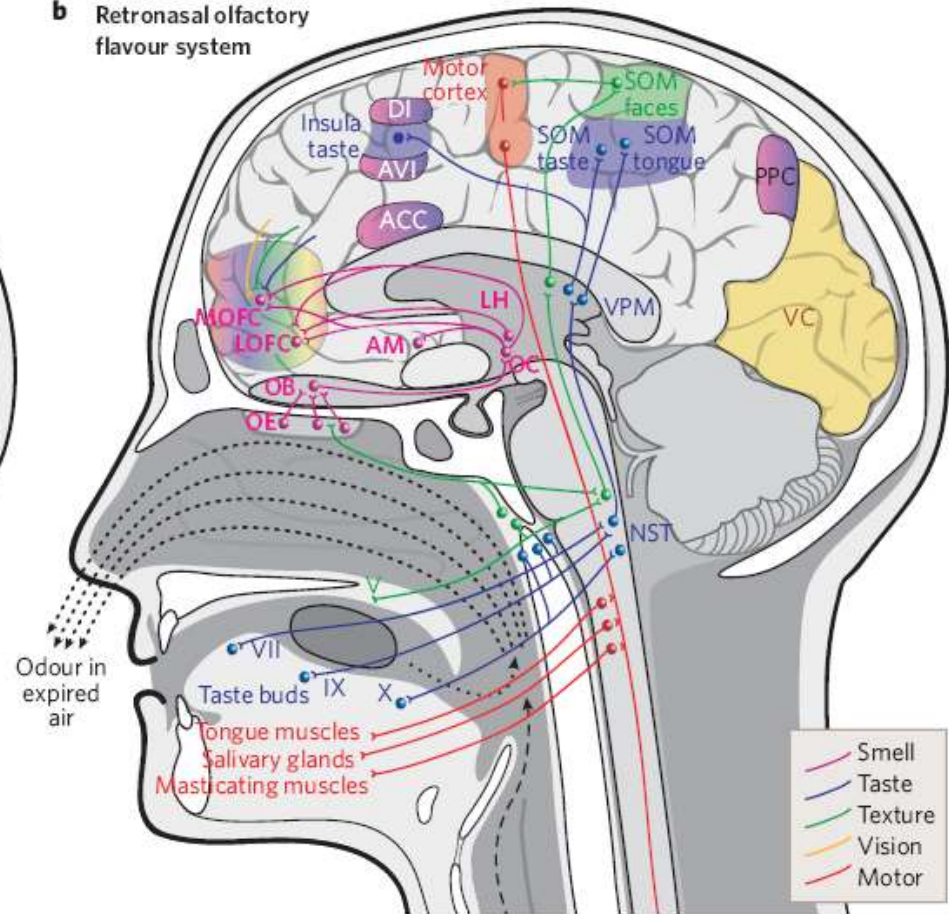


Figure 2 | The dual olfactory system. **a**, Brain systems involved in smell perception during orthonasal olfaction (sniffing in). **b**, Brain systems involved in smell perception during retronasal olfaction (breathing out), with food in the oral cavity. Air flows indicated by dashed and dotted lines; dotted lines indicate air carrying odour molecules. ACC, accumbens; AM, amygdala; AVI, anterior ventral insular cortex; DI, dorsal insular cortex; LH, lateral hypothalamus; LOFC, lateral orbitofrontal cortex; MOFC, medial orbitofrontal cortex; NST, nucleus of the solitary tract; OB, olfactory bulb; OC, olfactory cortex; OE, olfactory epithelium; PPC, posterior parietal cortex; SOM, somatosensory cortex; V, VII, IX, X, cranial nerves; VC, primary visual cortex; VPM, ventral posteromedial thalamic nucleus.

Spolupráce s čichem a dalšími smysly a emocemi při kontrole příjmu potravy – komplex řídicí potravní chování. Chuť úzce navázána na emoce, motivace, žádost. Důležité téma současnosti.

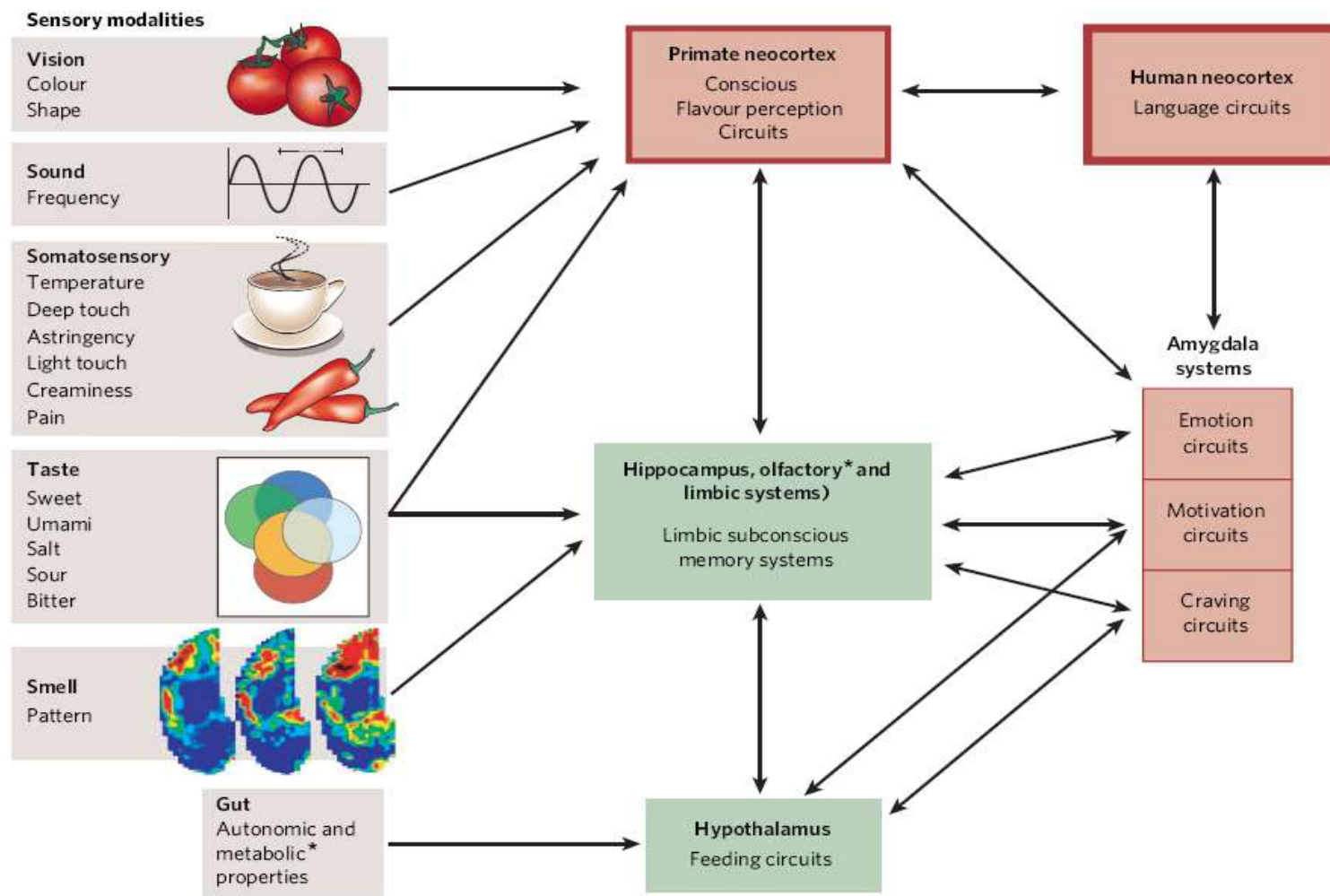


Figure 3 | The human brain flavour systems that evaluate and regulate food intake. The diagram shows the areas involved in the perceptual, emotional, memory-related, motivational and linguistic aspects of food evaluation mediated by flavour inputs^{32,41,54,55}. Left, different sensory modalities and submodalities that contribute to flavour perception. Middle and right, brain flavour system that evaluates and regulates food intake. Red regions mediate conscious sensory perception; thicker outlines indicate their greater importance in humans and other primates. Green regions mediate subconscious feeding regulation. Deficiencies in essential amino acids are sensed by the anterior olfactory cortex (asterisk).

