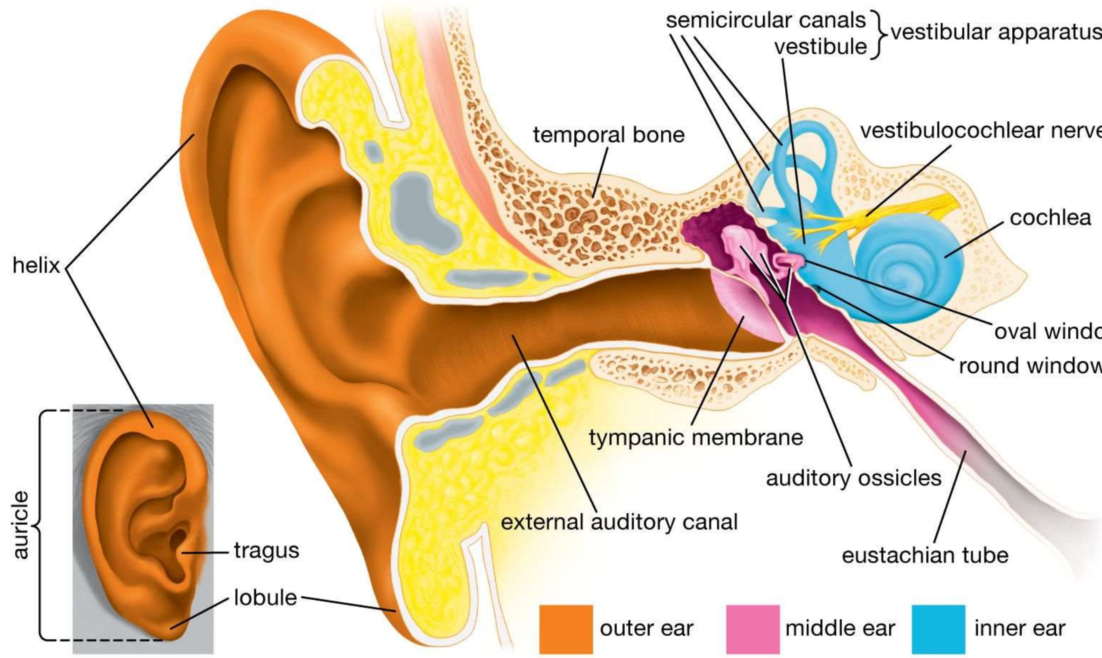
Hearing, vision, smell, taste

12.3.2024

Hearing

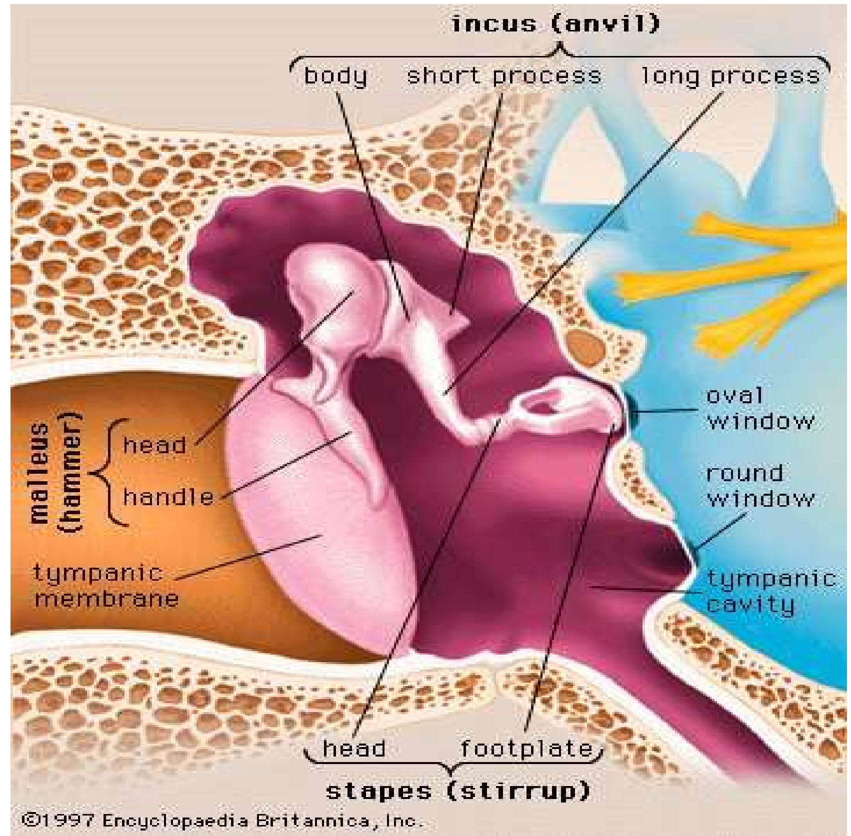
- Humans can sense frequencies between 20 and 20 000 Hz
- Receptors are in the cochlea of the inner ear where sound waves are transmitted via outer and middle ear



https://www.britannica.com/science/ear

Hearing

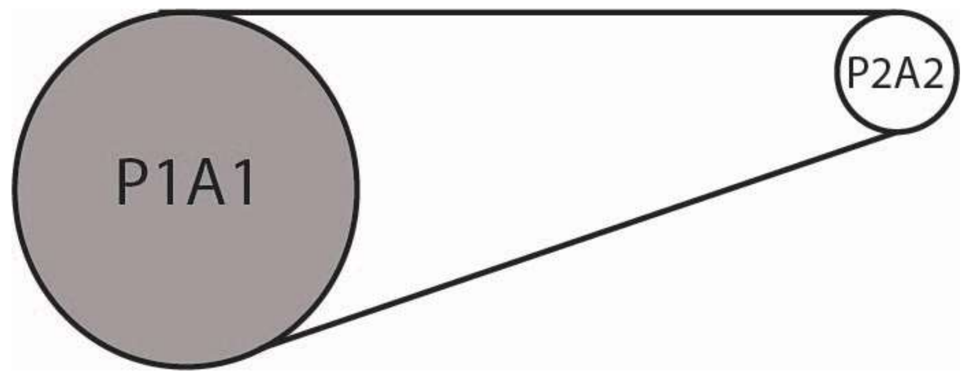
- Transmission of sound waves: Tympanic membrane → Auditory ossicles in the middle ear (malleus, incus, stapes) → Oval window → Fluid in the cochlea (perilymph) → Basilar membrane in cochlea → nerveimpulses in VIII cranial nerve to brainstem and via thalamus to cortex



https://www.britannica.com/science/ear

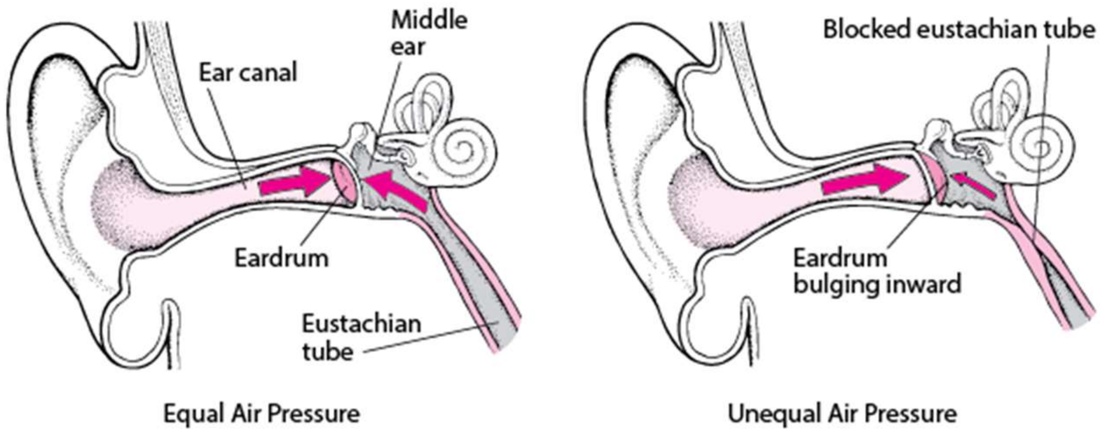
Outer and middle ear collect and amplify the sound

- Resistance of fluid >> resistance of air → Stronger sound pressure needed to be conducted in fluids
- P = F/A
- Area of the oval window 3 mm^2, tympanic membrane 50 mm^2 → P2 ≈ 17 x P1
- Malleus bone 1.3 x longer than incus (leverage) → F increases
- Tympanic membrane more rigid centrally where malleus attaches → F increases



Ear “clogged”

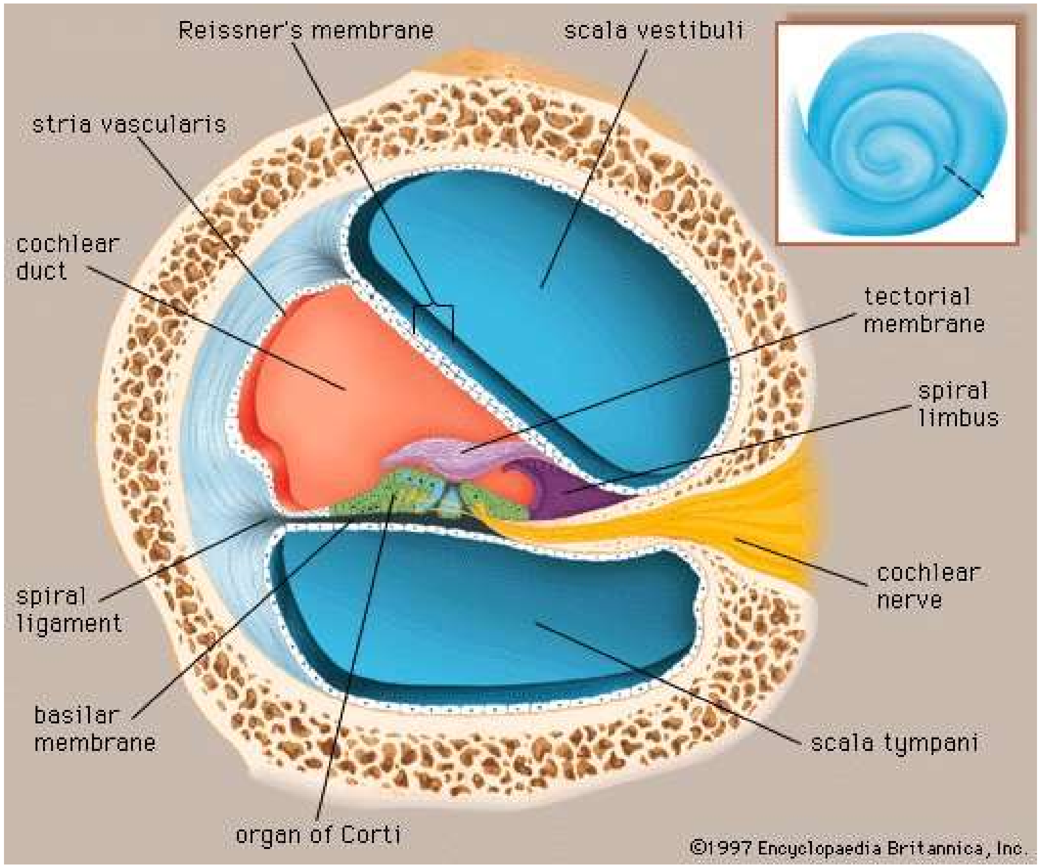
- Eustachian tube runs from the middle ear to pharynx and equalizes pressure
- Pressure difference, e.g., when the eustachian tube is blocked with mucus stiffens the ossicles and eardrum (tympanic membrane)



https://www.msdmanuals.com/

Sensitive receptors for hearing are in the cochlea

- Oval window vibrates → perilymph in the cochlea vibrates
- Cochlear duct filled by endolymph
- Organ of Cortin between scala tympani and cochlear duct
- Vibration of endolymph → basilar membrane vibrates



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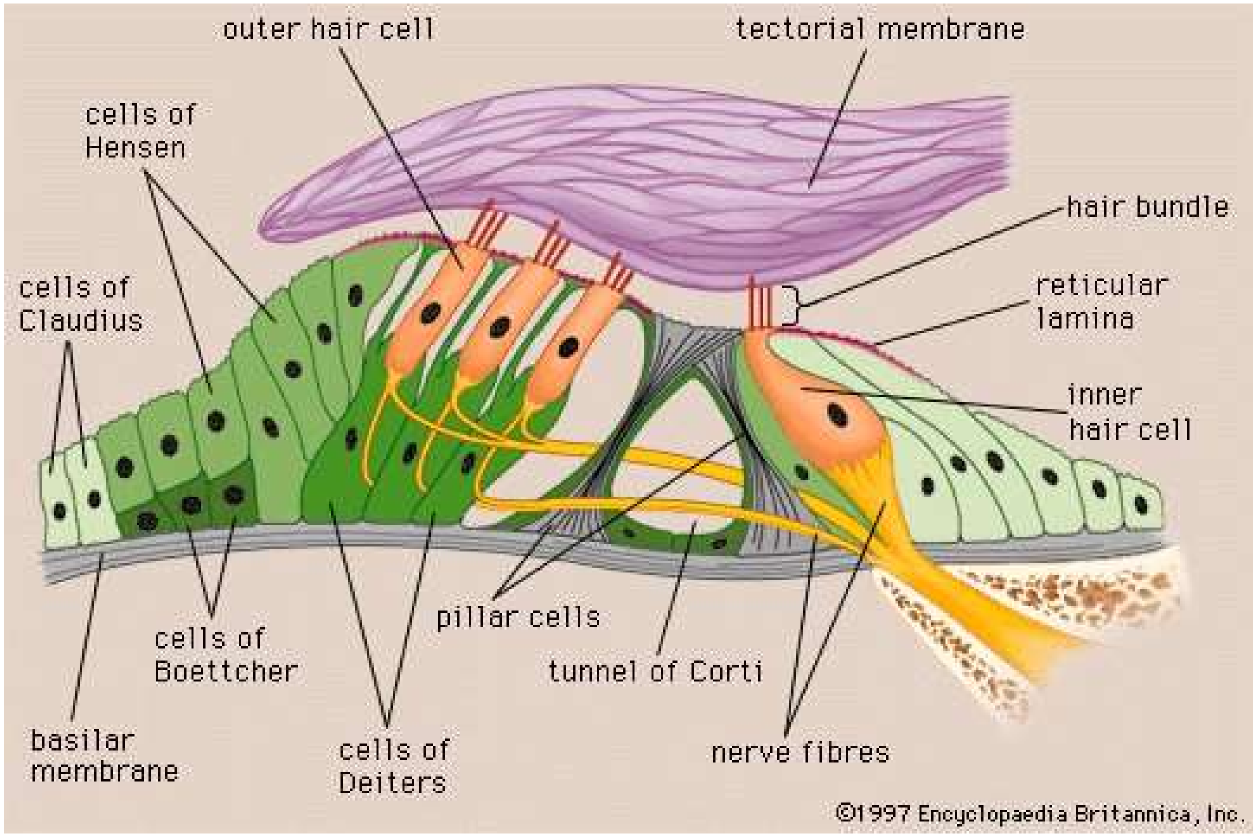
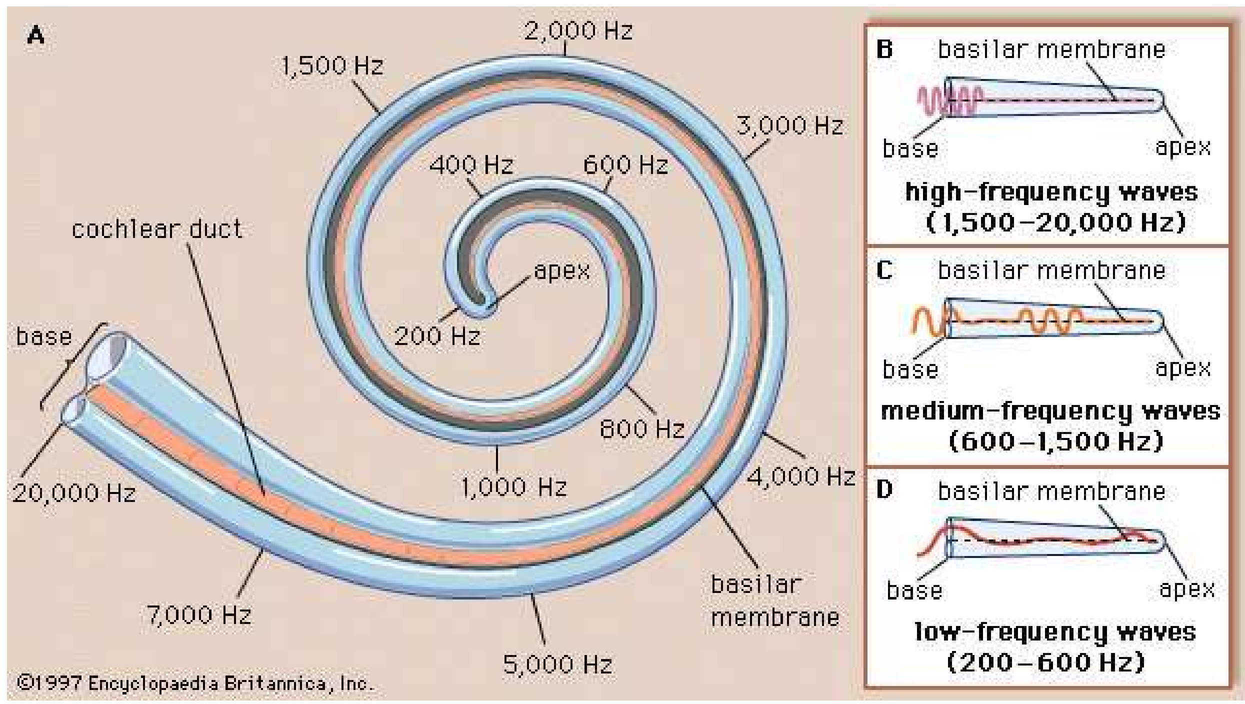


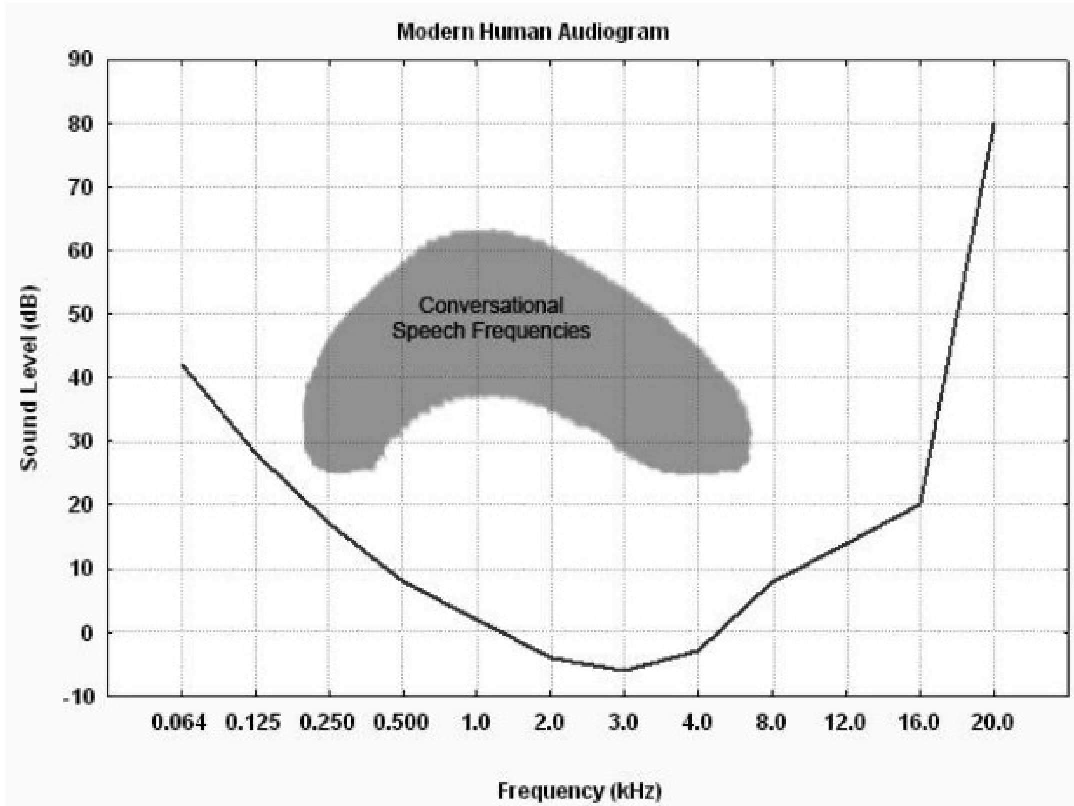
Coding of sound frequency: Place and temporal theories

- High-frequency sounds are sensed near the oval window and low frequency near the inner tip of cochlea → Place theory (e.g., Helmholz, 1863)
- Also the firing rate of nerve cells follows the sound frequency up to 4000 Hz → Temporal theory



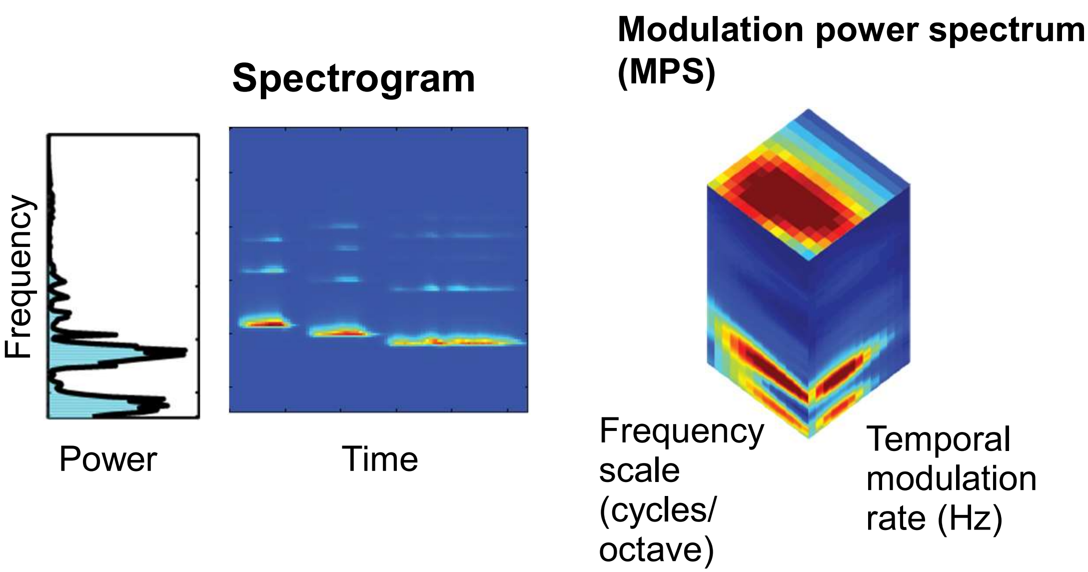
Hearing area in humans

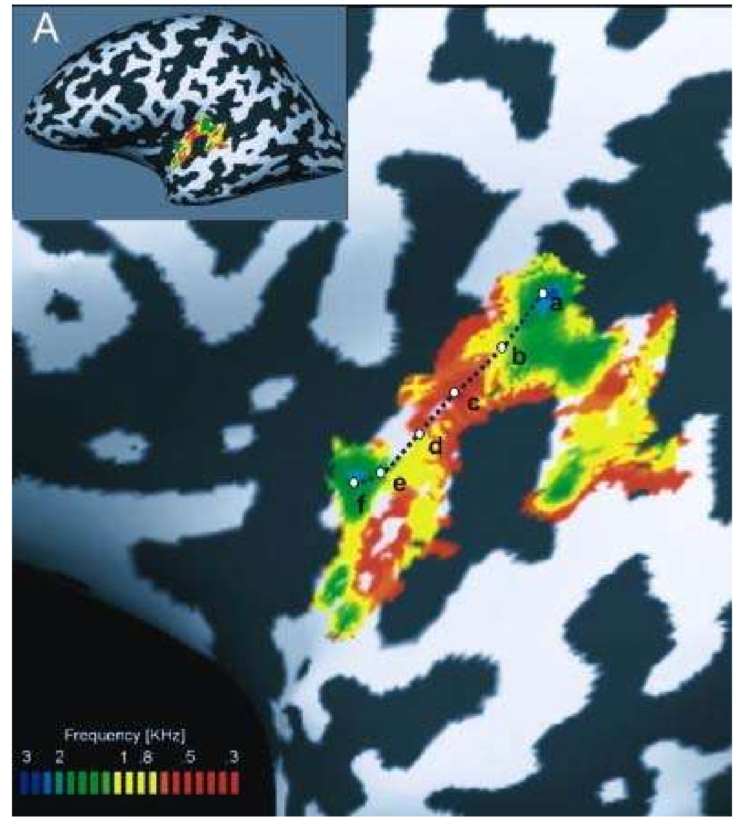
- N.15000 hearing receptors per ear
- Sensitive to noise
- Very loud sounds trigger acoustic reflex to attenuate the sound entering the ear
- Age-related hearing loss



Quam et al. 2012

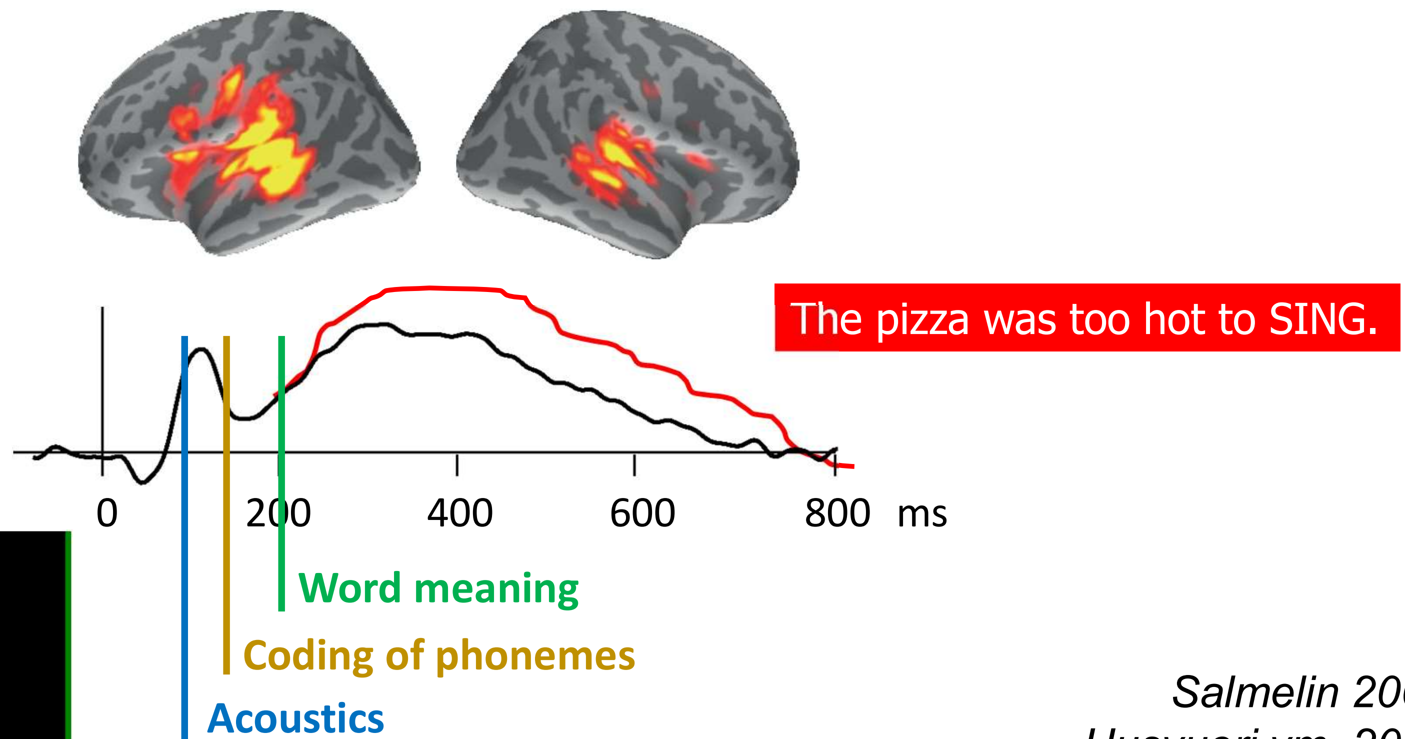
Acoustic analysis of sounds continues in the auditory nerve and at the auditory cortex

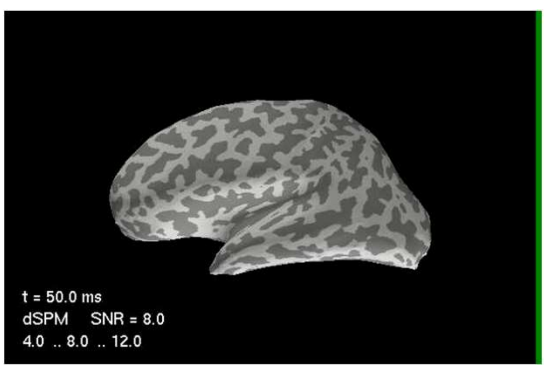




Nora et al. 2020, Formisano et al. 2003

Speech perception in time

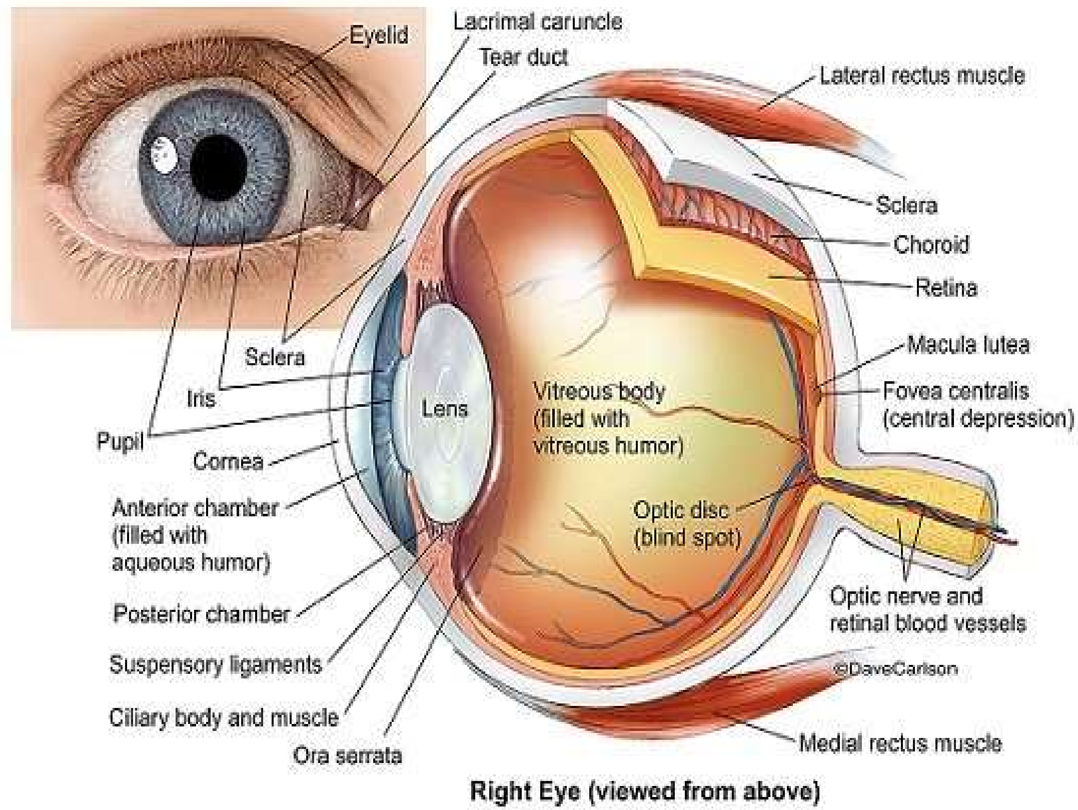




Salmelin 2007
Uusvuori ym. 2008
Helenius ym. 2002
Näätänen ym. 1997

Vision

- Light is refracted via cornea, anterior chamber, lens, and vitreous body to the retina where the receptors reside, and send nerve impulses via optic nerve to the visual cortex

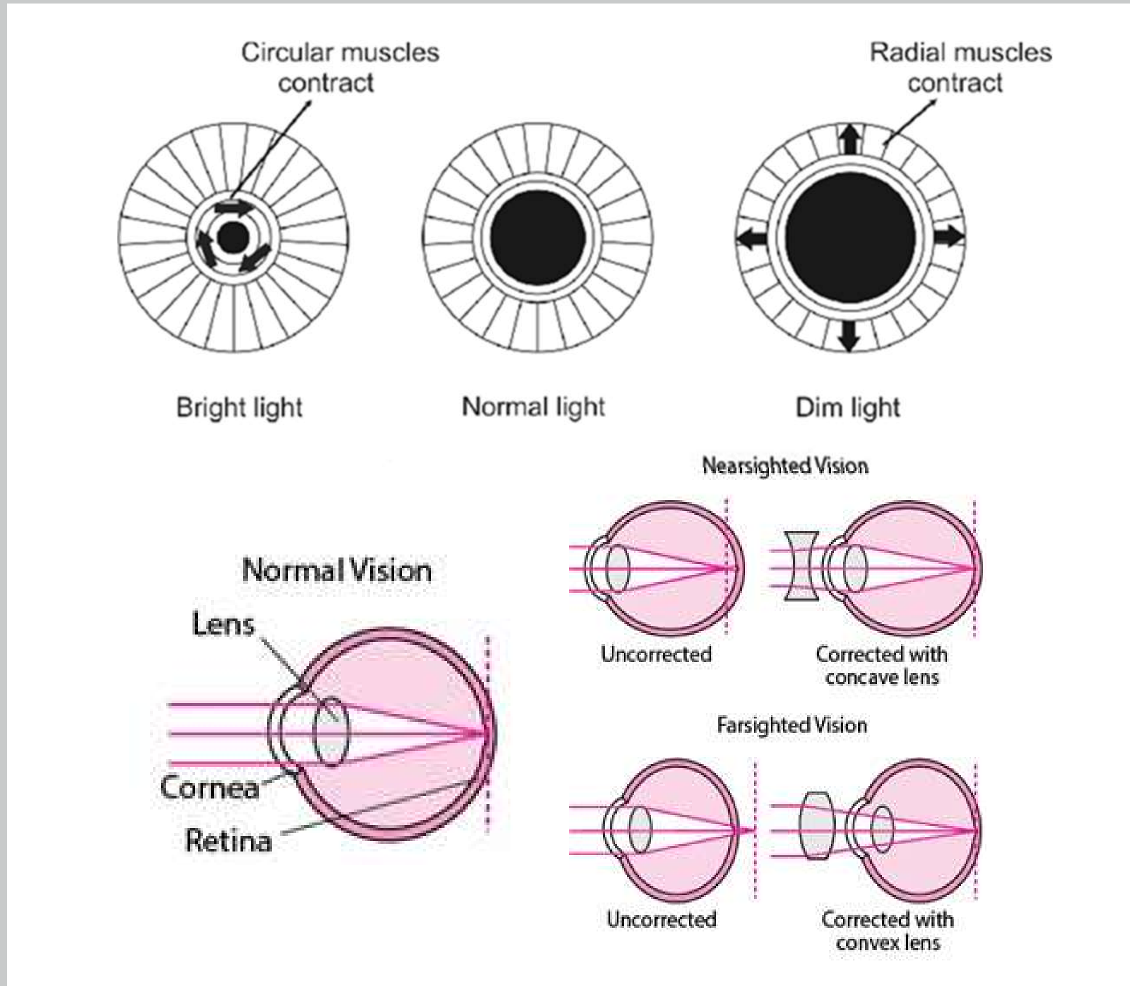


https://www.vision-and-eye-health.com/eye-anatomy.html

Optics of the eye in forming the picture

- The amount of light is regulated by the circular and radial muscles in the iris

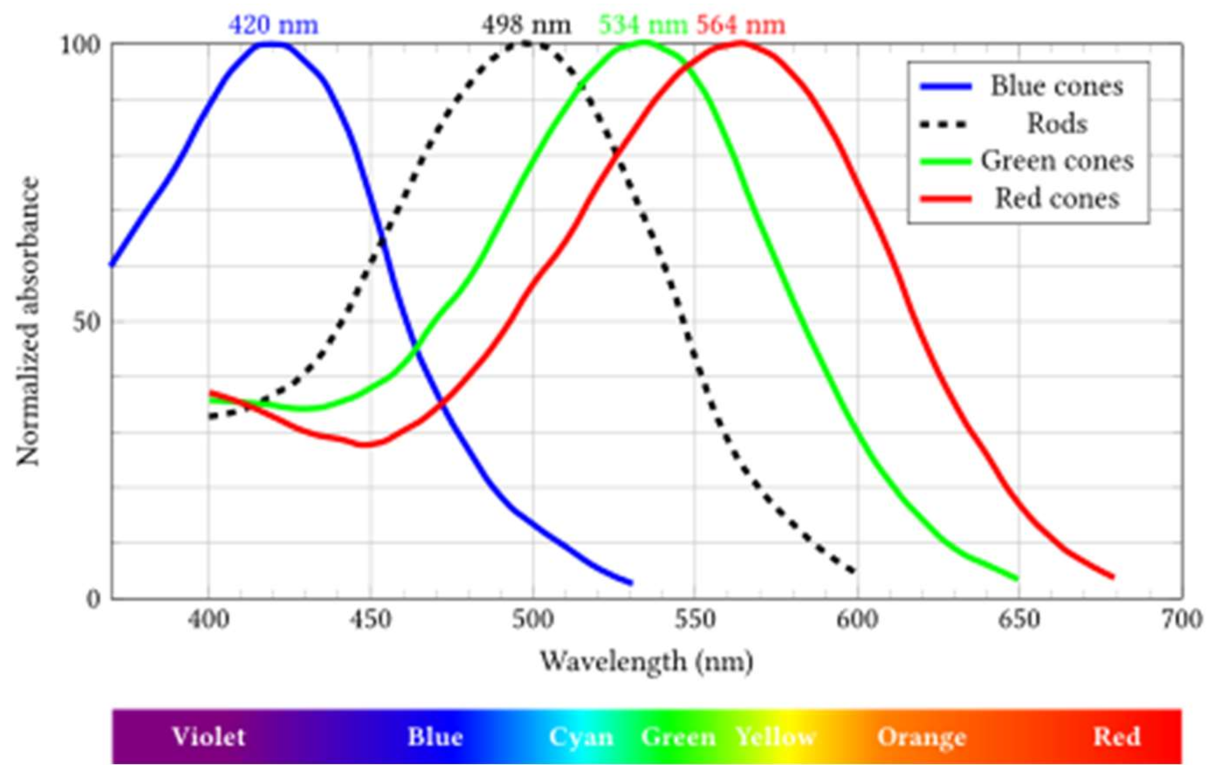
- Light reflection is regulated by the ciliary muscle of lens
  - ✓ accomodation = ciliary muscle contracts/relaxes when looking at near/far distance
  - ✓ Myopia
  - ✓ hyperopia
- Cornea and lens avascular



Szczepanowska-Nowak et al., 2004, Merckmanuals.com

Structure and function of retina

- Human photoreceptors are sensitive to visible light (appr. 400-700 nm)
- In addition to photoreceptors, retina includes other nerve and glial cells → visual information is transformed already at the level of retina



Wikipedia

Rods and cones

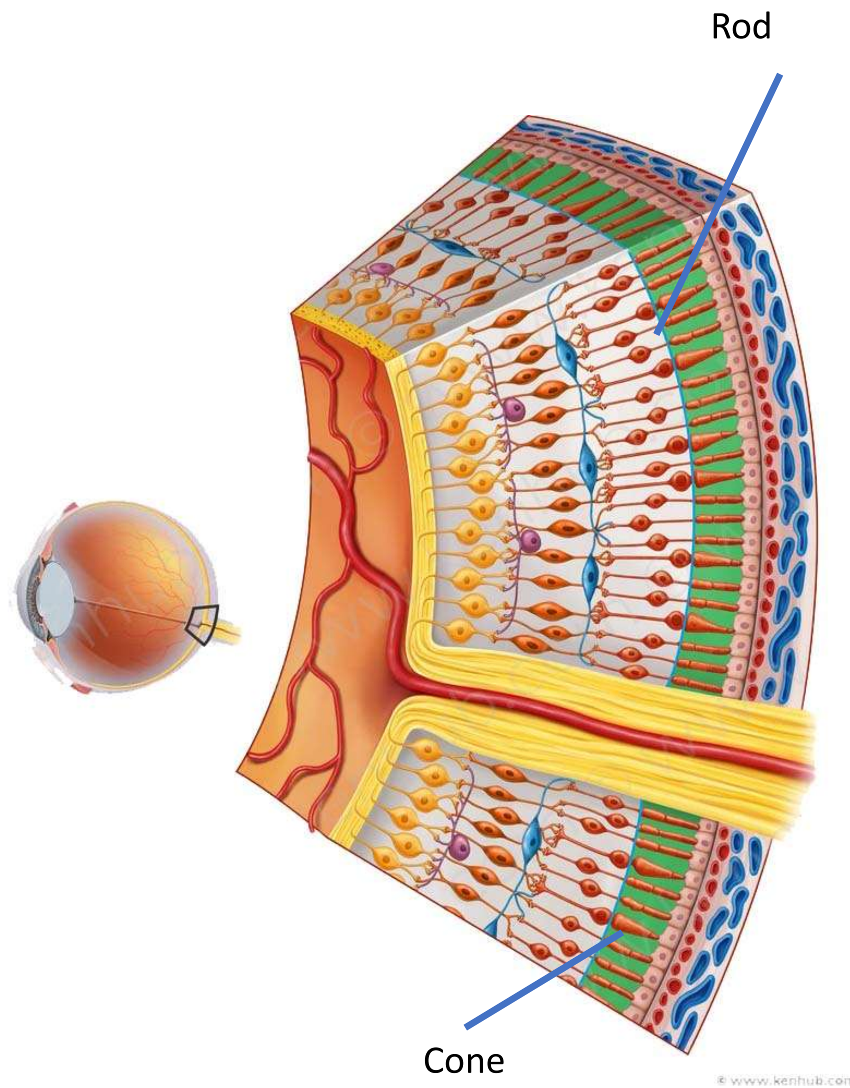
- Both retinas contain appr. 125 million rods

✓ Dark vision: appr. 5 photons needed for visual perception

- Appr. 5 milj. cones per eye

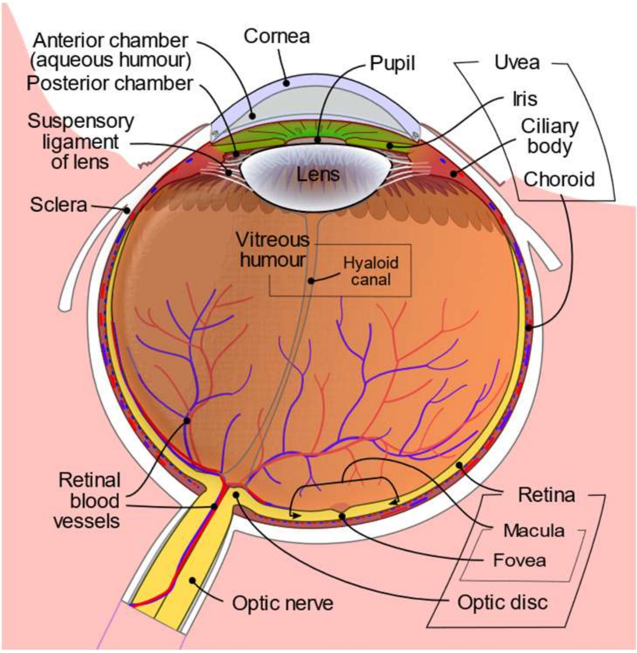
✓ Color vision

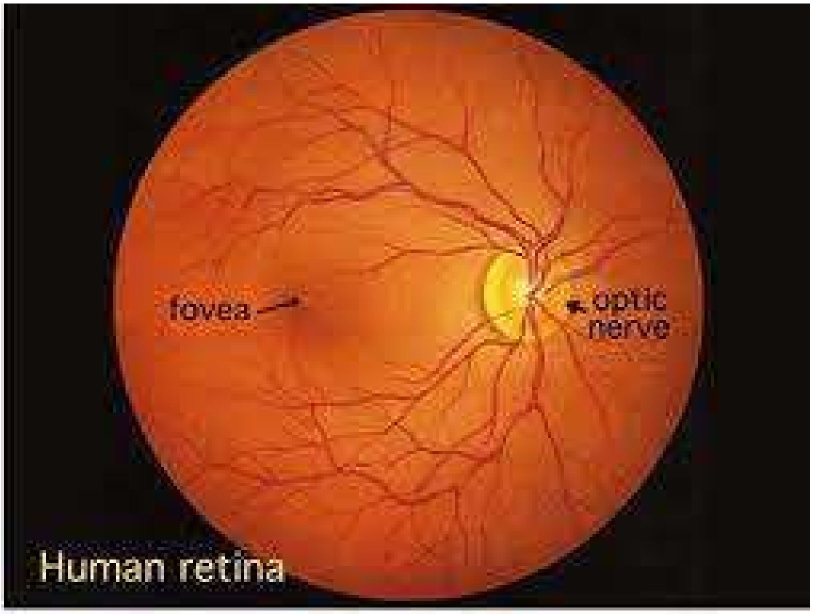
- Most bottom layer of the retina



Lots of cones in macula

- Fovea
- Optic disc: no receptors, so-called 'blind spot'

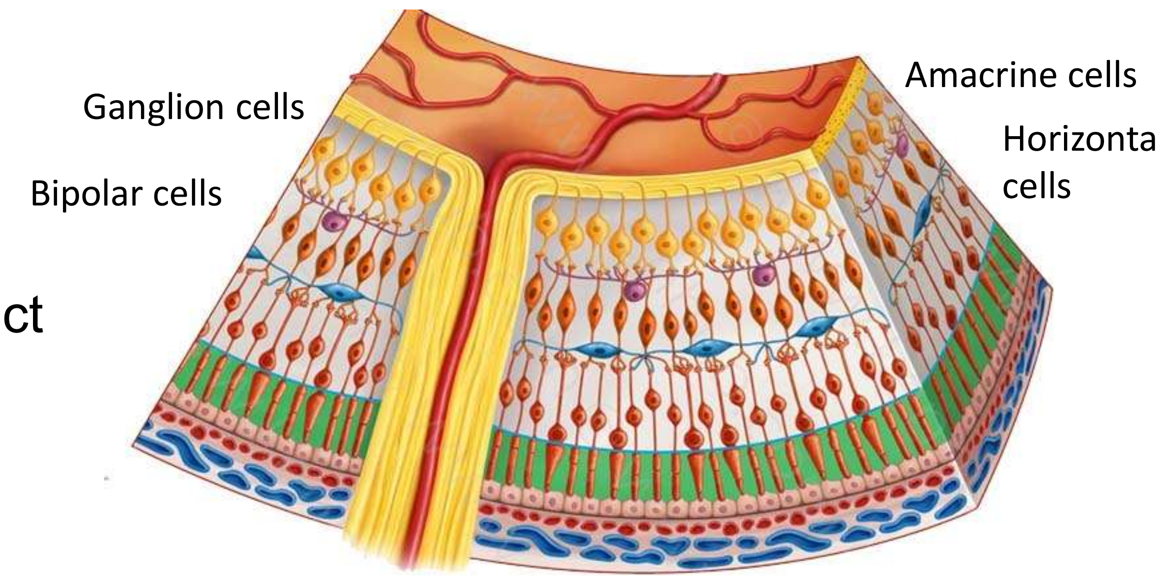




Wikipedia

Light causes chemical reaction in the visual pigment

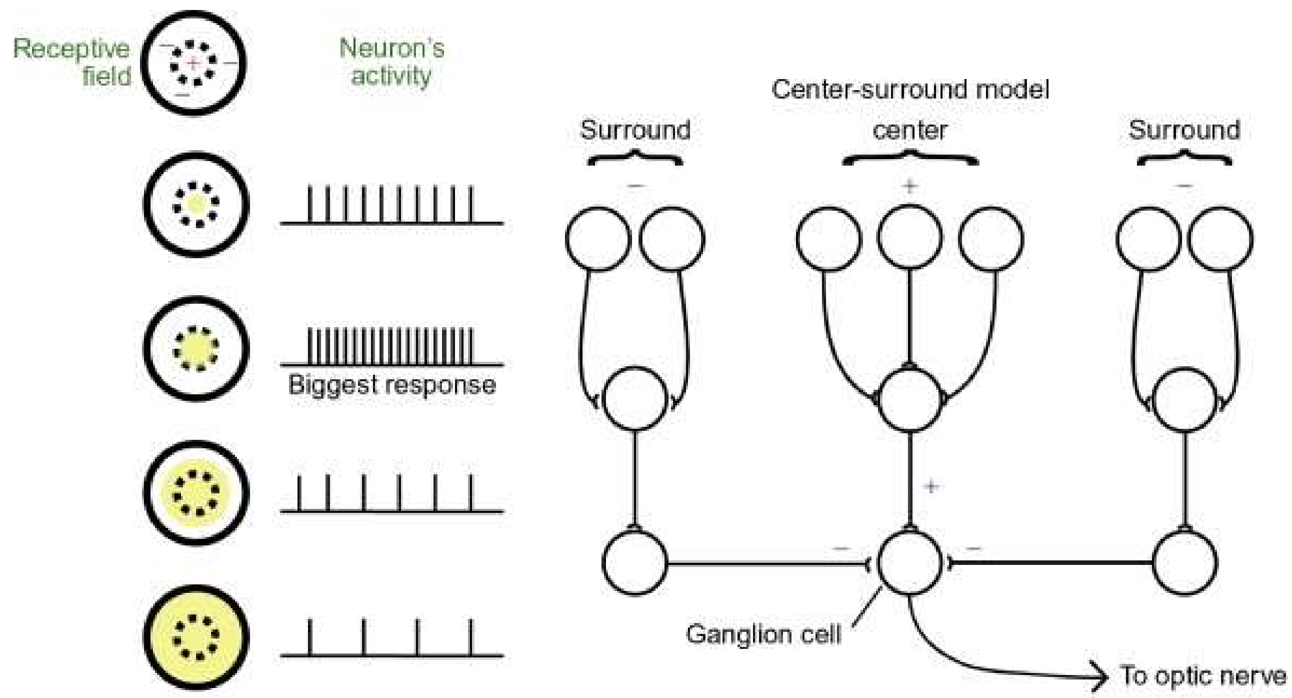
- Rhodopsin = pigment found in rods
- Cones contain three different pigments (blue, green, red)
- Transfomation in the pigment results in hyperpolarisation
- Three first neurons of visual tract reside in retina: rod/cone → bipolar cell → ganglion cell
- Additional amacrine and horizontal cells



Kenhub.com

The receptive fields of ganglion cells increase contrast sensitivity

- The ON center and OFF surrounding of ganglion cells results in maximum response when the edge of light occurs in the receptive field



Gage ja Barns, 2018

Gage ja Barns, 2018

Dark and light adaptation

In darkness

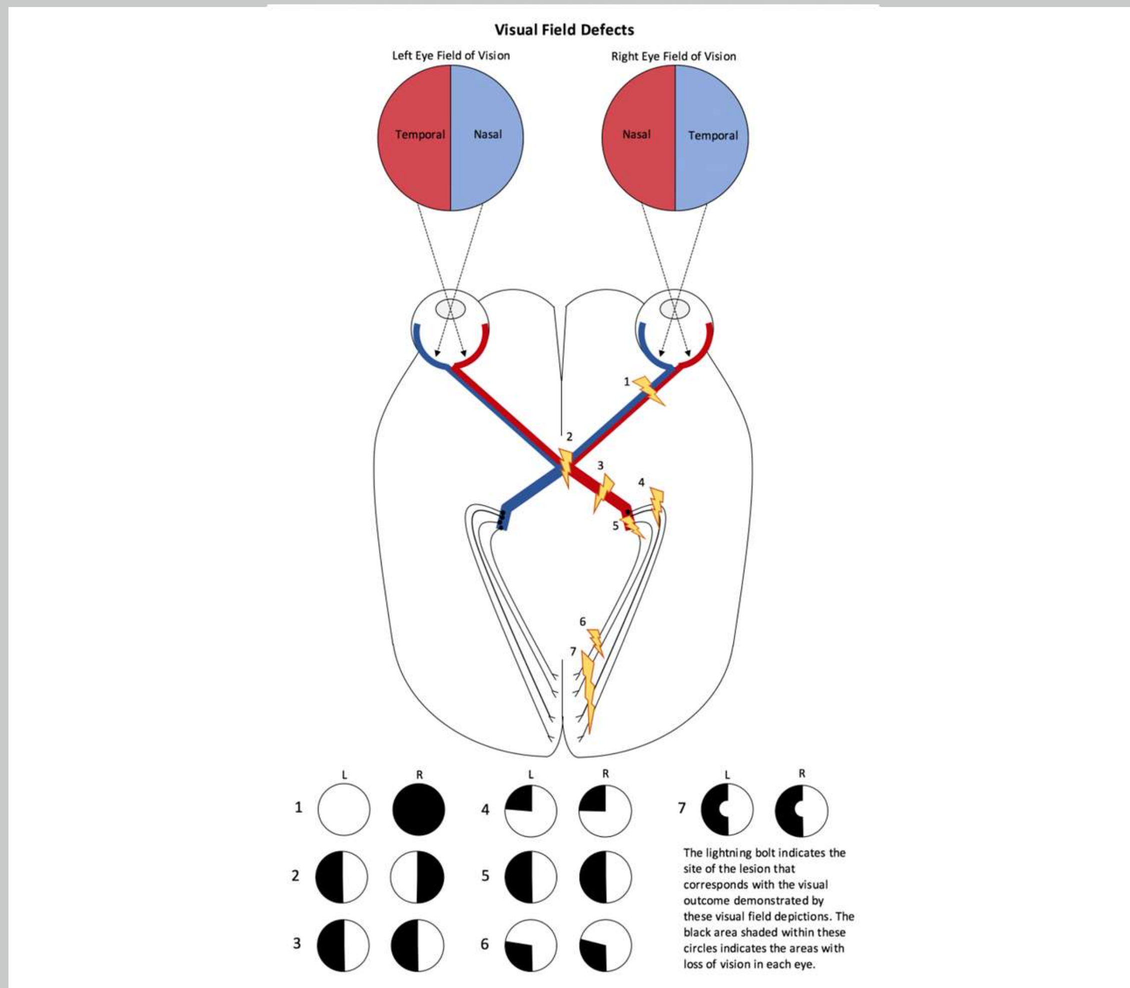
- ✓ Pupil dialates
- ✓ Rhodopsin and other visual pigments are reformed (> 5-10 min)
- ✓ Horizontal cells collect information from a larger population of rod cells

In bright light

- ✓ Pupil contracts
- ✓ Rhodopsin depletes rapidly

Visual tract

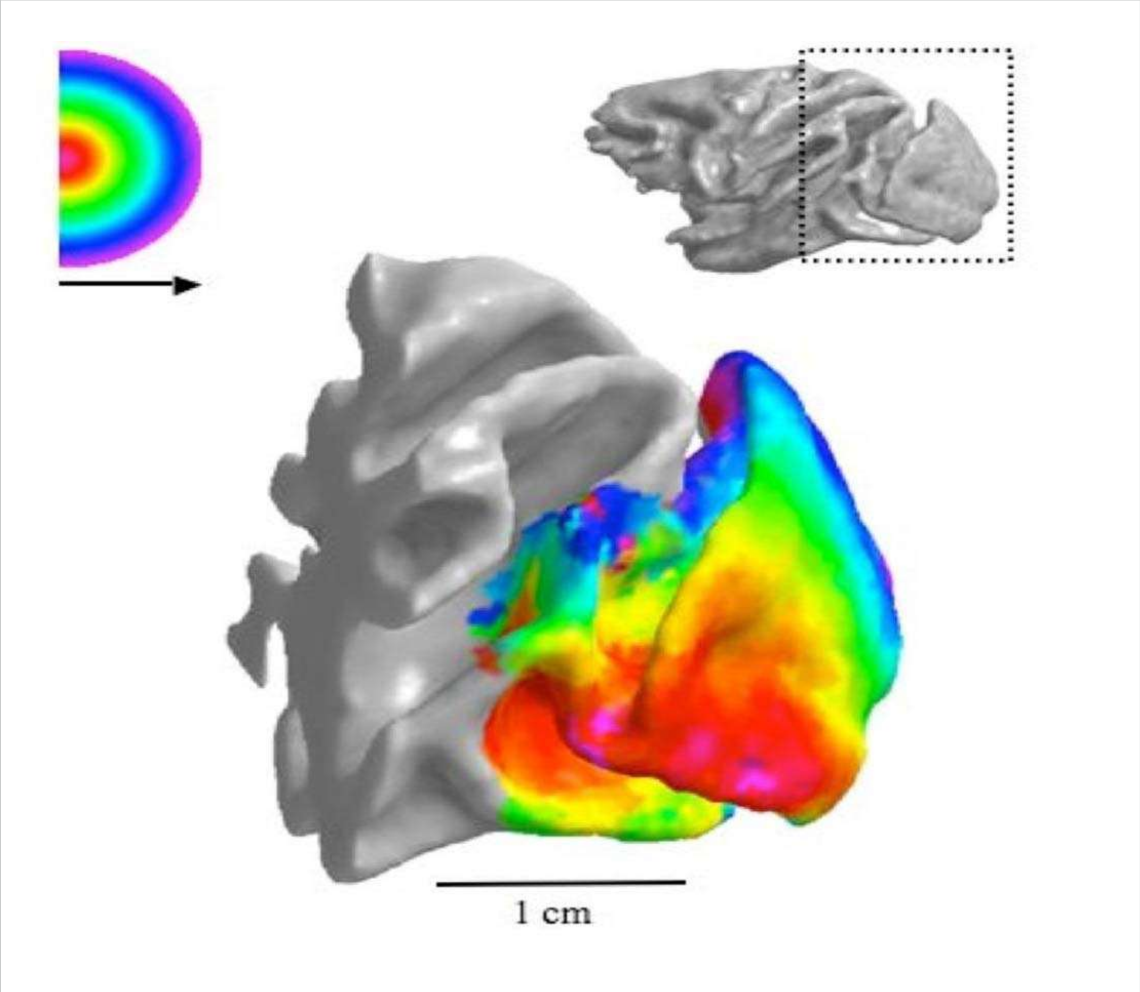
- Optic tracts cross in optic chiasm
- 4th neuron from the thalamus to the visual cortex
- Left hemisphere receives information from the right visual hemifield, and vice versa: Information from the visual hemifields is combined only later



https://morancore.utah.edu/basic-ophthalmology-review/hemianopsia/

Visual cortex

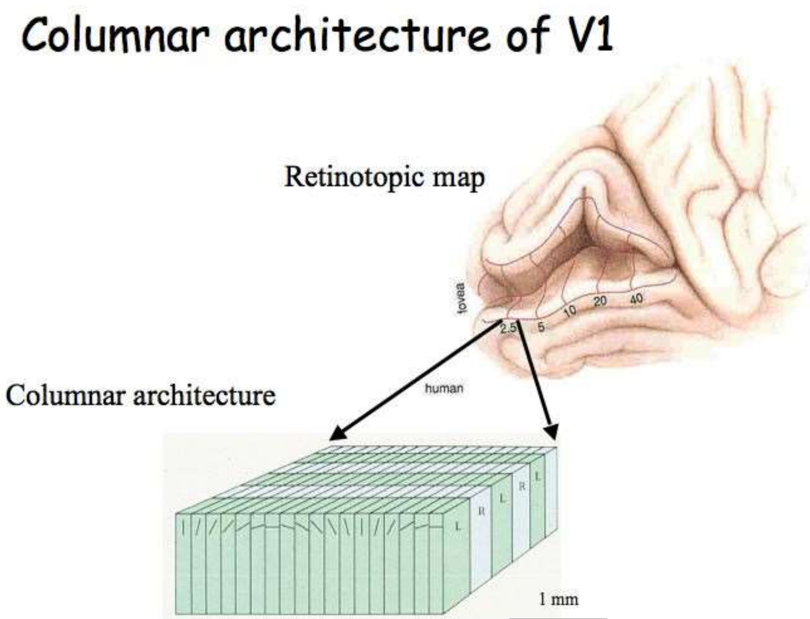
- Receptive fields and information processing gets more complicated
- Retinotopy: Close-by points in the visual hemifield/retina are mapped next to each other at the cortex

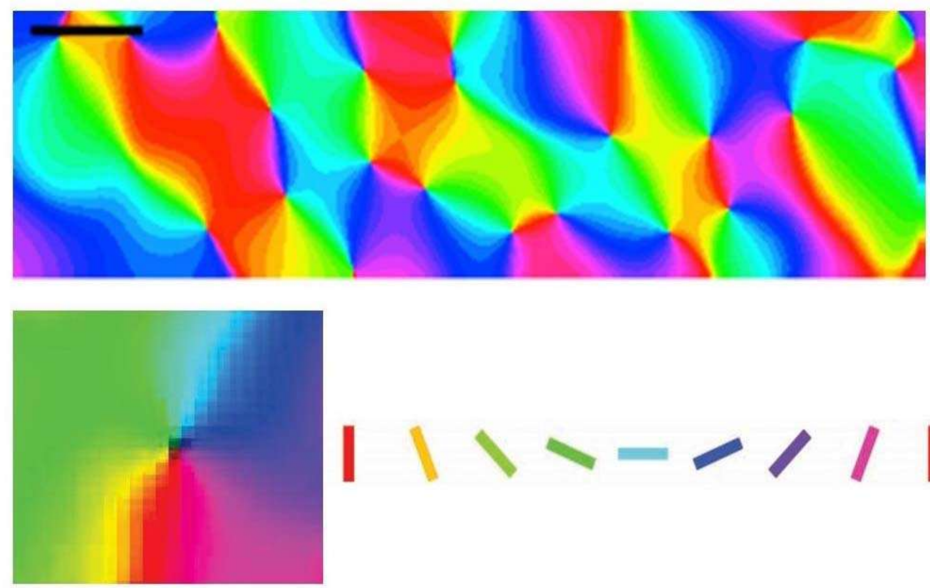


Ibbotson ja Jung, 2020

Visual cortex

- Orientation selectivity
- Ocular columns: The represention of the eyes alternate at the visual cortex

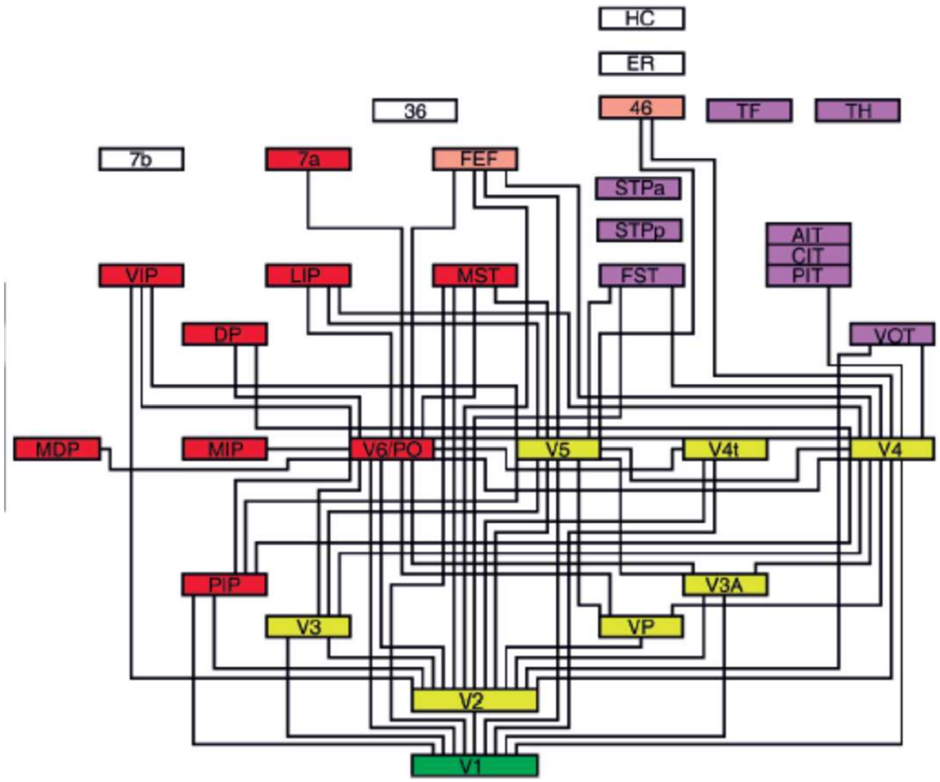




www.cns.nyu.edu/~david/courses/perception/lecturenotes/V1/lgn-V1.html, Ibbotson ja Jung, 2020

Visual system at the cortical level is highly specialized

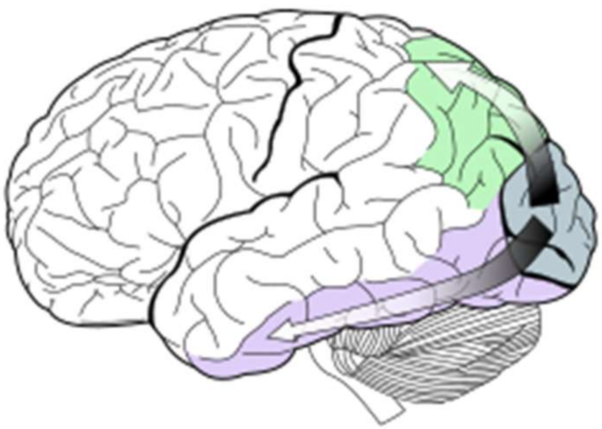
- E.g., in monkeys,10 hierarchical levels suggested

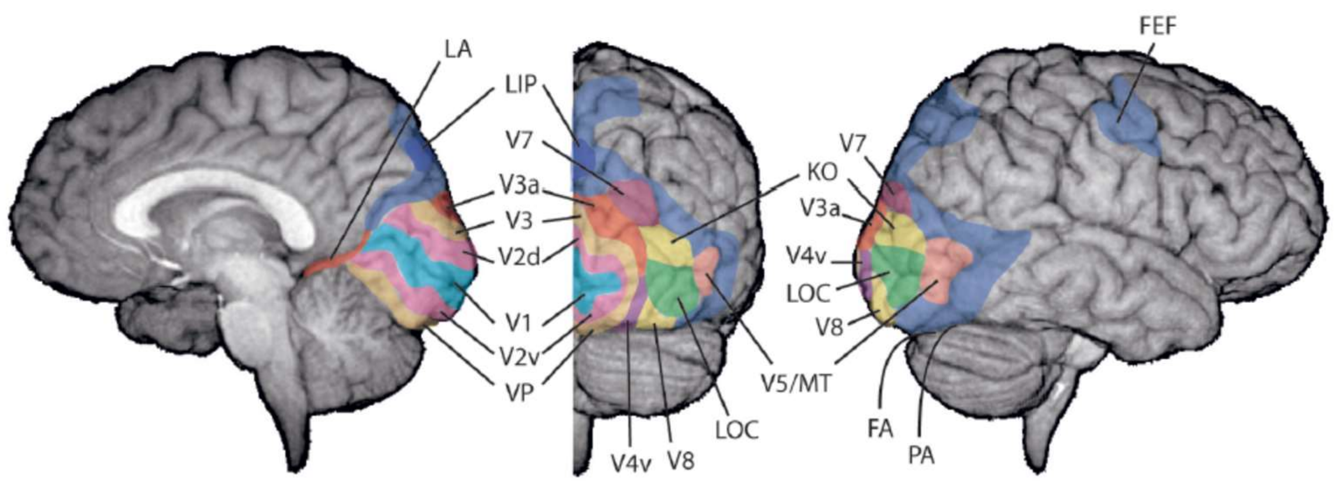


Vanni 2004, modified from Felleman and Van Essen 1991

Visual system at the cortical level is highly specialized

- "What" and "where" streams
- Specialized areas for recognizing colours, motion, faces, etc.

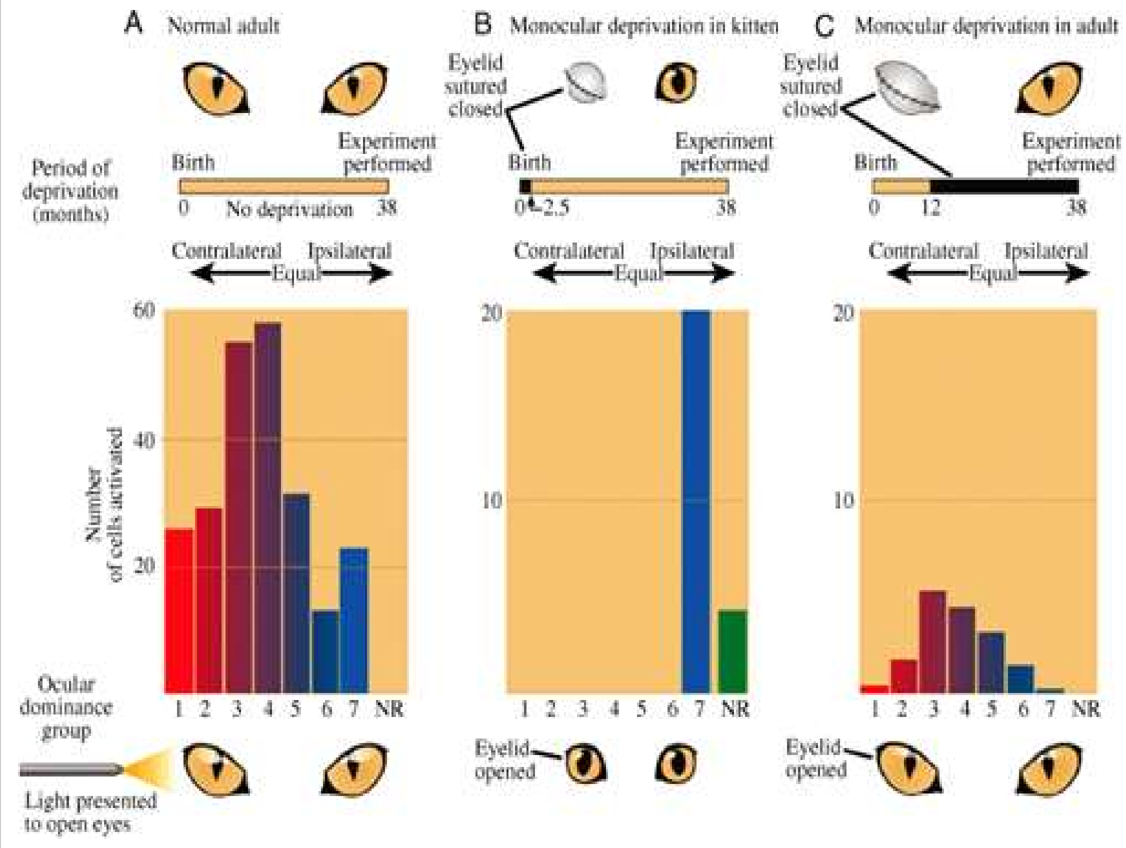




Wikipedia, Vanni 2004

Critical period in development of visual cortex

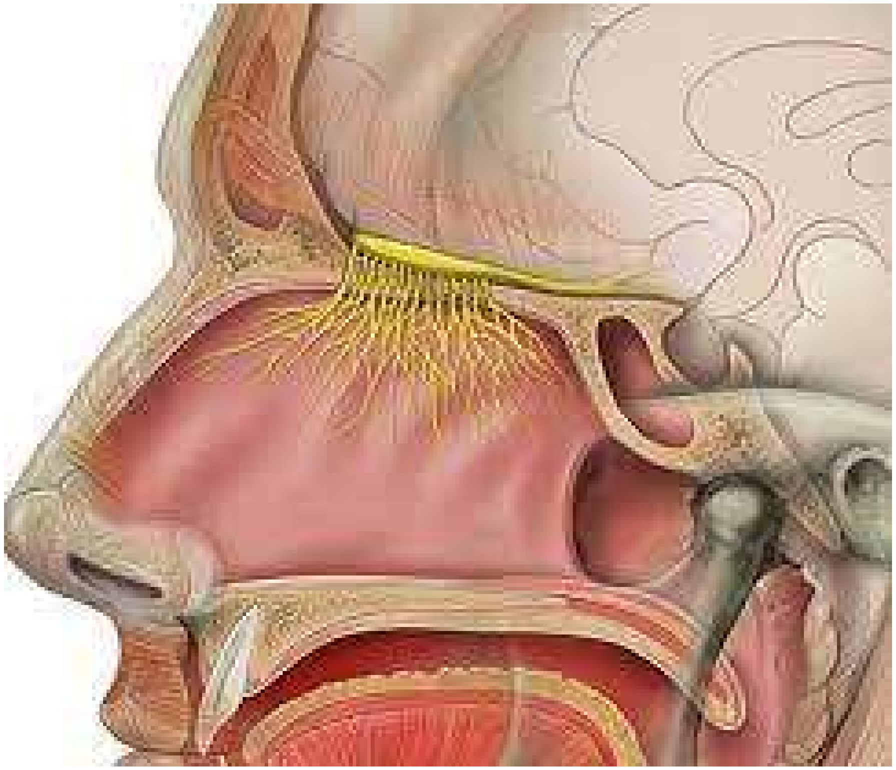
- Wiesel ja Hubel, Nobel price 1981
- Strabismus treatment with occlusion therapy as a child



Purves ym. 2008

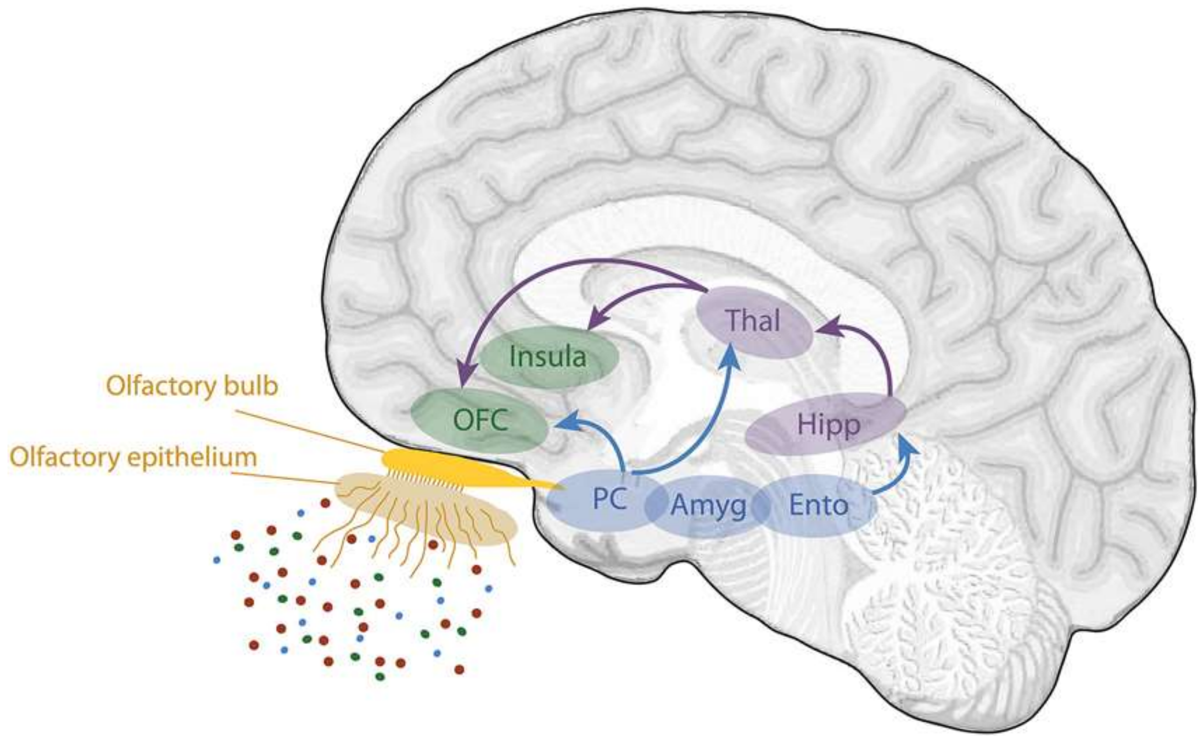
Smell

- Dendrites of the nerve cells as receptors
- Pass through the cribriform foramina and terminate at olfactory bulbs
- Very good in humans: even billion different kind of smells can be distinguished (Bushdid et al. 2014)!
- ~ 1000 genes code the olfactory receptors (Buck ja Axel, 1991)



Wikipedia

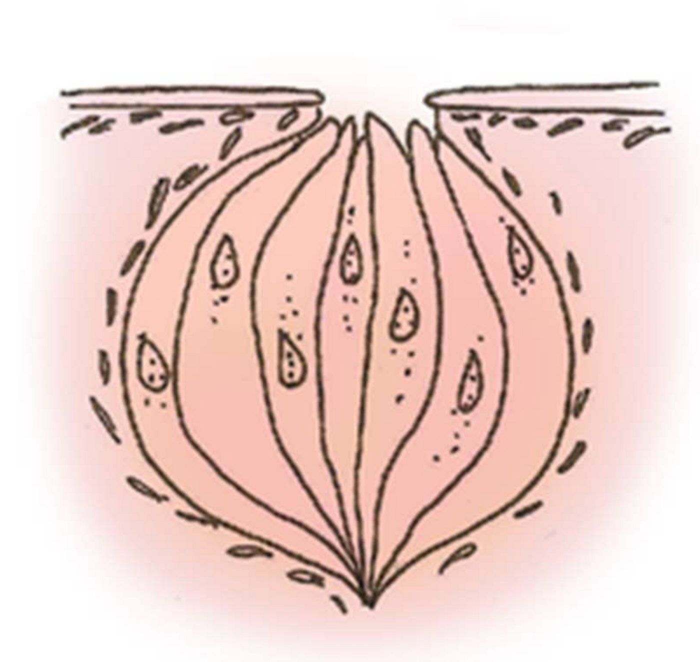
- Information delivered in olfactory nerve directly to the cortex (no route via thalamus)
- Wide anatomical contacts to areas important for memory and emotions
- Rapidly adaptating



Saive ym. 2014

Taste

- Receptor cells in the tongue, oral cavity, walls of the pharynx and larynx
- Sweetness, sourness, saltiness, bitterness, savoriness
- Tastebuds contain 50-100 receptor cells which renew continuously
- Substances soluble in saliva react with the receptor cells → VII, IX, X cranial nerves
- Cortical representations at the somatosensory cortex



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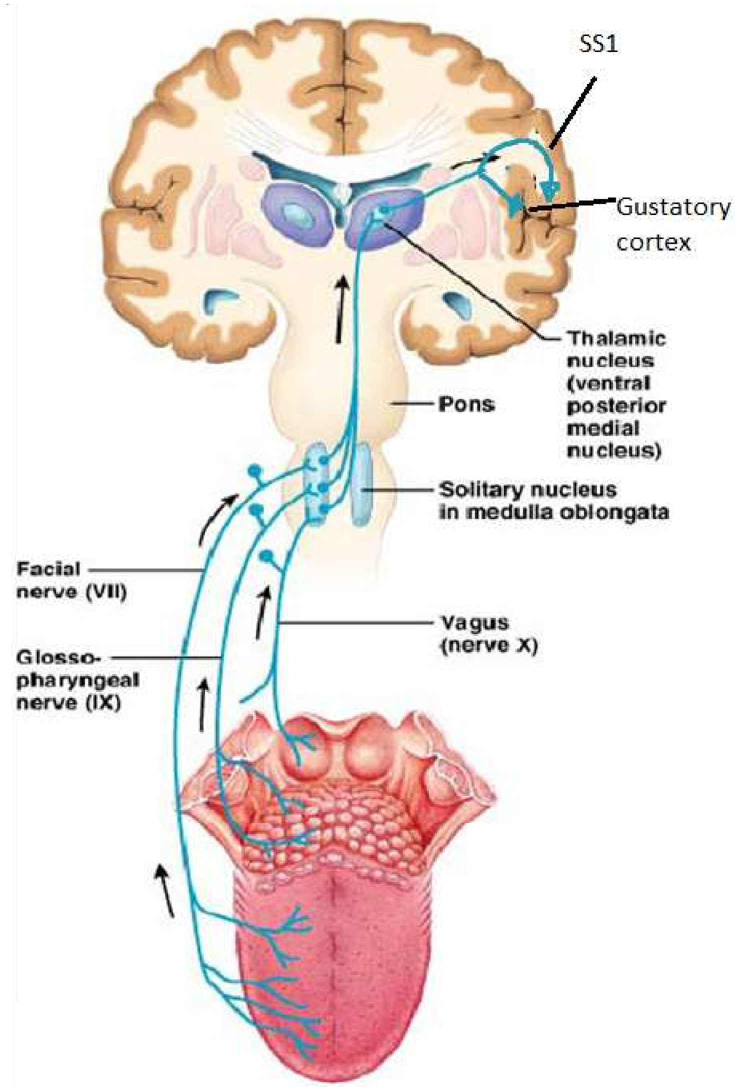

https://brain-for-ai.fandom.com/wiki/Gustatory_pathway