Sensory Systems and Perception: Audition, Somatosensation

Week 7

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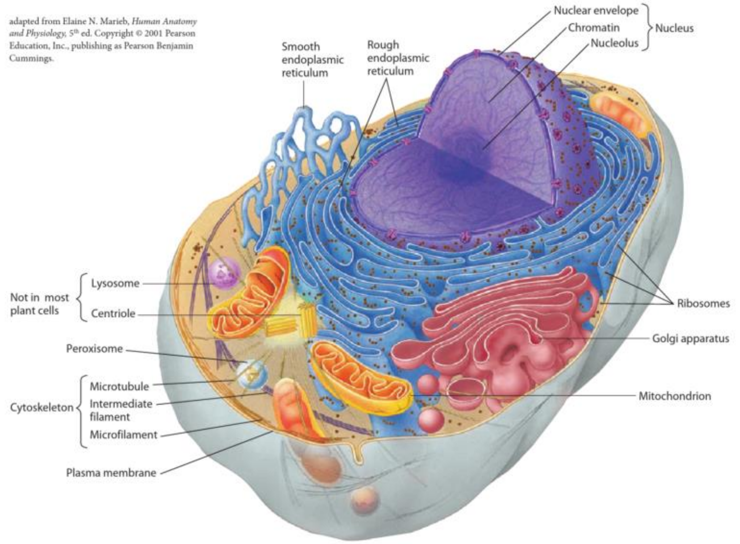
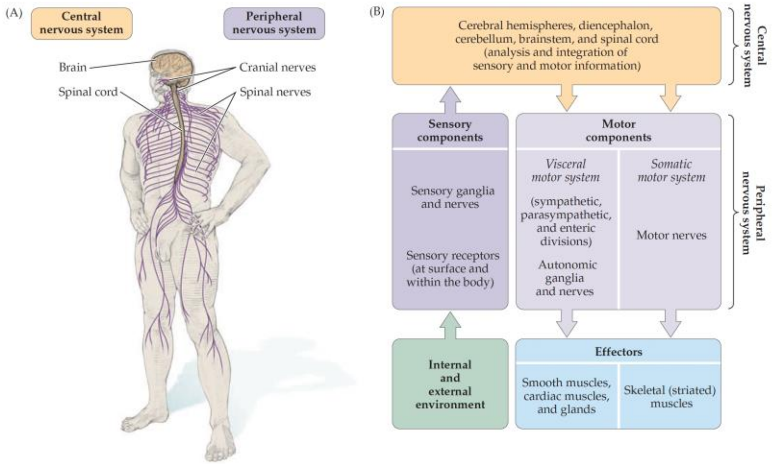
Slide credit: adapted from
EPFL BIO-311 (P. Ramdya)

feedback

Thank you to those who provided feedback on the course!

- Expectations / what will be on exam / what to learn
    - Mostly understanding. See questions
    - But we also think you should have a core vocabulary to be able to interact with biologists
    - For exam: you will be able to bring your handwritten notes
- We're skimming over a lot of content
    - Yes, we feel giving you an overview of the study of the brain with some examples is the most effective





Learning Objectives – Week 7

Describe key components of hearing: outer/middle ear, inner ear/cochlea, hair cells, auditory nerve fibers, auditory cortex

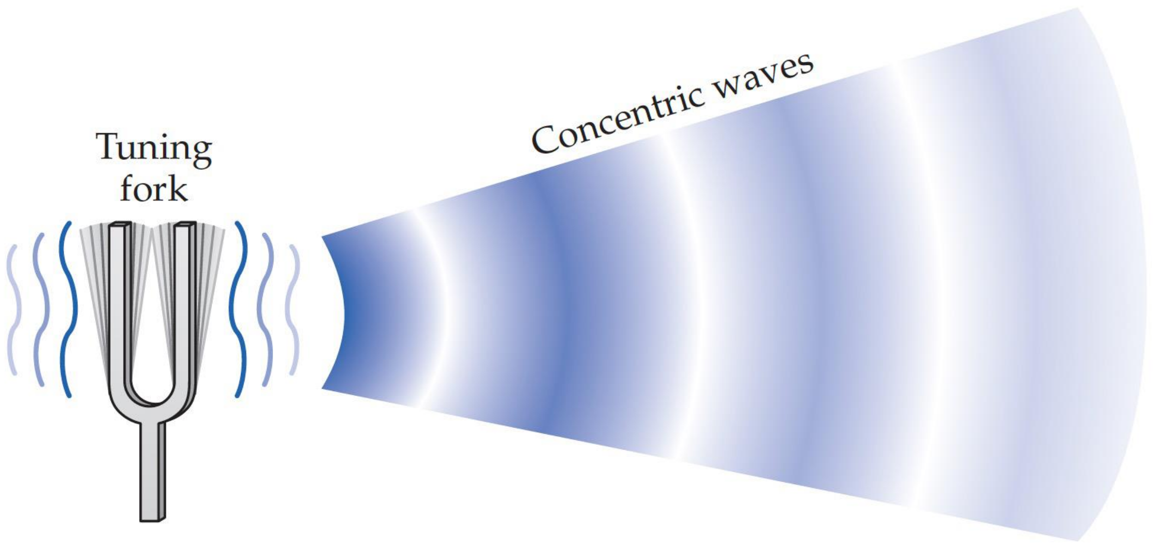
Explain how sound source localization is computed

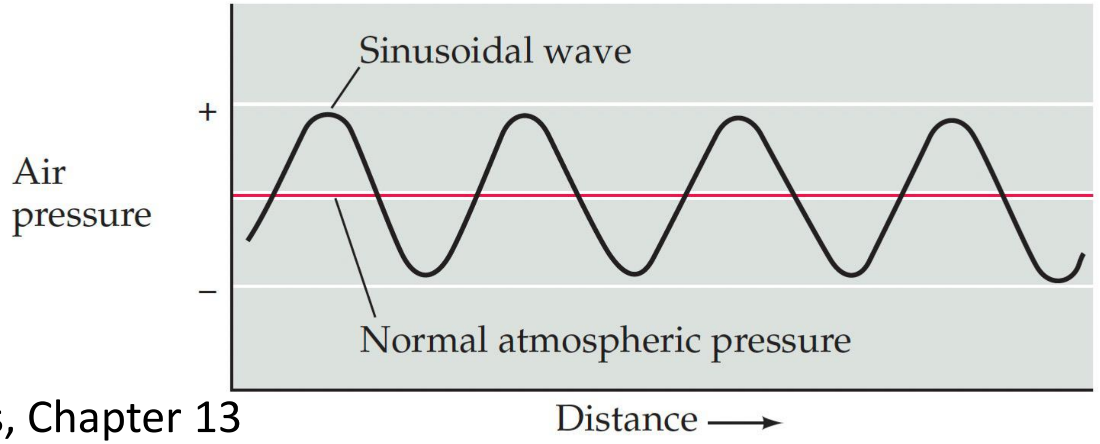
Understand tonotopic and somatopic organization

Explain what the homunculus is

Describe the pathway for mechanosensing

Audition: pure sound





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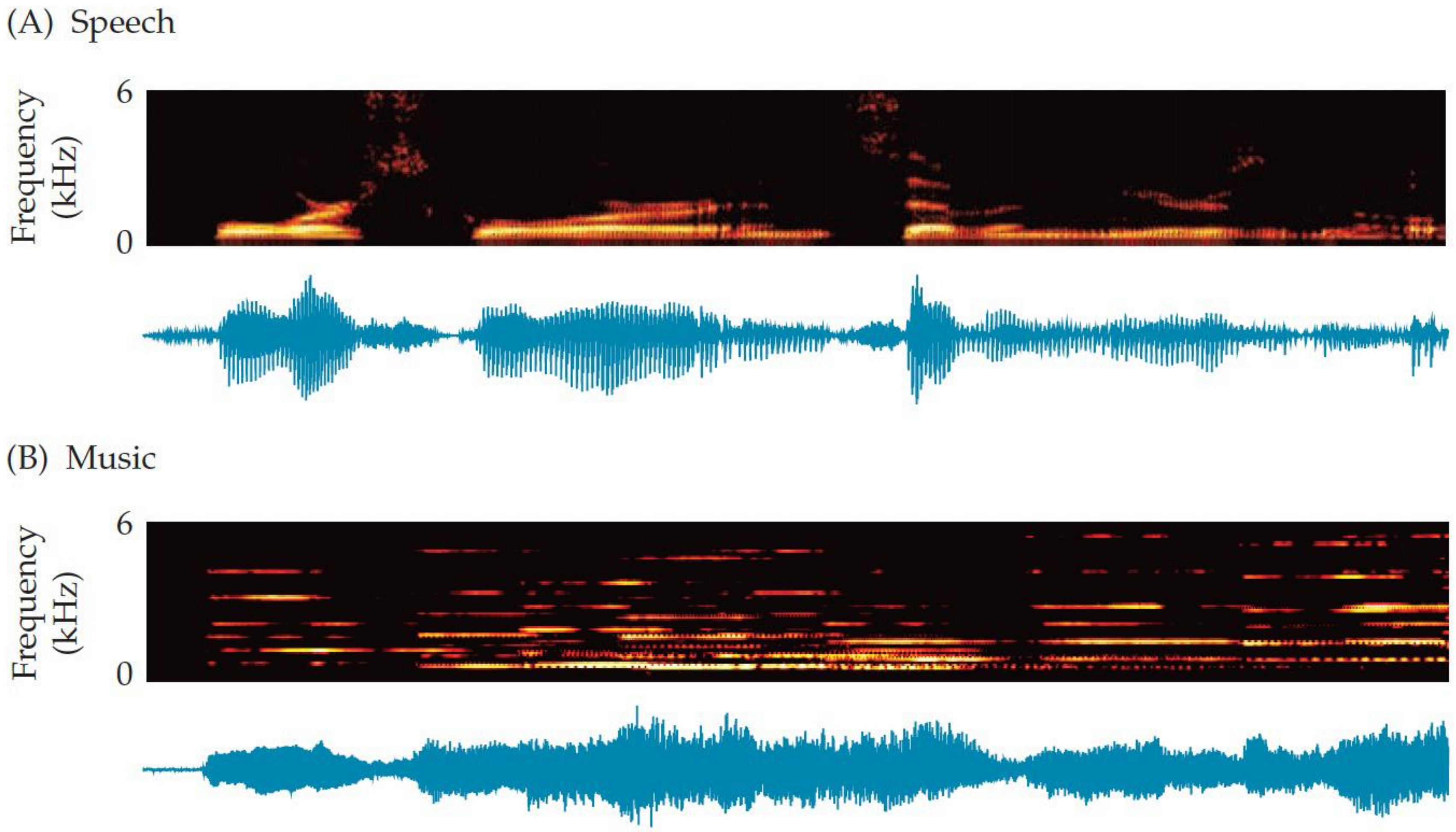
Pure tone = periodic oscillation of air pressure at a single frequency

Characterized by amplitude (dB) and frequency (Hz)

Audition: complex sounds



Complex sounds like speech and music are superimposition of pure sounds

Inner ear **decomposes** these sine waves

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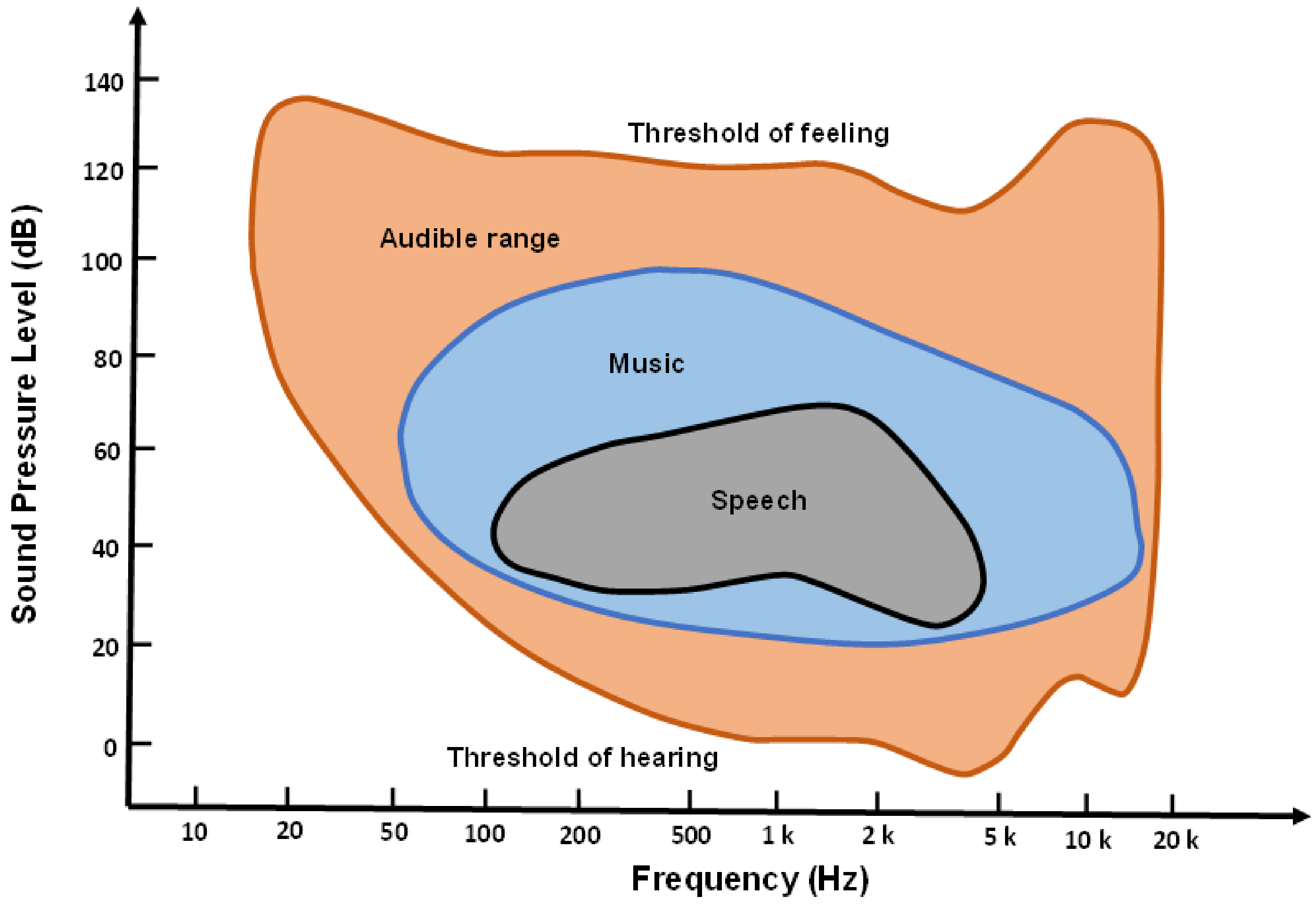
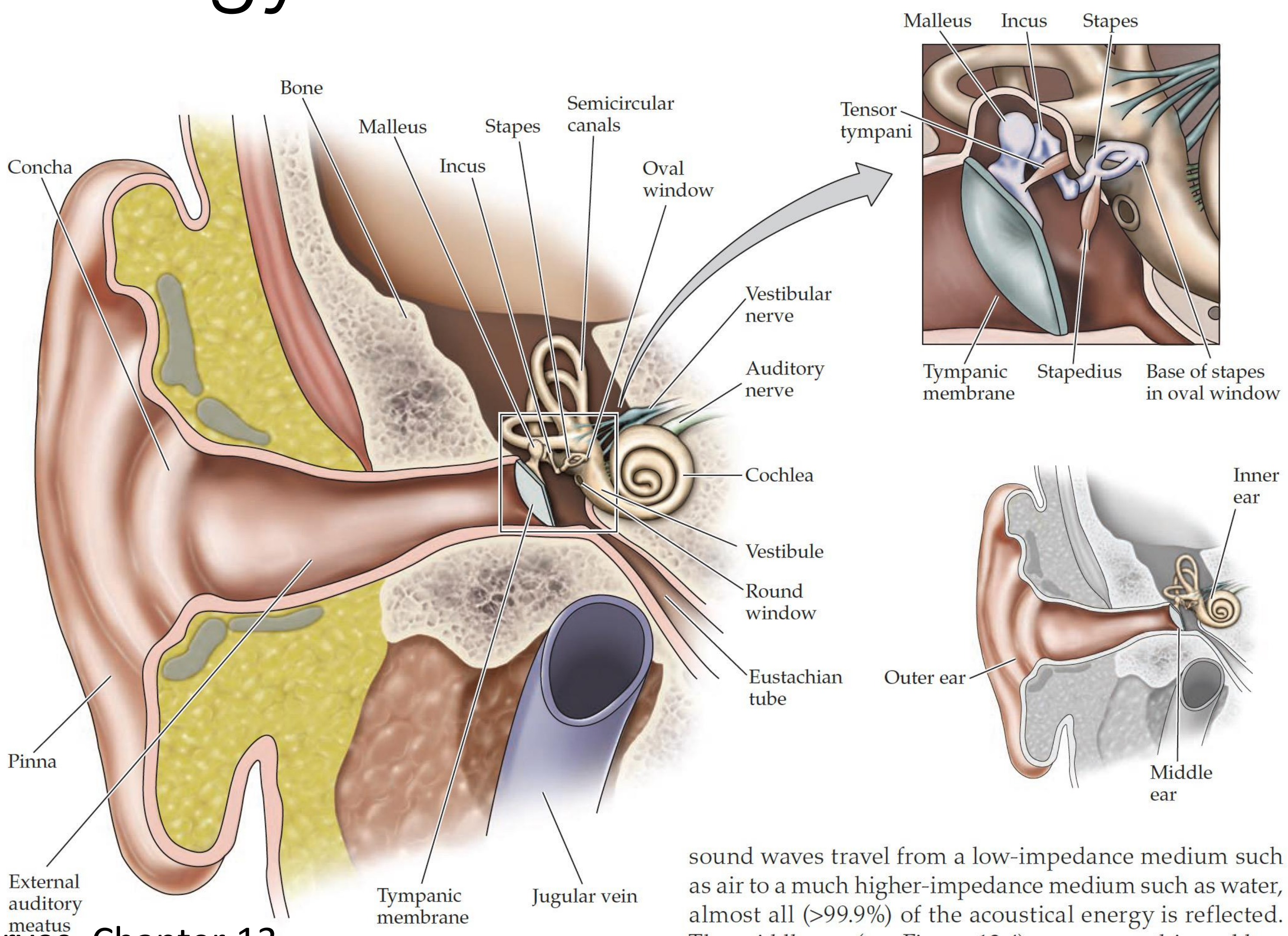
Human hearing range



Human hearing ranges between 20 Hz – 20 kHz

https://www.sound2020.org/sound/audible/

Outer and middle ear transmit sound wave energy to the inner ear



sound waves travel from a low-impedance medium such as air to a much higher-impedance medium such as water, almost all (>99.9%) of the acoustical energy is reflected.

Outer ear: focus sound

Middle ear: boost sound (impedence matching, 200x boost)

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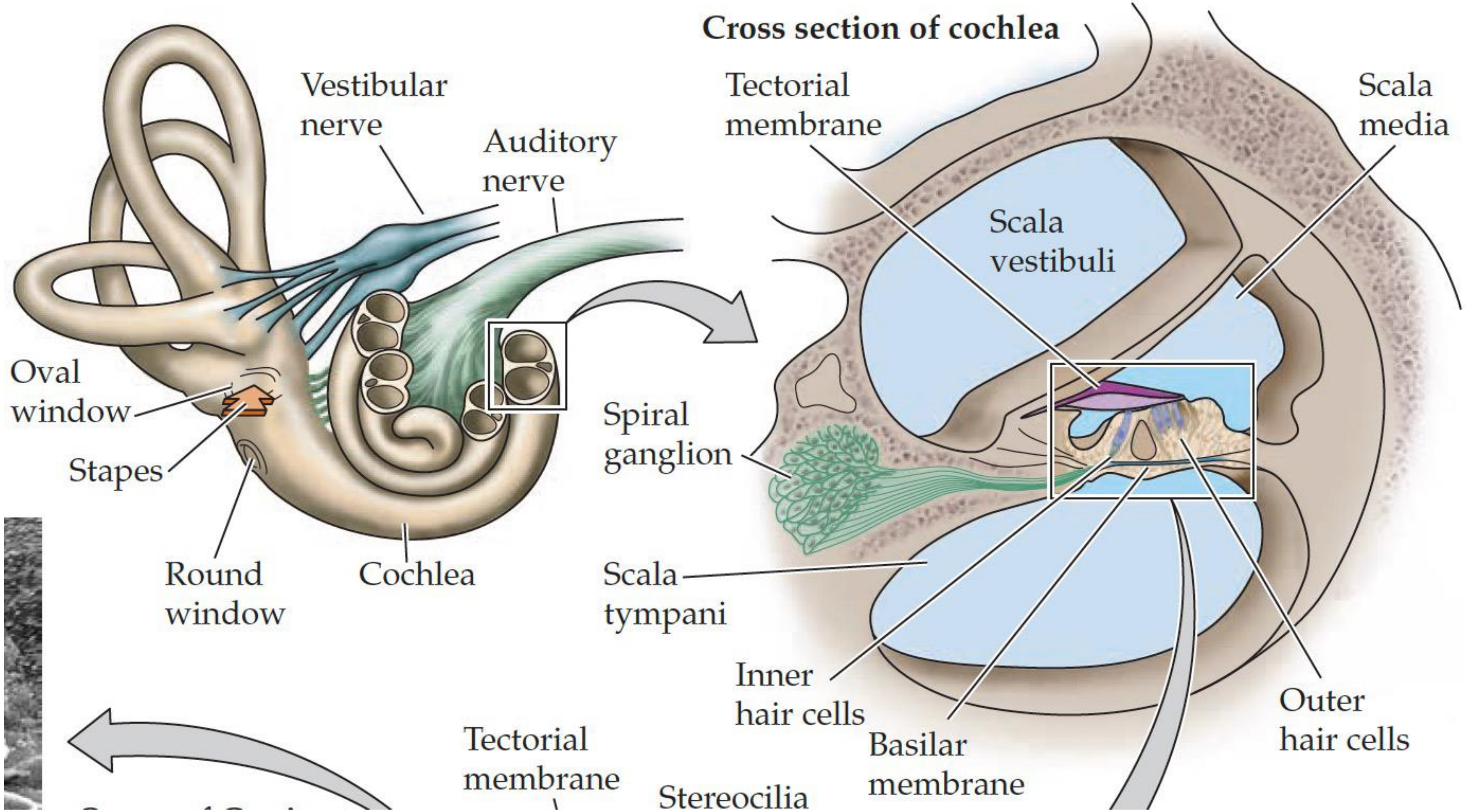
Inner ear cochlea



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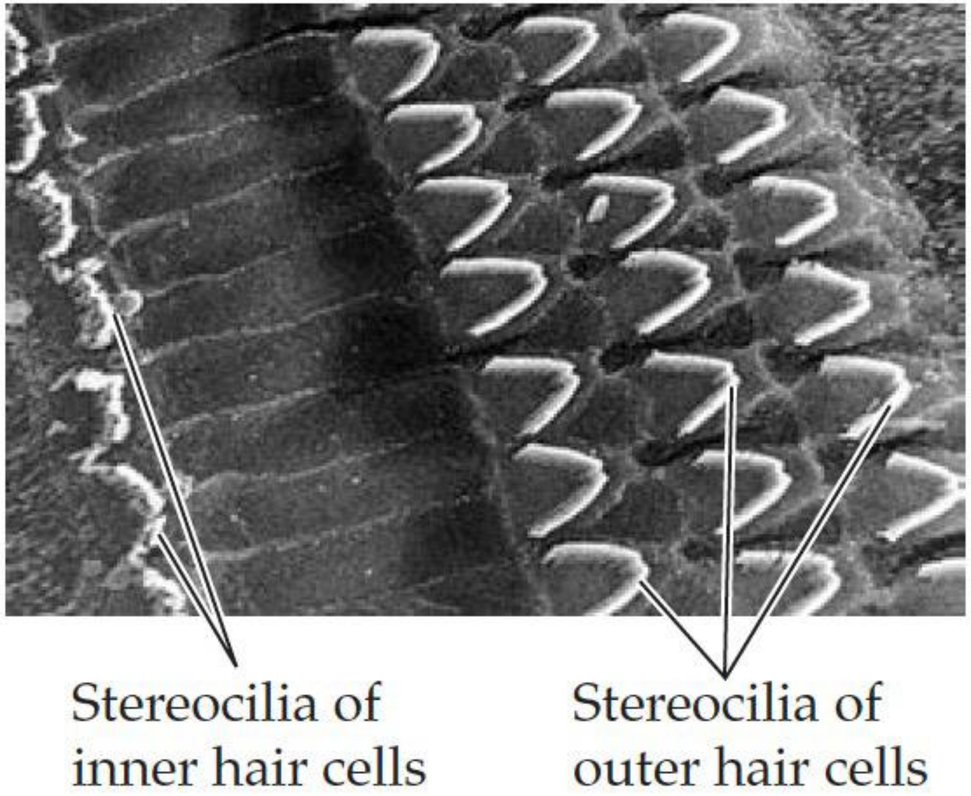
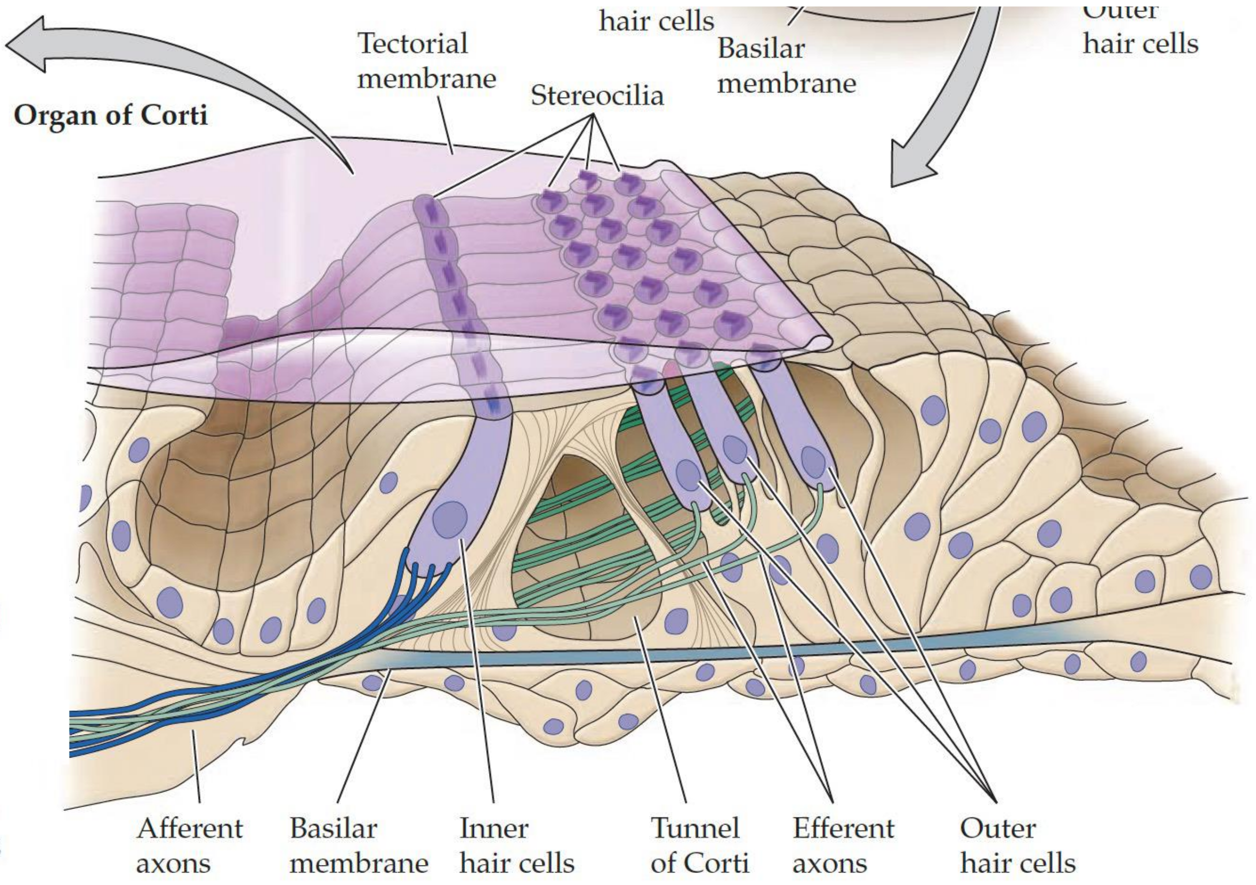
Hair cells





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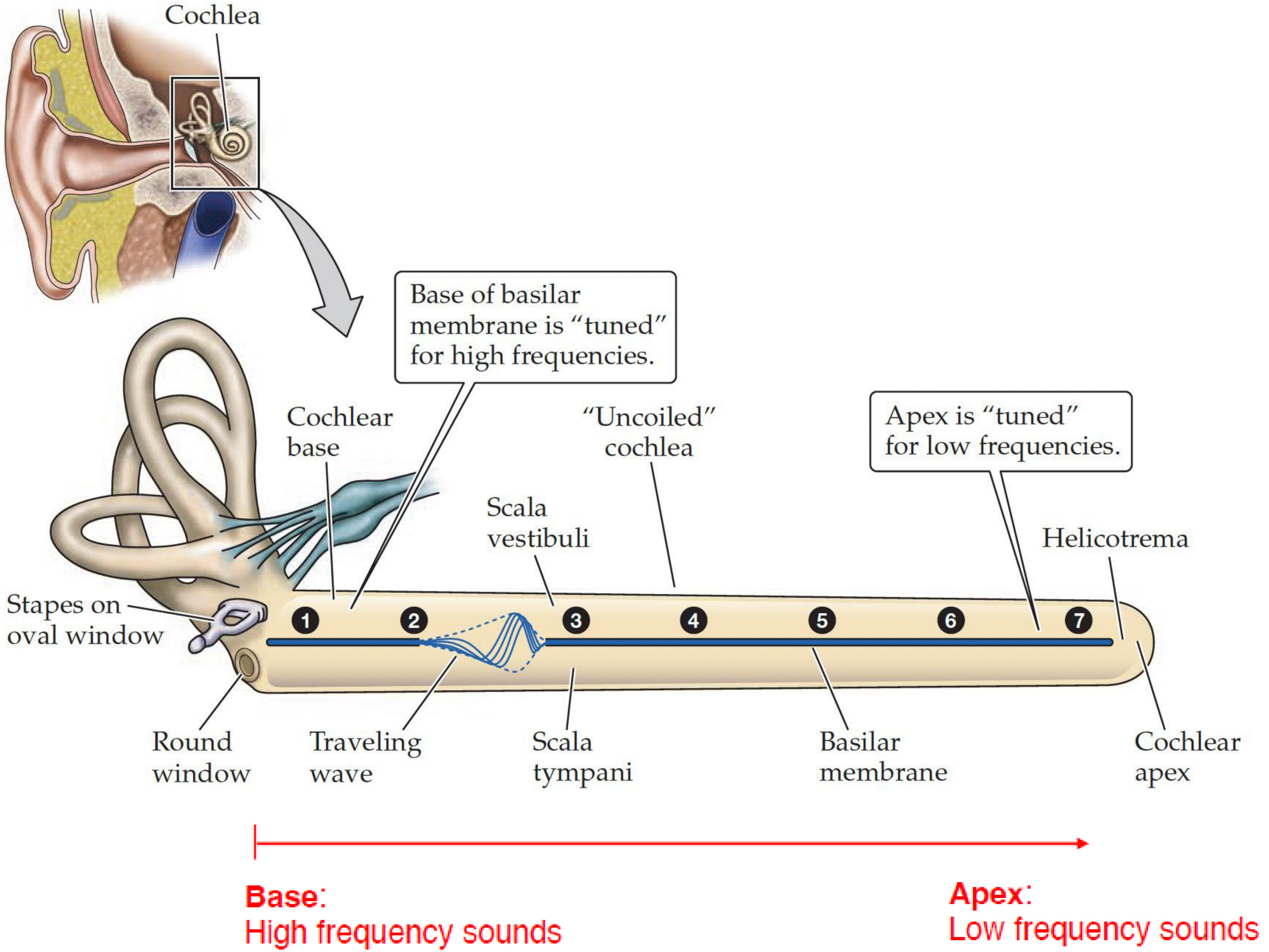
Hair cells respond to sound frequency



Stapes transmits sound vibrations

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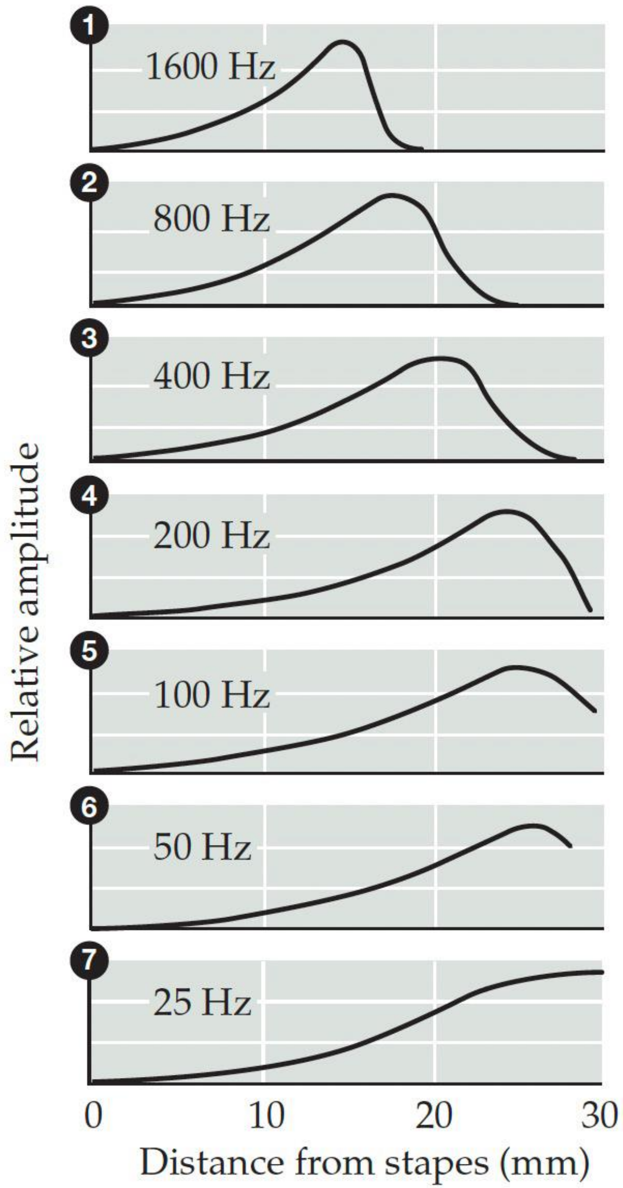
Tonotopy



Location of maximum activity depends on sound frequency and is smooth with increasing distance

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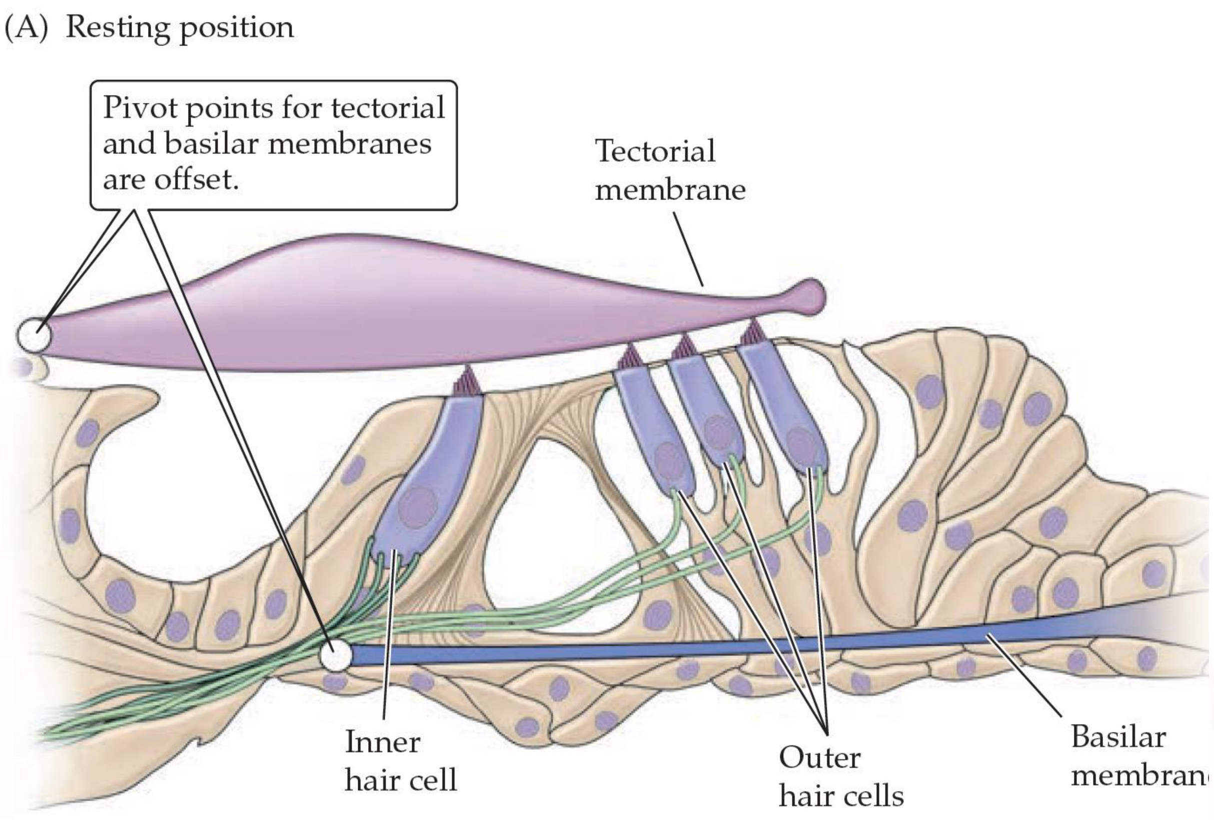
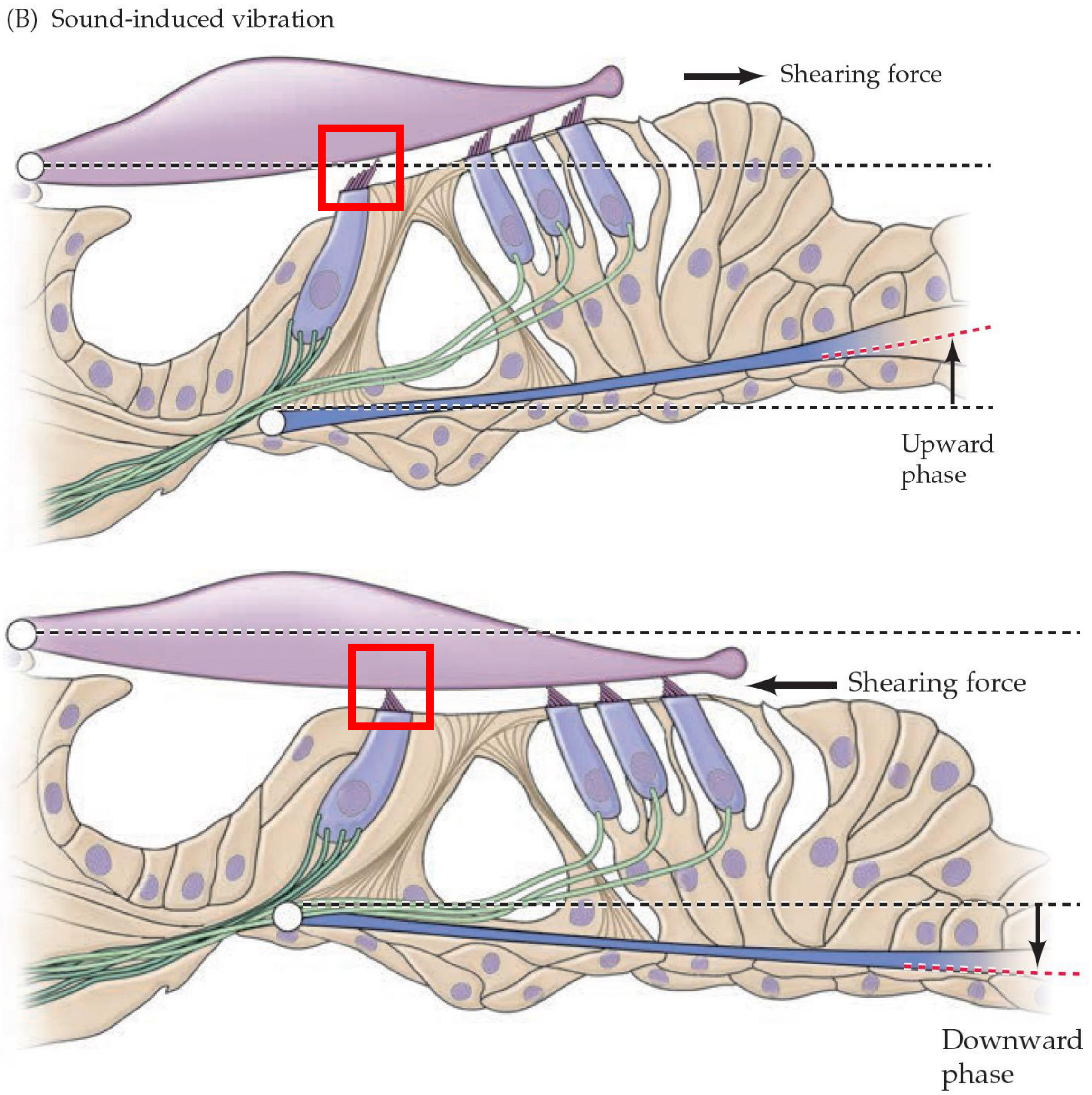
Bending hair cells transform sound waves into electrical potentials





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Primary sensory transduction in inner hair cells

- Depolarization of inner hair cell
- Ca2+ channel opening at base
- Local Ca2+ influx
- Transmitter release at base (Glutamate)

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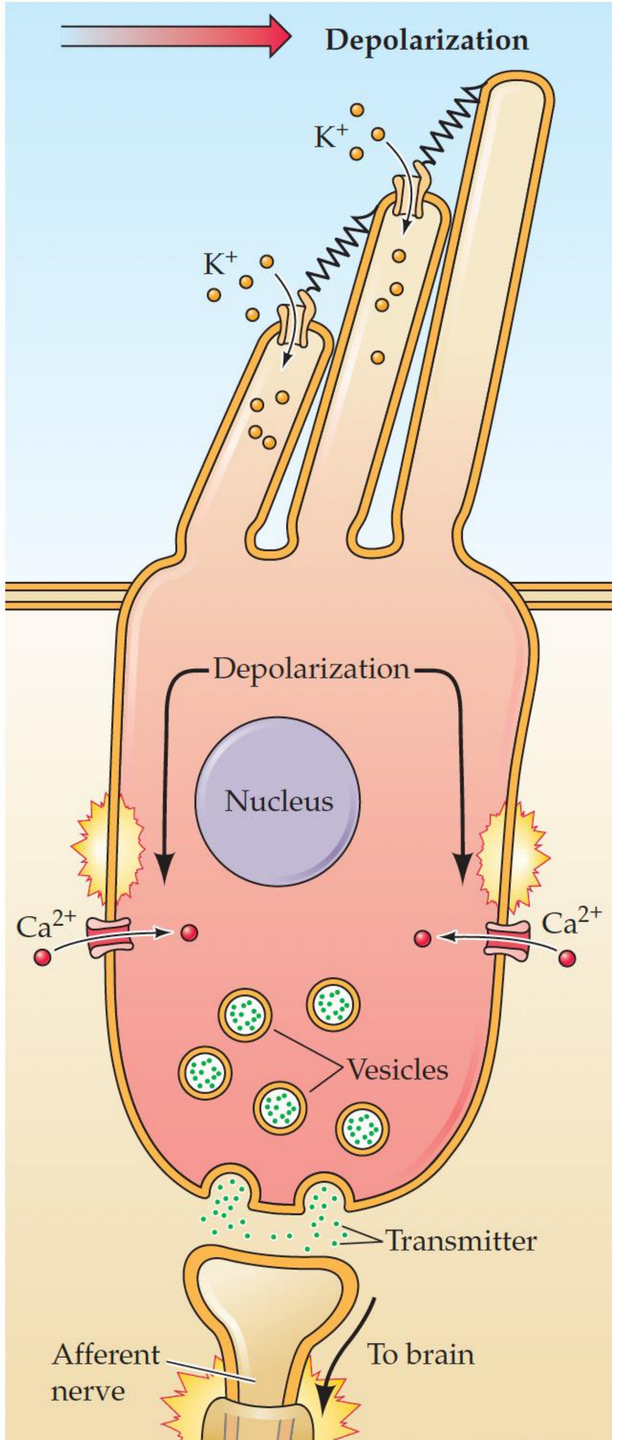
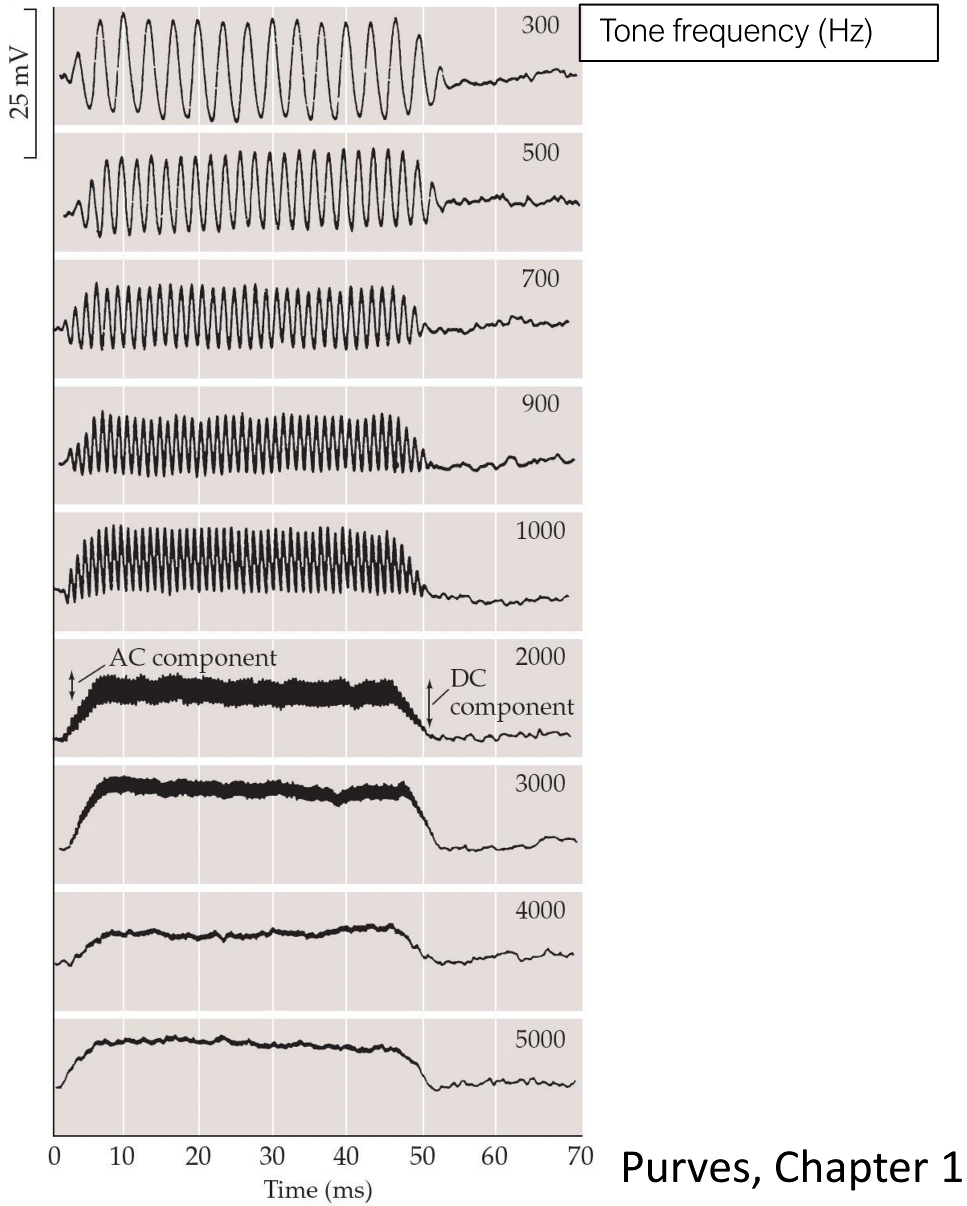


Receptor potentials of an inner hair cell in response to pure tones

- <u>No</u> action potentials
- Phase locking (up to 2 kHz)
- Sounds above 2 kHz: frequency only encoded by tonotopy



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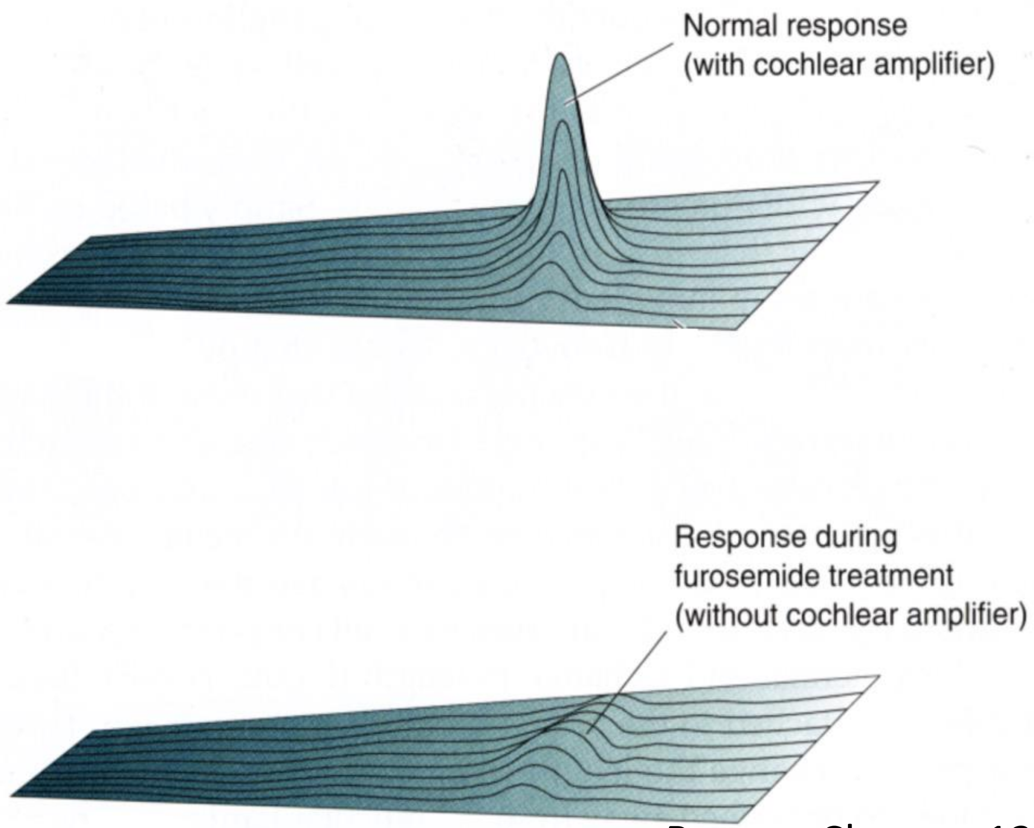
Outer hair cells

- Function as cochlear amplifiers
- Possible cause of tinnitus



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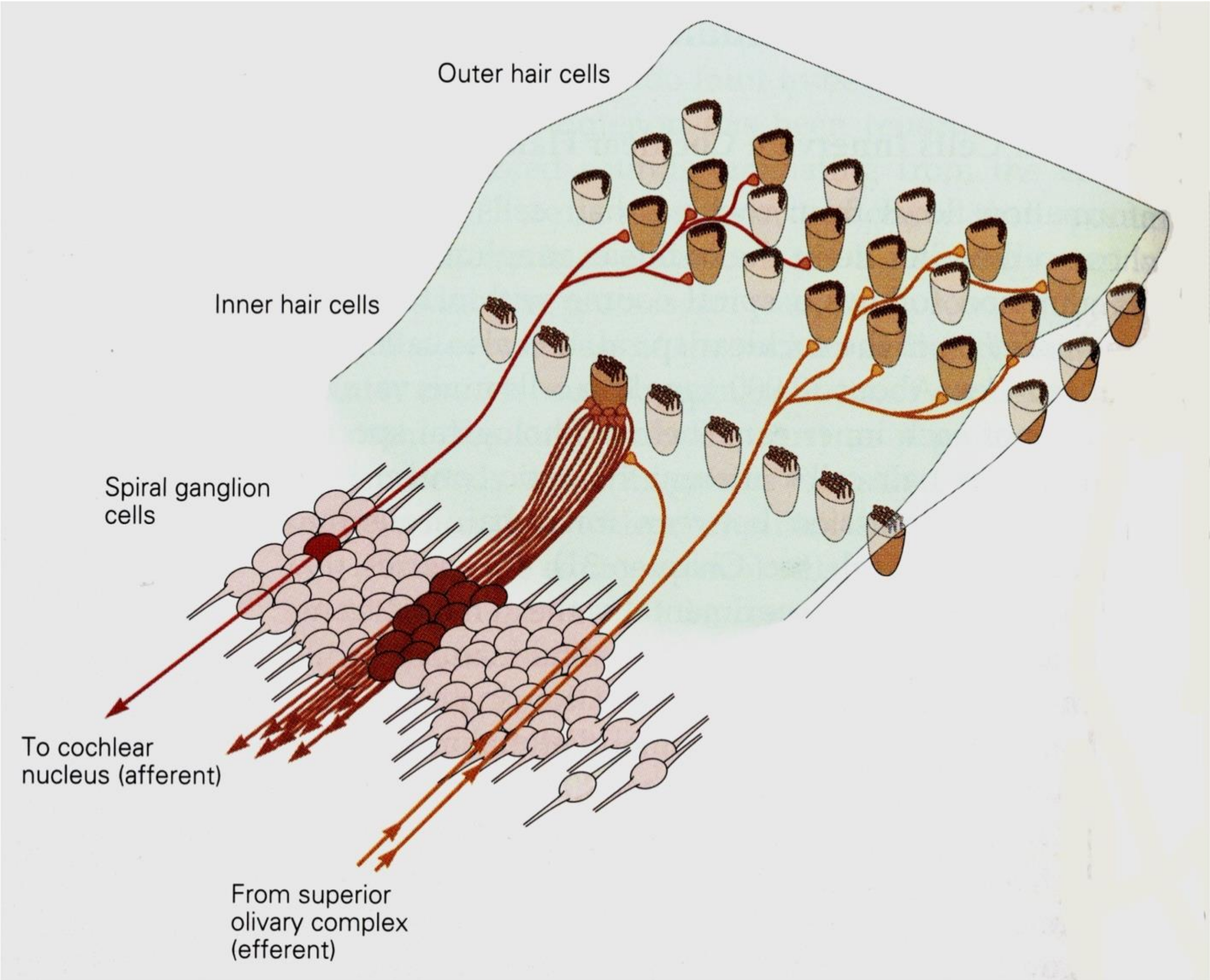
Auditory nerve fiber synapse: connect inner hair cells to central nervous system



Inner hair cells

Innervated by (connects to) 8-10 afferent nerve fibers (from ear to brain)

Outer hair cells

Innervated by efferent fibers (signals from brain to ear, feedback)

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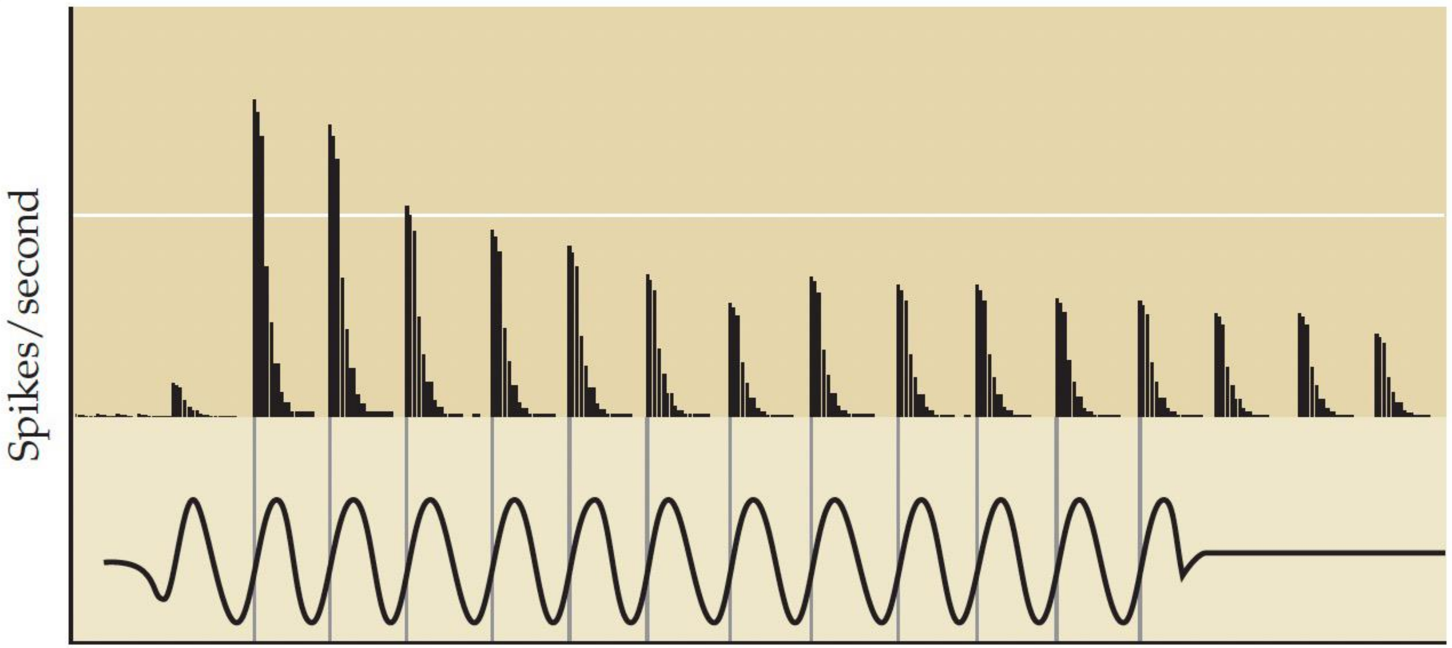
Auditory nerve fibers

Action potentials in low-frequency auditory nerve fiber are *phase locked*



260 Hz Tone, 50 ms duration

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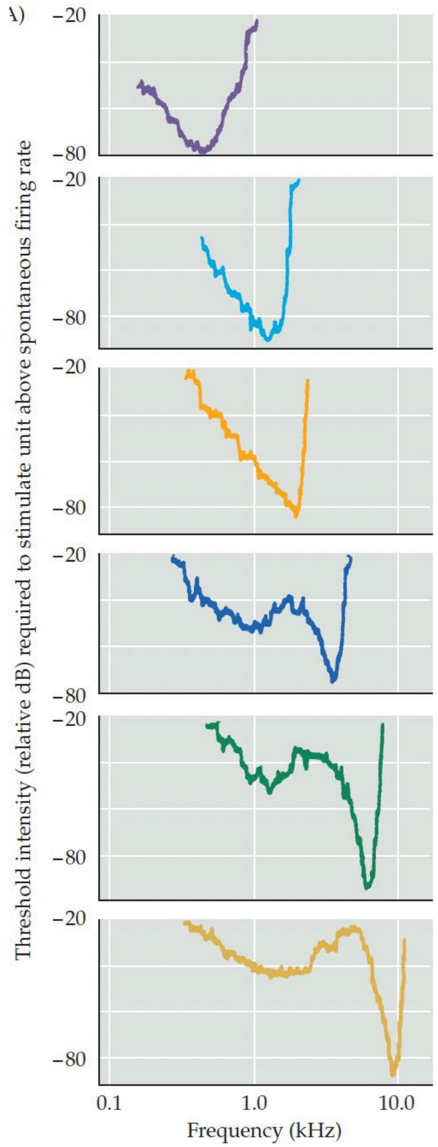
Frequency tuning curves of auditory fibers

Each fiber has characteristic sound frequency at which it fires with a minimal threshold

→ weakest sound intensity to which neurons responds



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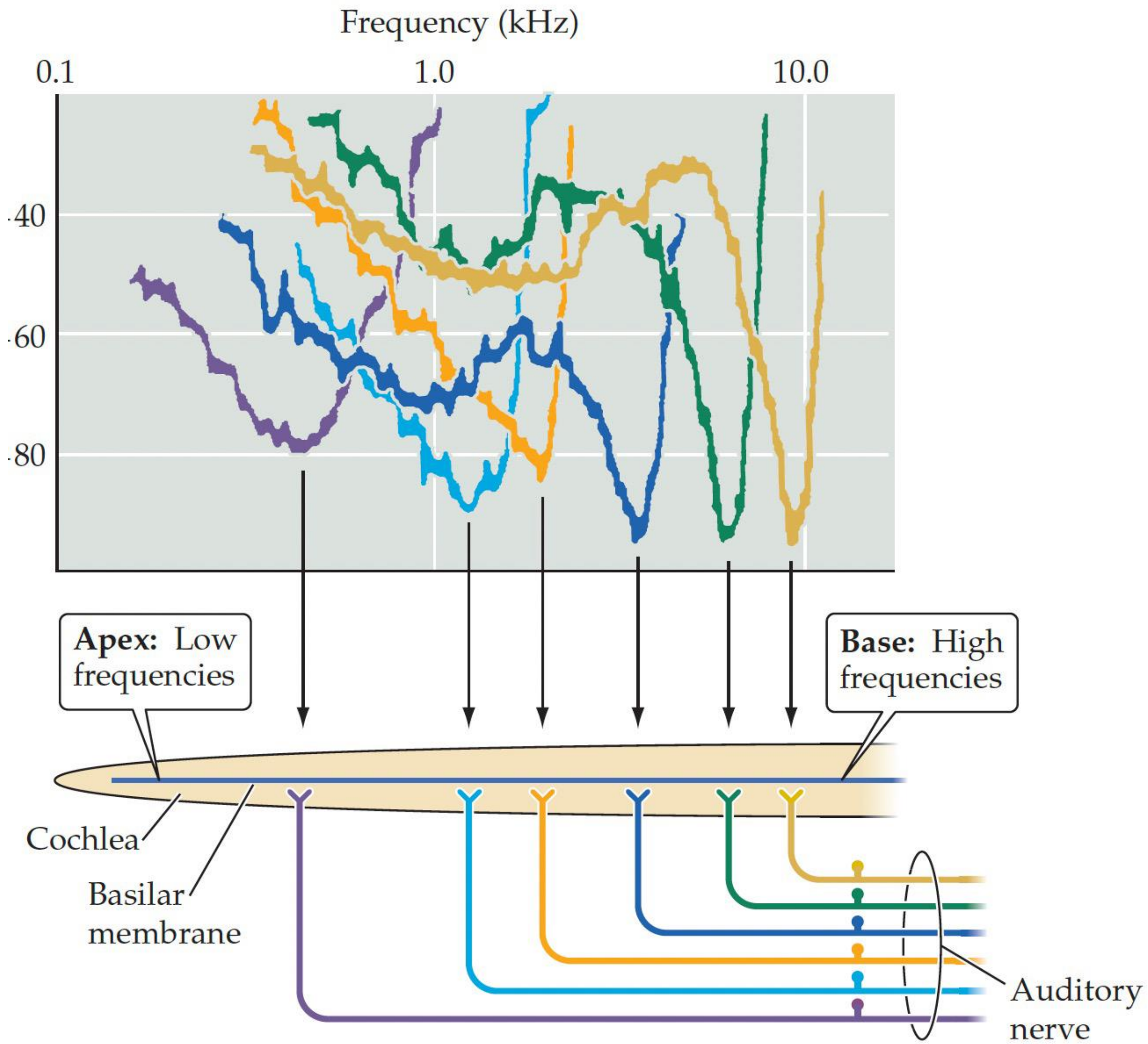
Tonotopy: tuning of auditory nerve fibers depends on location along cochlea



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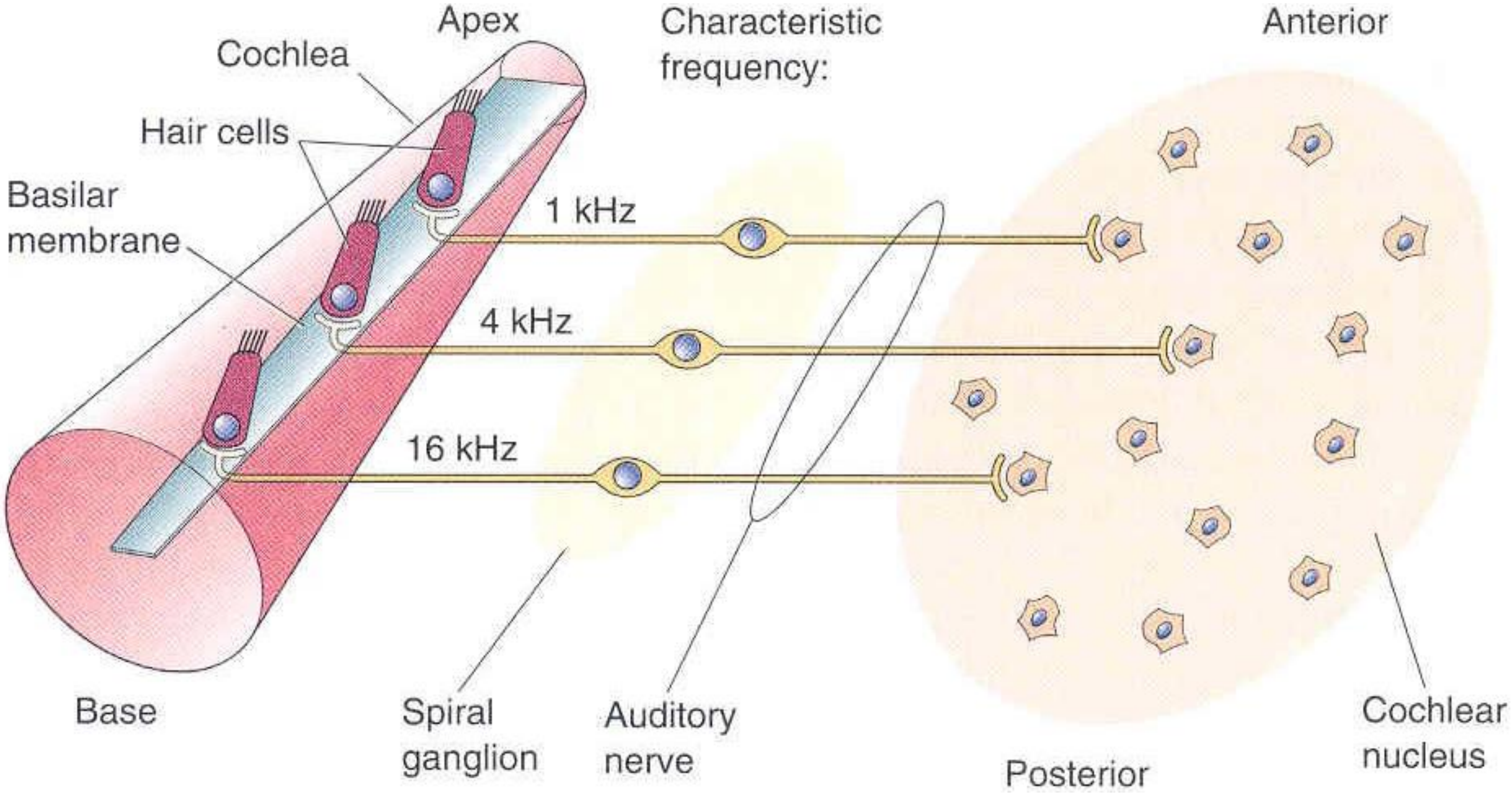
Tonotopic representation of sound frequency in cochlea, spiral ganglion and cochlear nucleus



Tonotopic map is carried through to cochlear nucleus and up to primary auditory cortex A1

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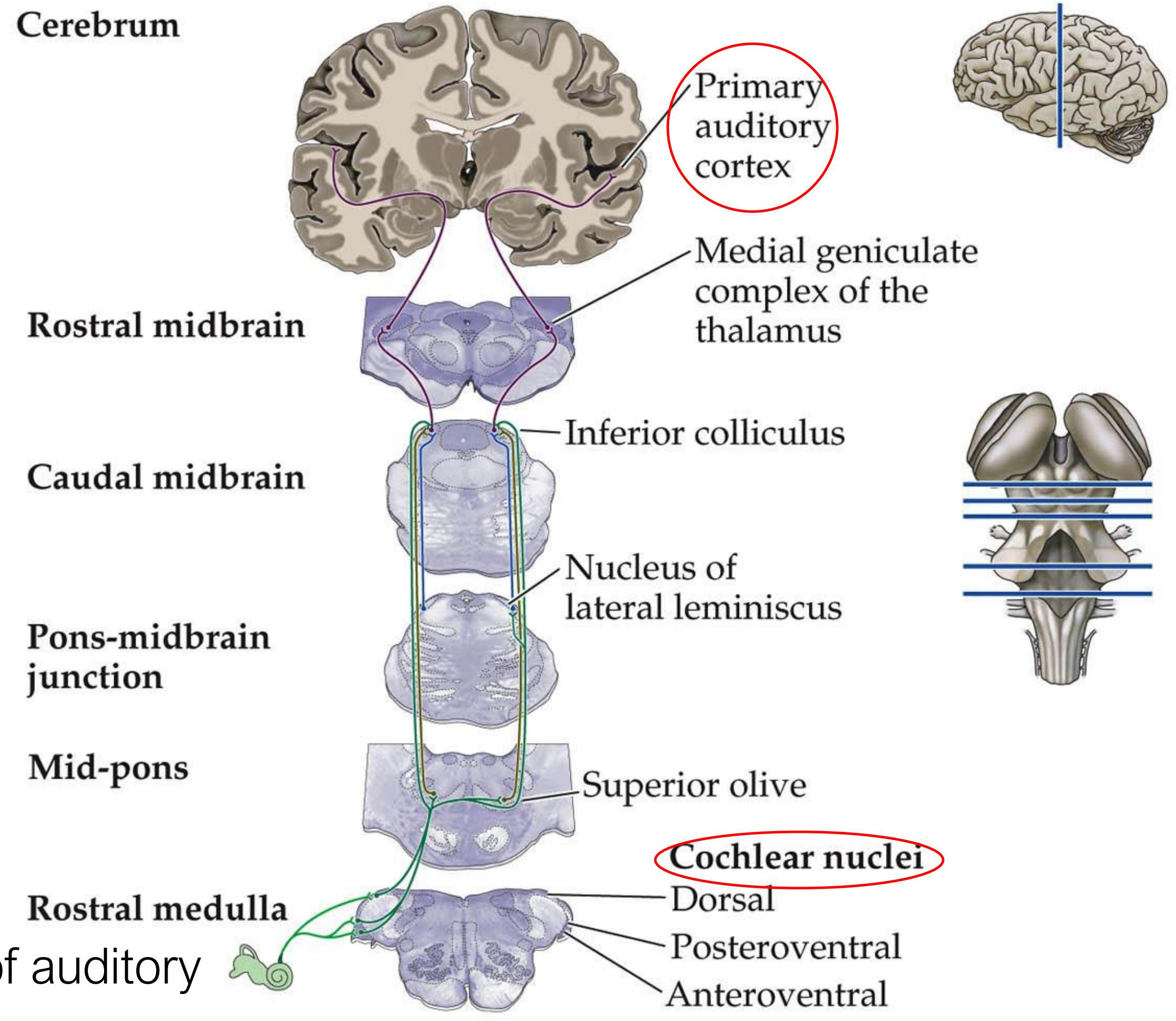
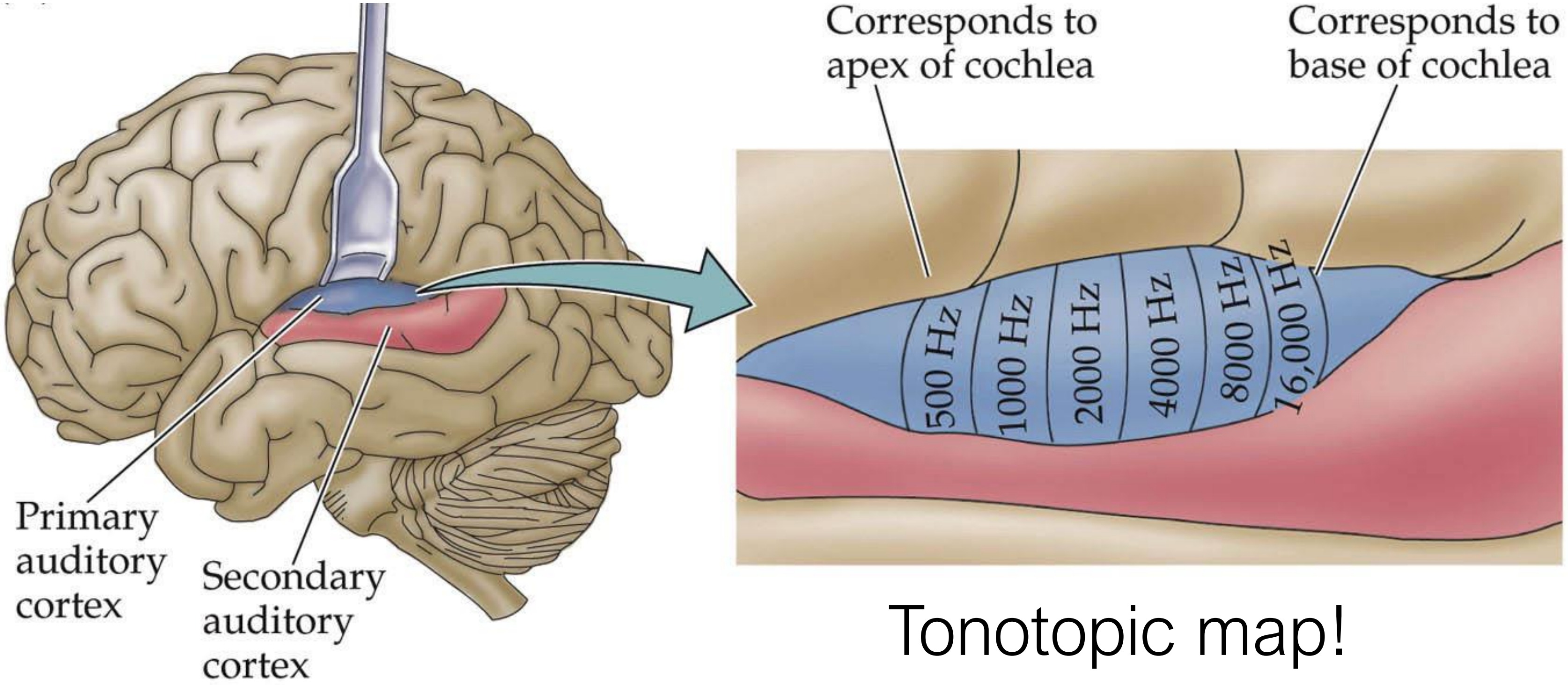
Auditory nuclei and pathways



Projection of auditory nerve fibers

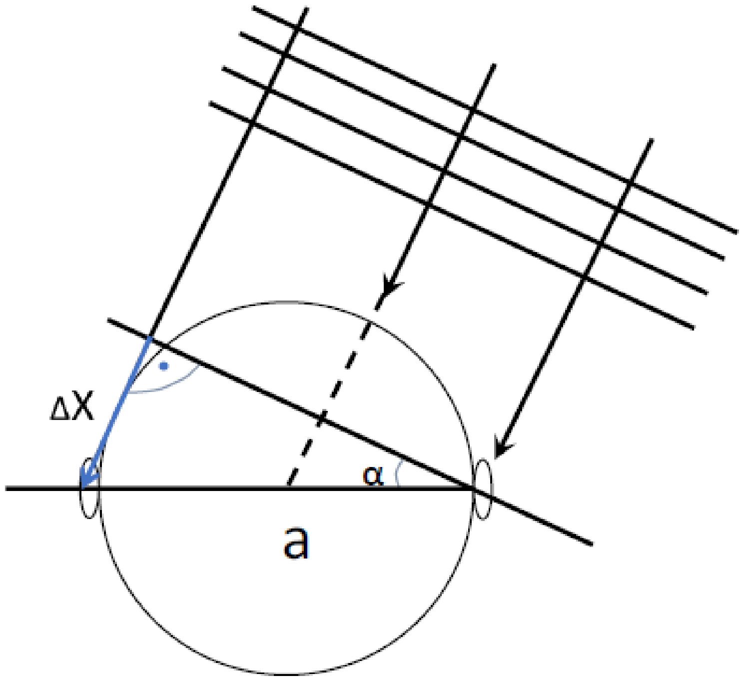
NEUROSCIENCE, Third Edition, Figure 12.12 © 2004 Sinauer Associates, Inc.

Human auditory cortex



Tonotopic map!

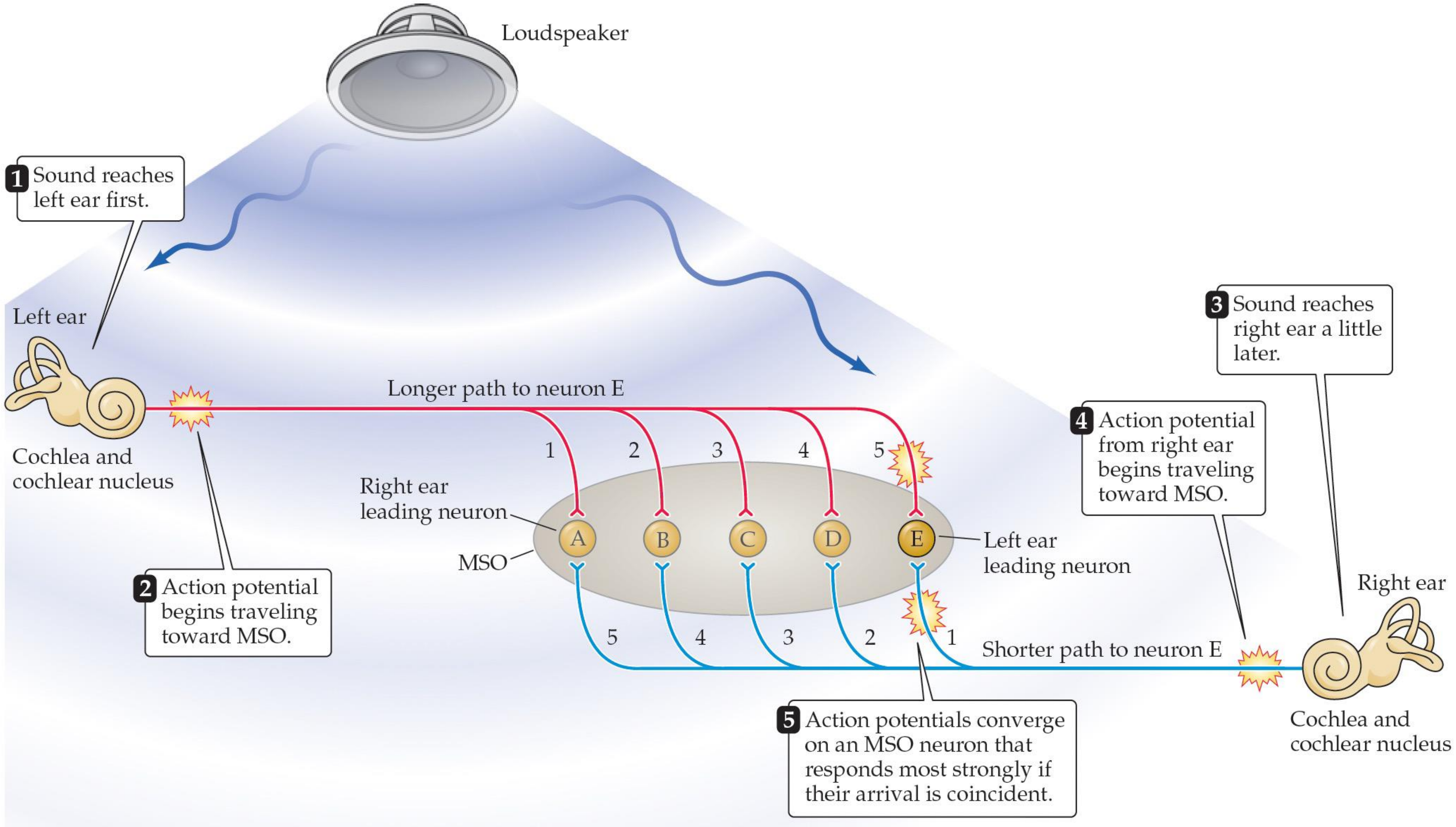
Sound source localization



head diameter: a = 15 cm = 150 mm
speed of sound: c = 340 m/s (= 340 mm/ms)
$\Delta X = a * sin\alpha$ = 150 mm * $sin\ 10^o$ = 26 mm
$\Delta t = \Delta X / c$ = 26 [mm] / 340 [mm/ms] = 0.077 ms

This is calculated as a function of head width and incoming sound angle.
In practice it is well below 1ms (!) even for a large angle of $\alpha = 10^\circ$

Interaural time differences are computed by medial superior olive nucleus



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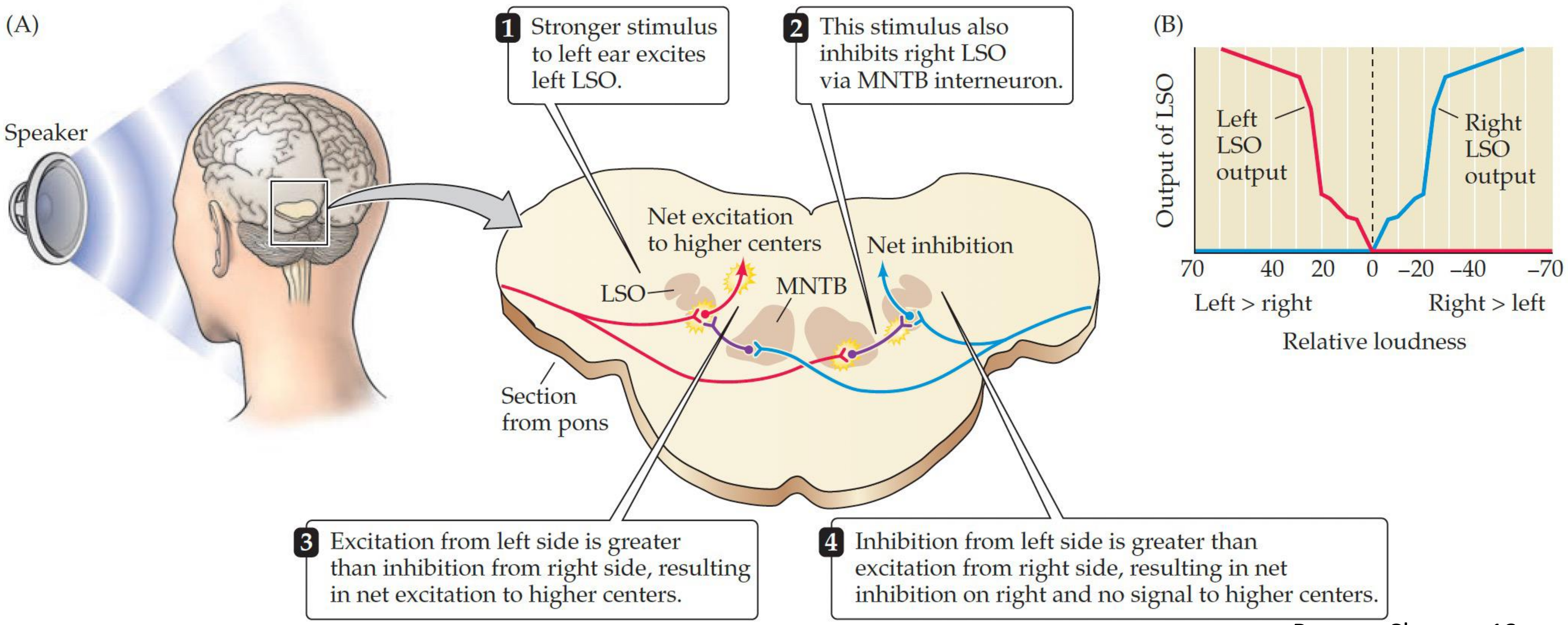
Interaural intensity differences are computed by lateral superior olive



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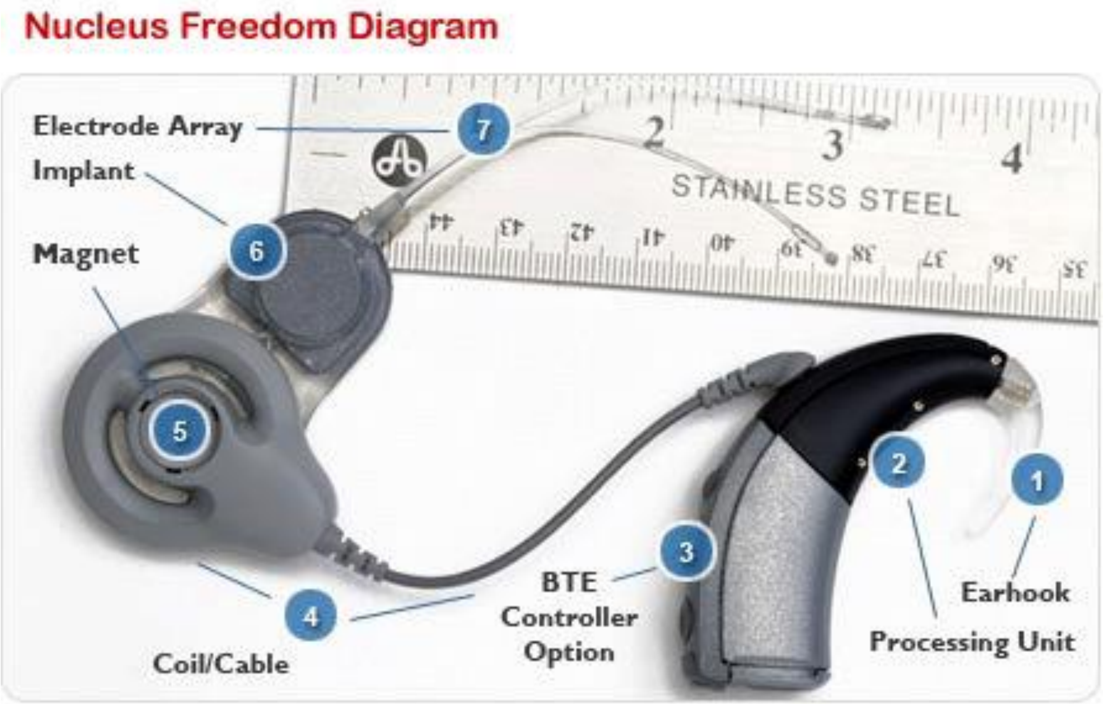
Cochlear implants to treat congenital deafness

- 0.1% of children are born deaf or with severe hearing loss
- Around 400 known syndromes involve severe hearing loss
- Gene mutations can jeopardize hearing mechanism



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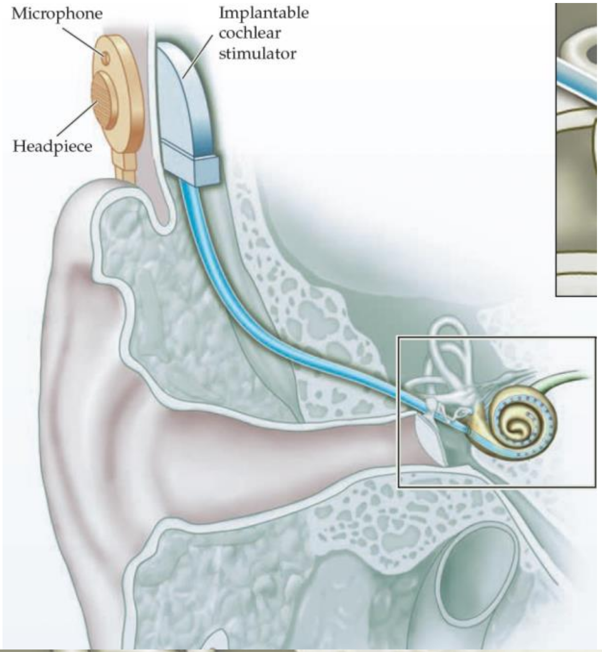

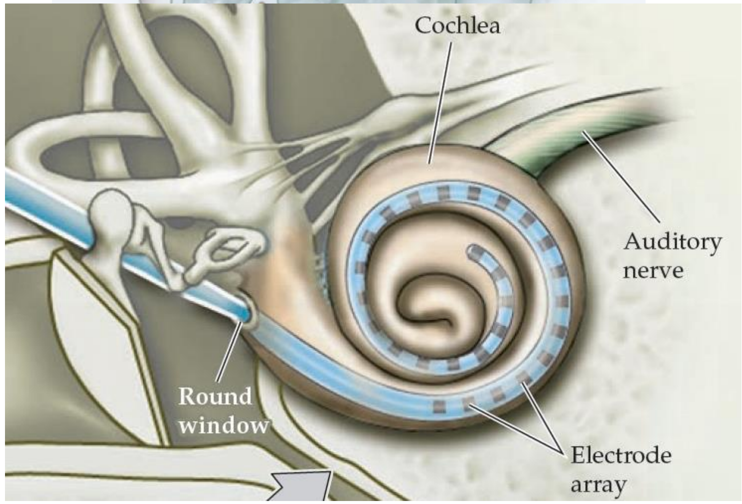

- Series of electrodes that are inserted into the cochlea
- Auditory nerve is electrically stimulated at specific sites depending on sound frequency components (tonotopic organization)
- Can be used as long as the auditory nerve is intact

→ 80% of patients can lead a conversation without lip-reading 6 years after implantation

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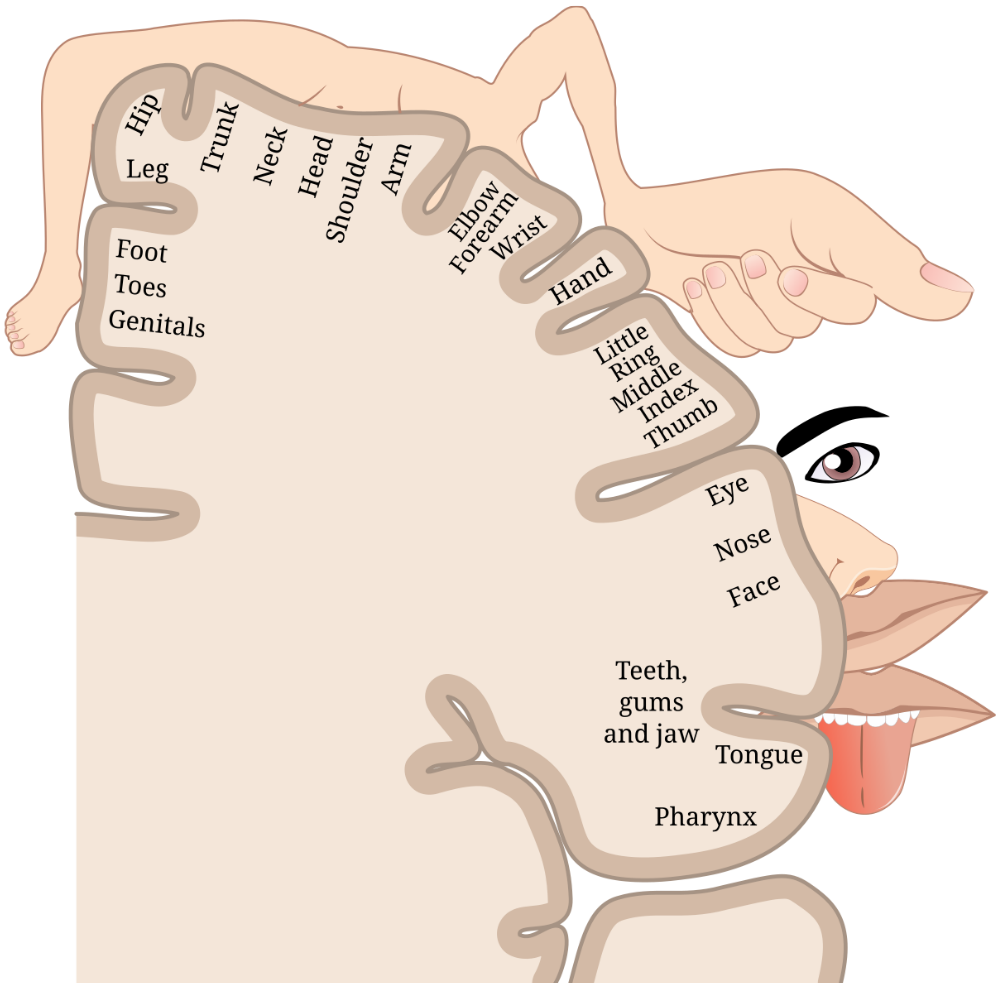
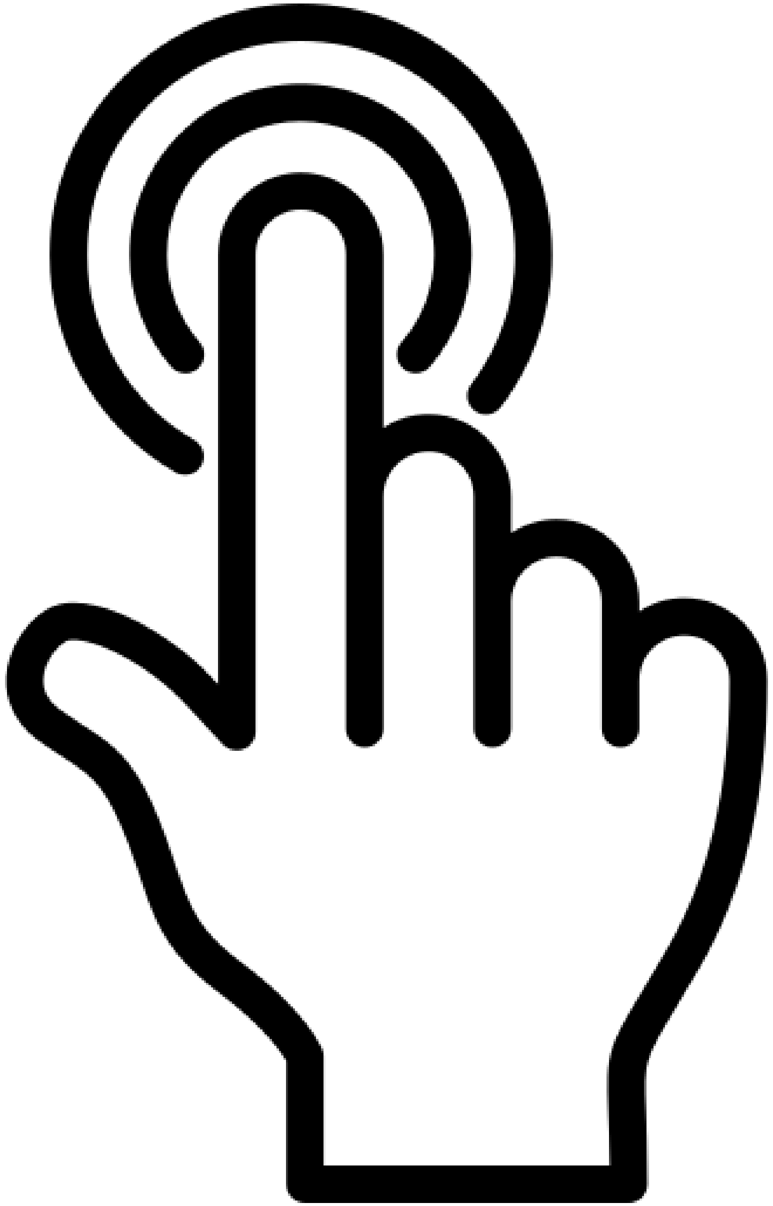
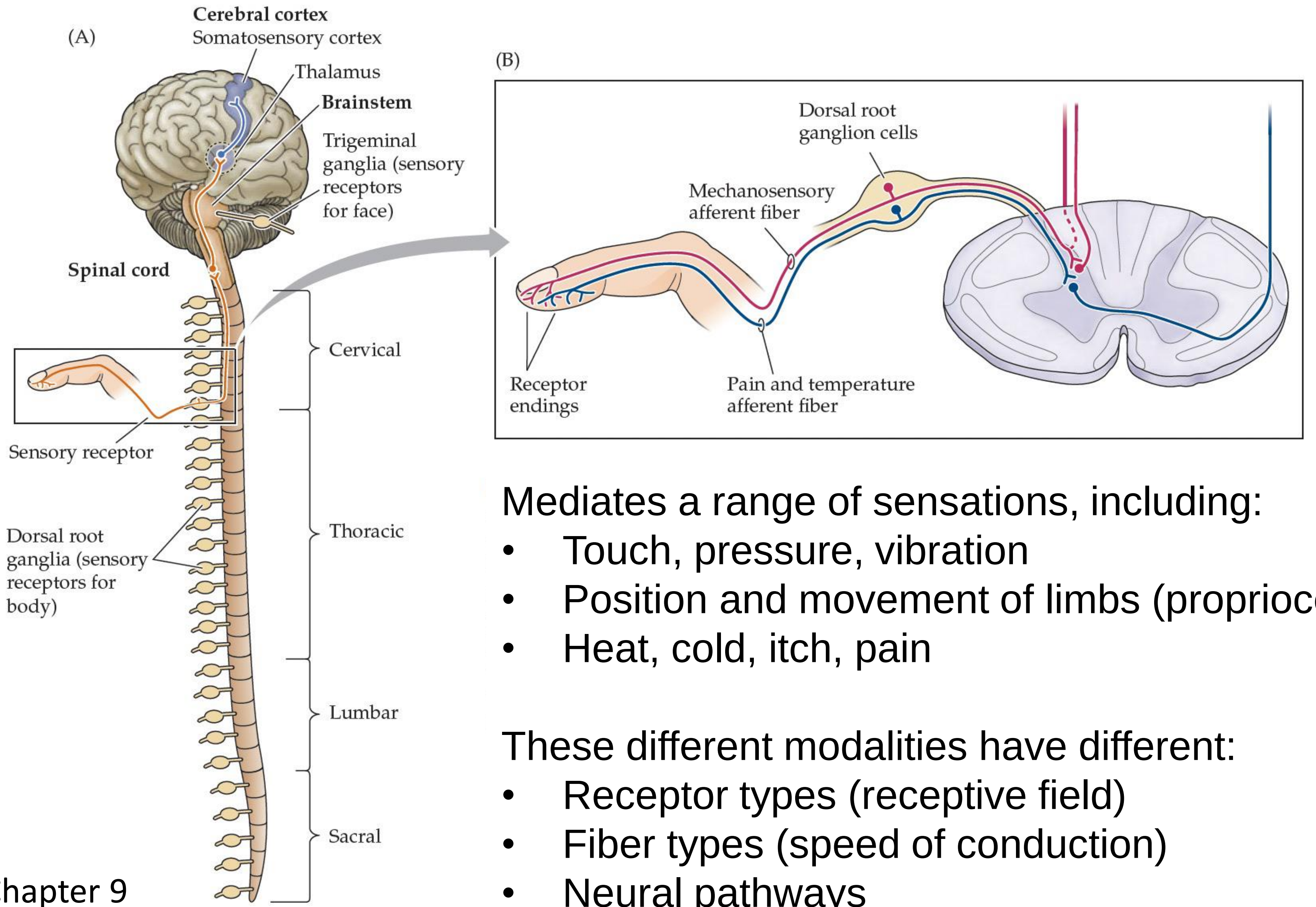
Somatosensation: sense of touch





The somatosensory system



Mediates a range of sensations, including:

- Touch, pressure, vibration
- Position and movement of limbs (proprioception)
- Heat, cold, itch, pain

These different modalities have different:

- Receptor types (receptive field)
- Fiber types (speed of conduction)
- Neural pathways

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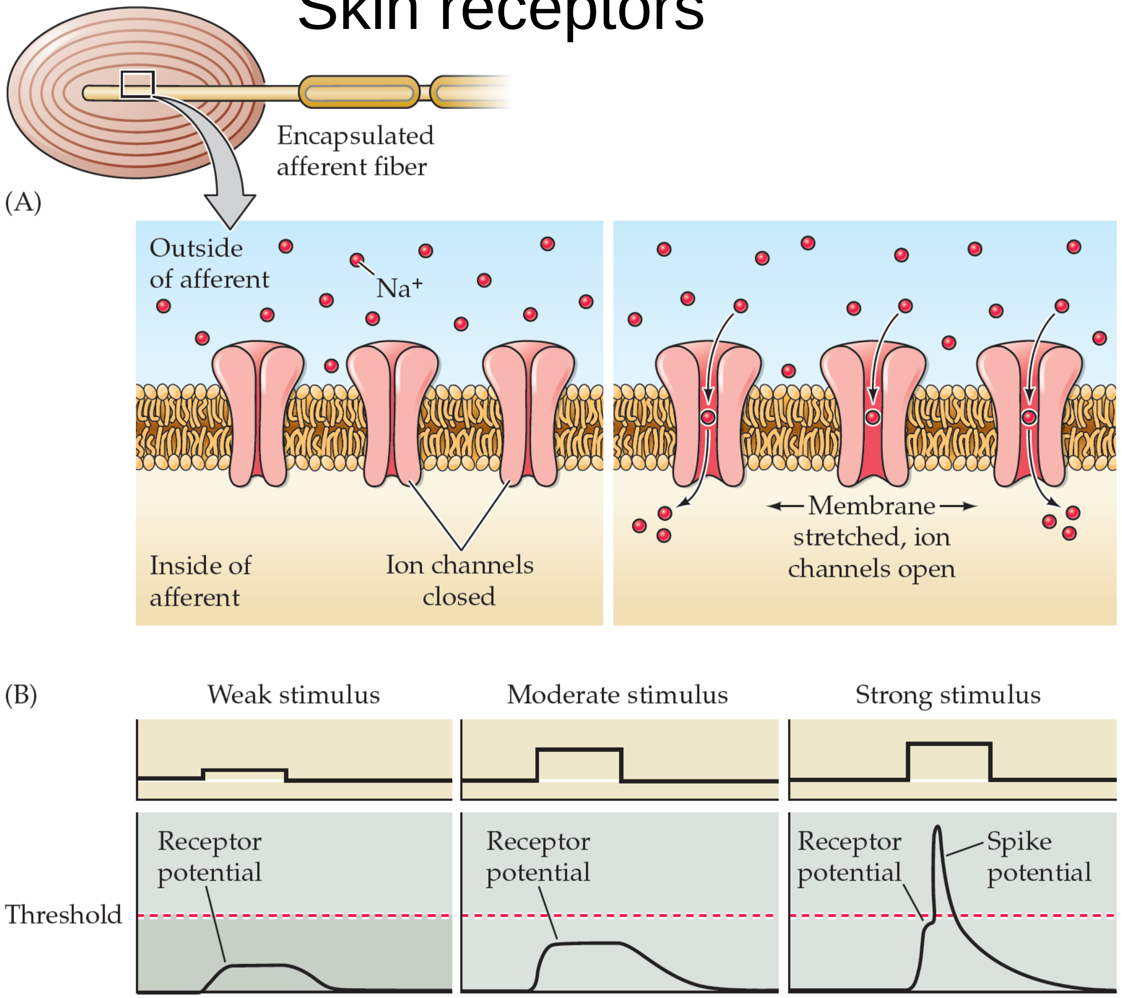
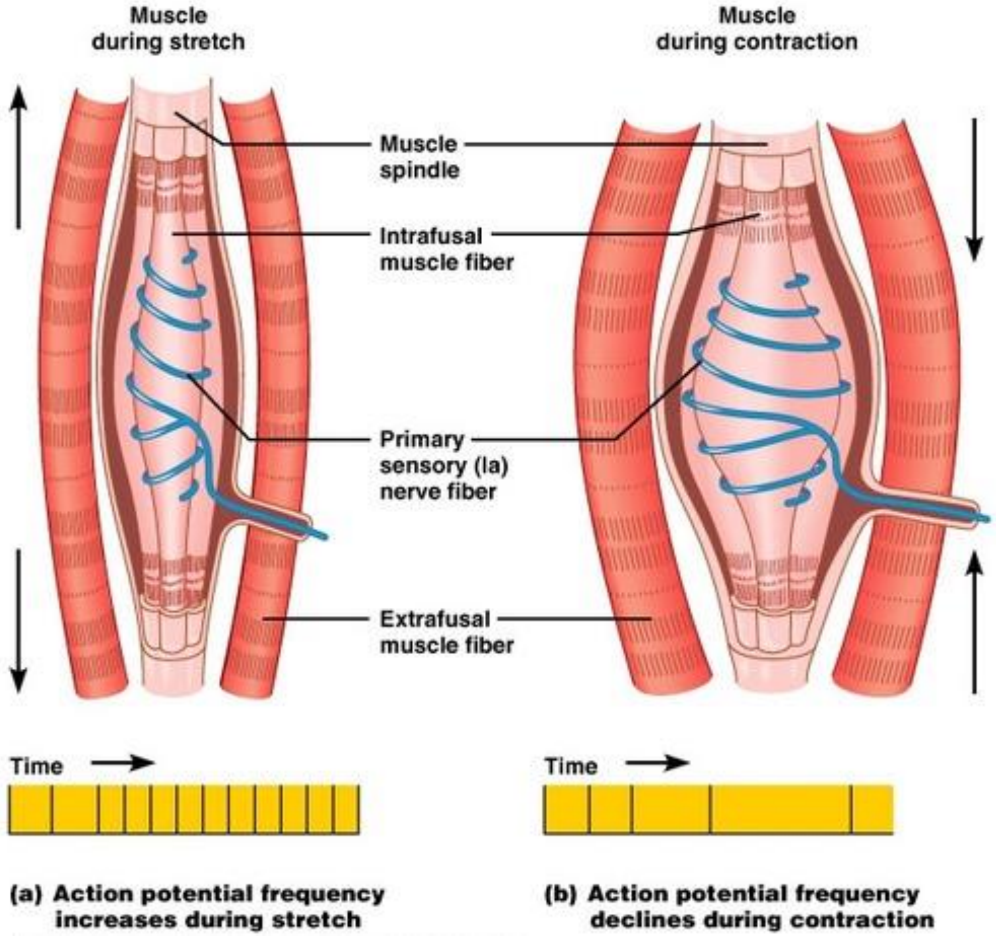
Mechanoreceptors mediate sensory transduction

Skin receptors



Muscle spindle



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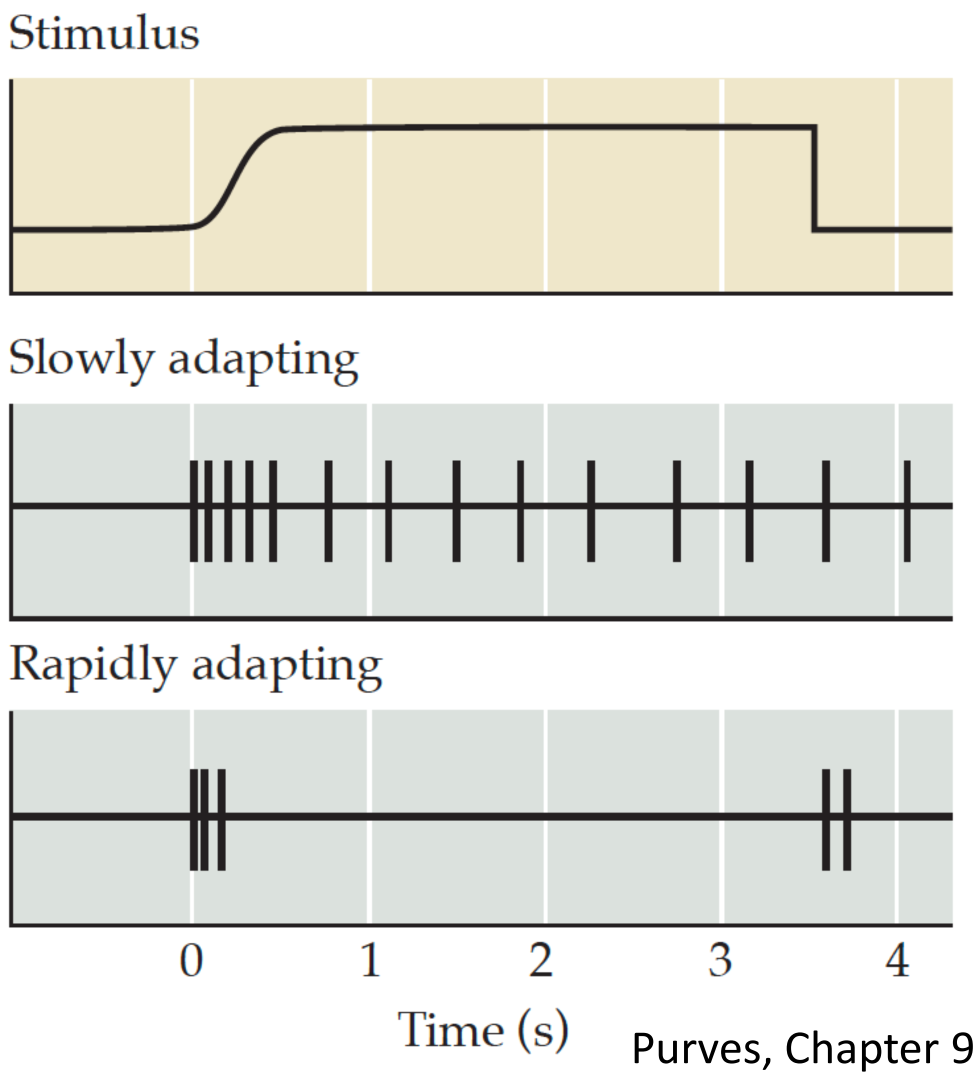
Mechanoreceptors have different rates of adaptation



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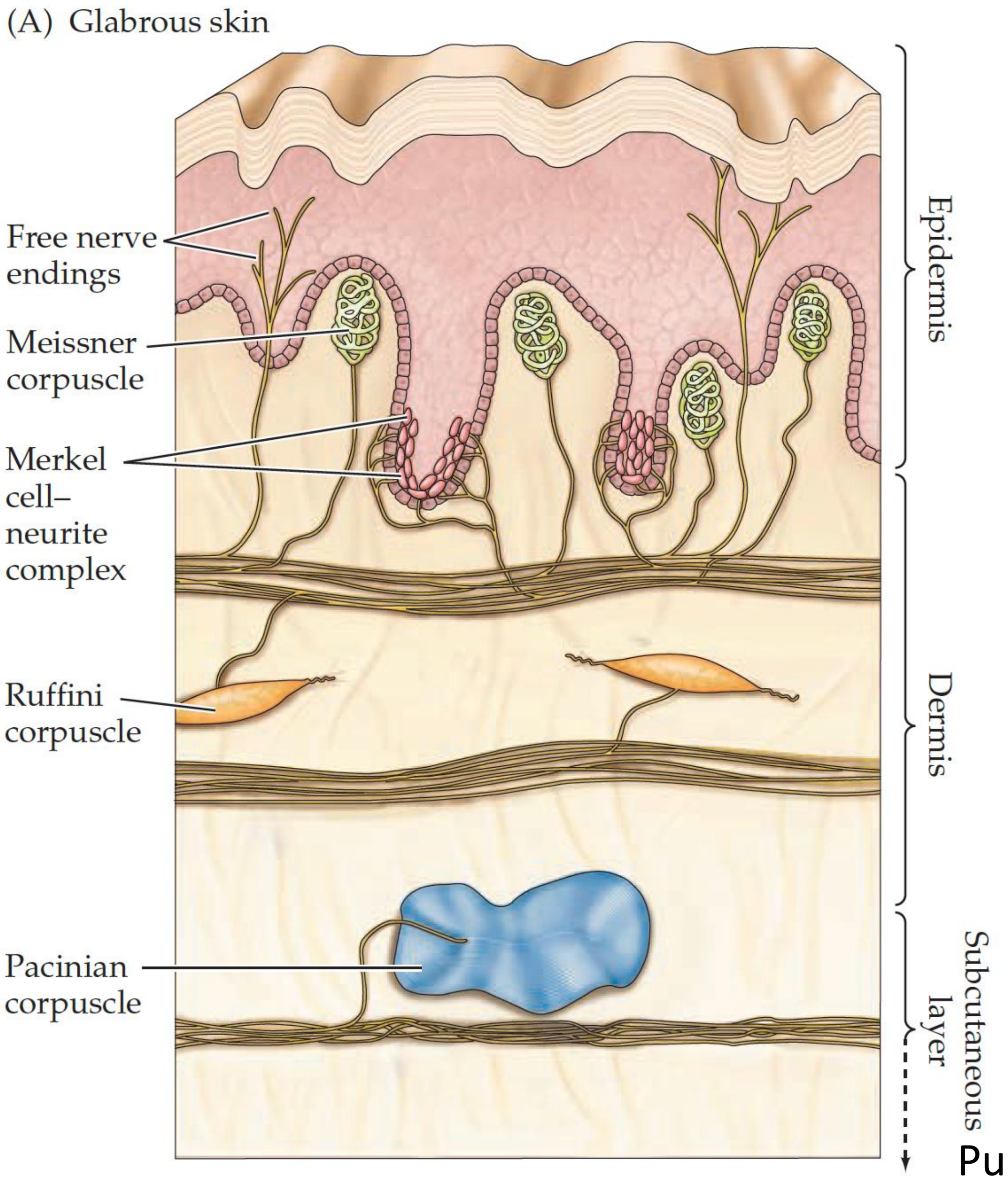
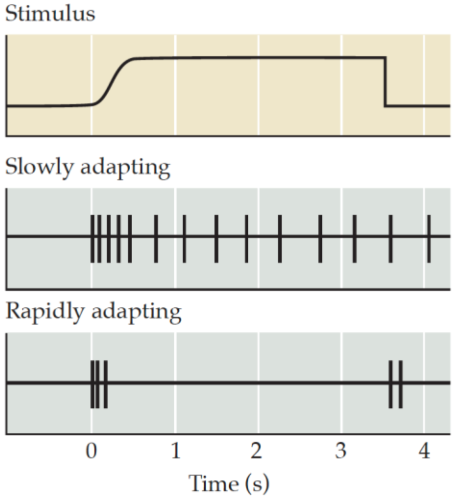
- These provide different information
- This is also part of the reason for why you don’t feel your clothes on your body

Variety of distinct touch mechanoreceptors



The different receptor types are sensitive to different tactile stimuli:

- Range of vibration frequencies (texture)
- Spatial resolution (tactile acuity)
- Slowly adapting (sense shapes)
- Rapidly adapting (sense movements)



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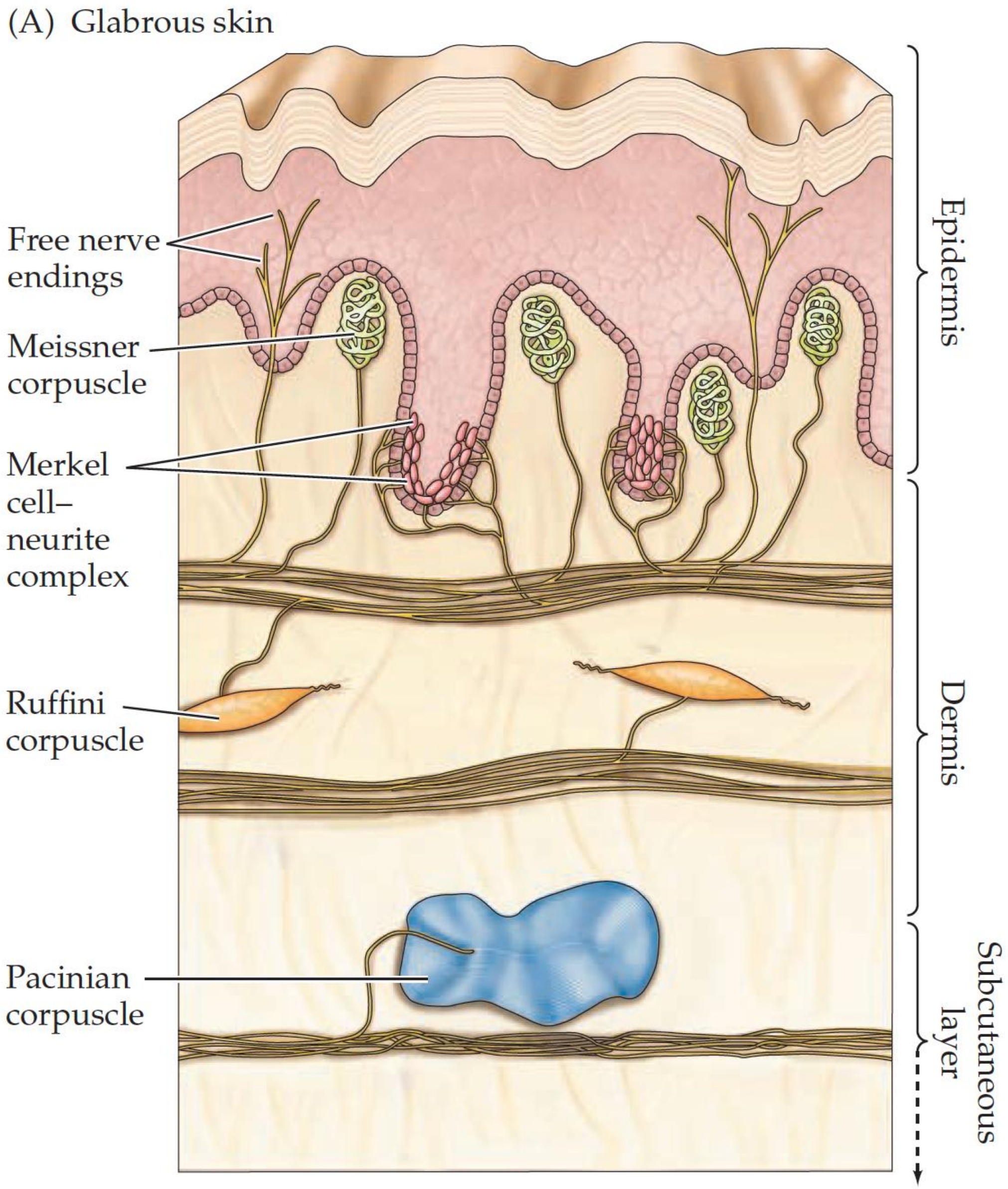
Variety of distinct touch mechanoreceptors



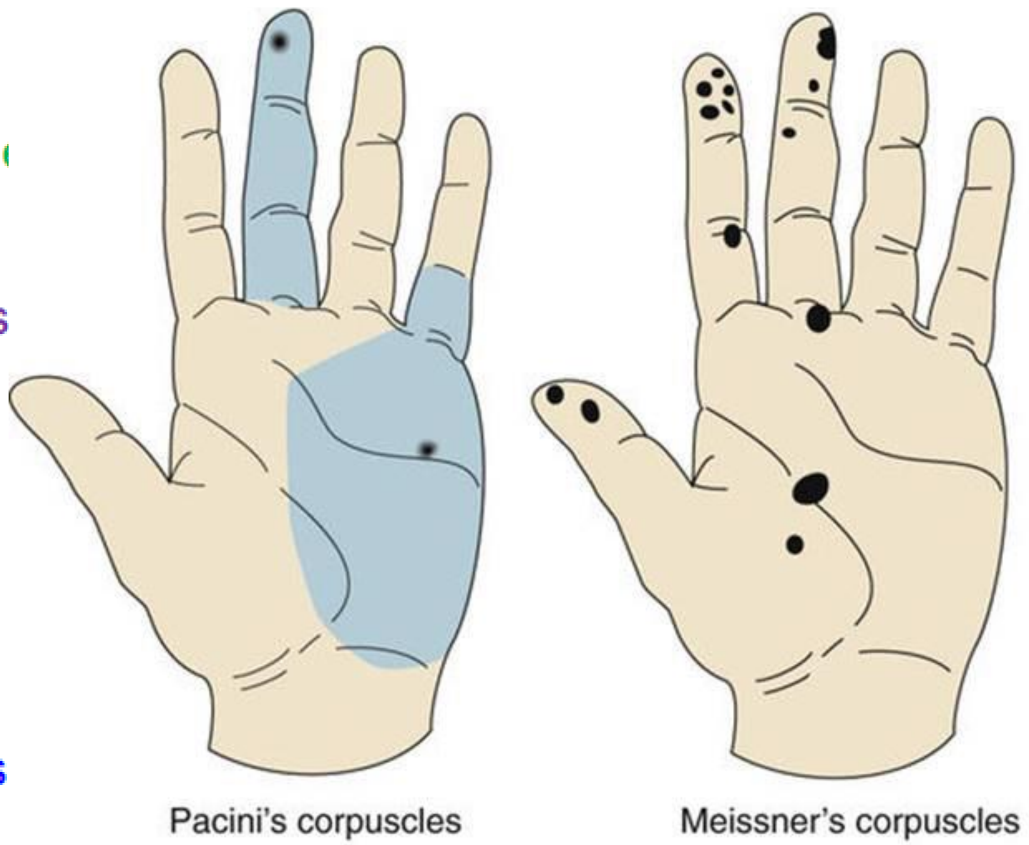
Free nerve endings
(esp. important for *pain* sensation)

Meissner's corpuscl
3-40 Hz (low frequency)

Merkel cell afferents
slowly adapting; highest spatial resolution

Rufini's endings

Pacinian corpuscles
(250 -350 Hz)
High sensitivity (10 nm)



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Somatosensory neurons

- Receptive field: part of the outer world to which a given sensory neuron is most responsive ~ somatotopic map

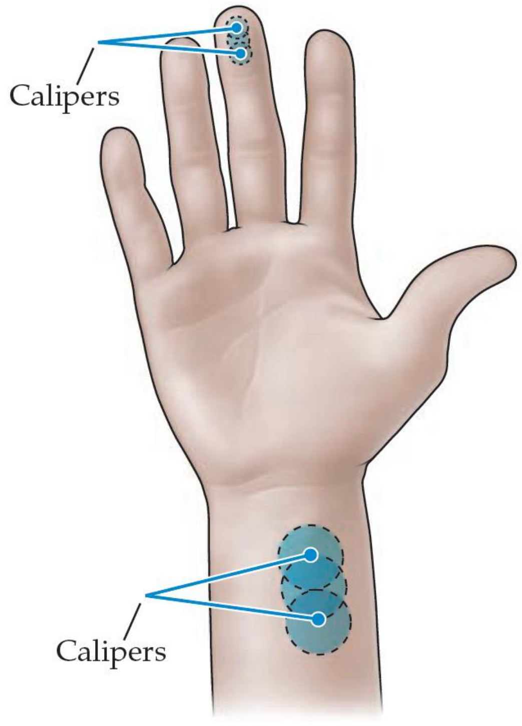
Remember

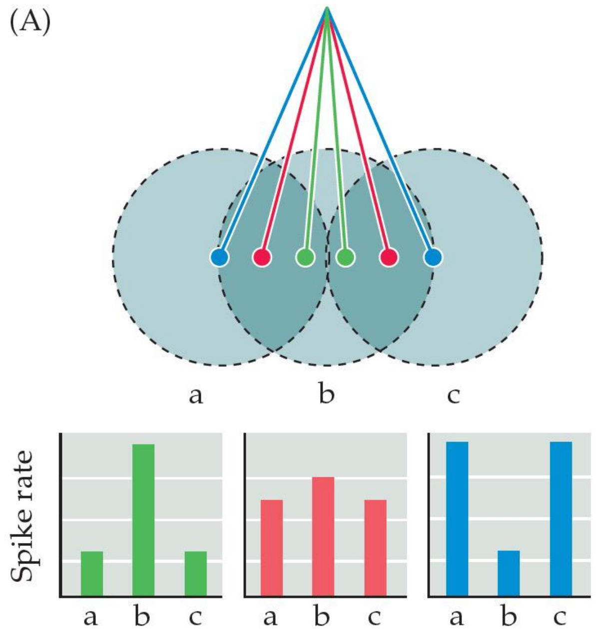
- Vision: area of the visual field which drives a neuron most strongly ~retinotopic map
- Audition: sound frequency to which a neuron responds most strongly ~tonotopic map

Somatosensory neurons

<u>Two-point discrimination threshold</u>:

Minimum distance to perceive **two separate touches**, rather than just one





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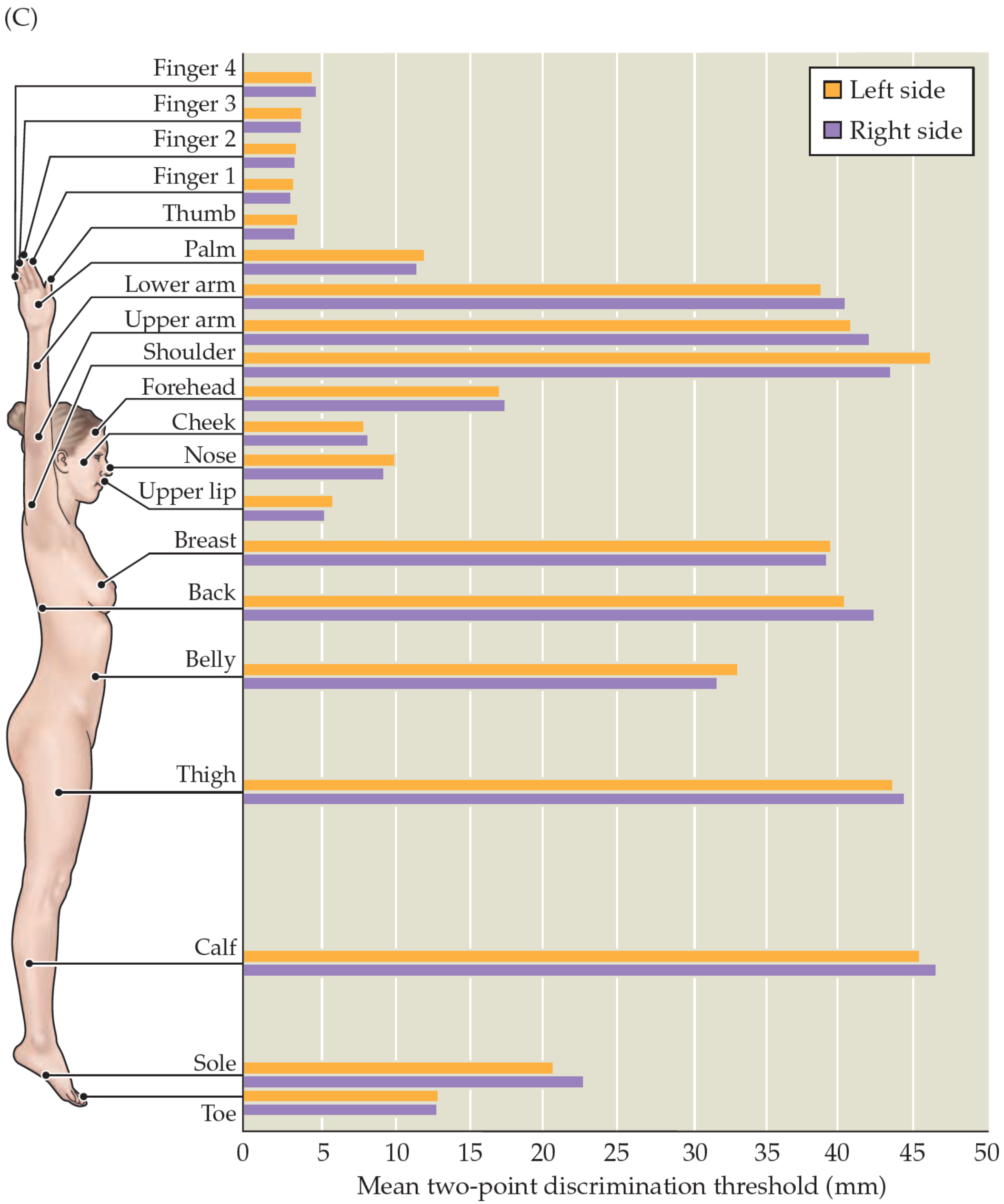
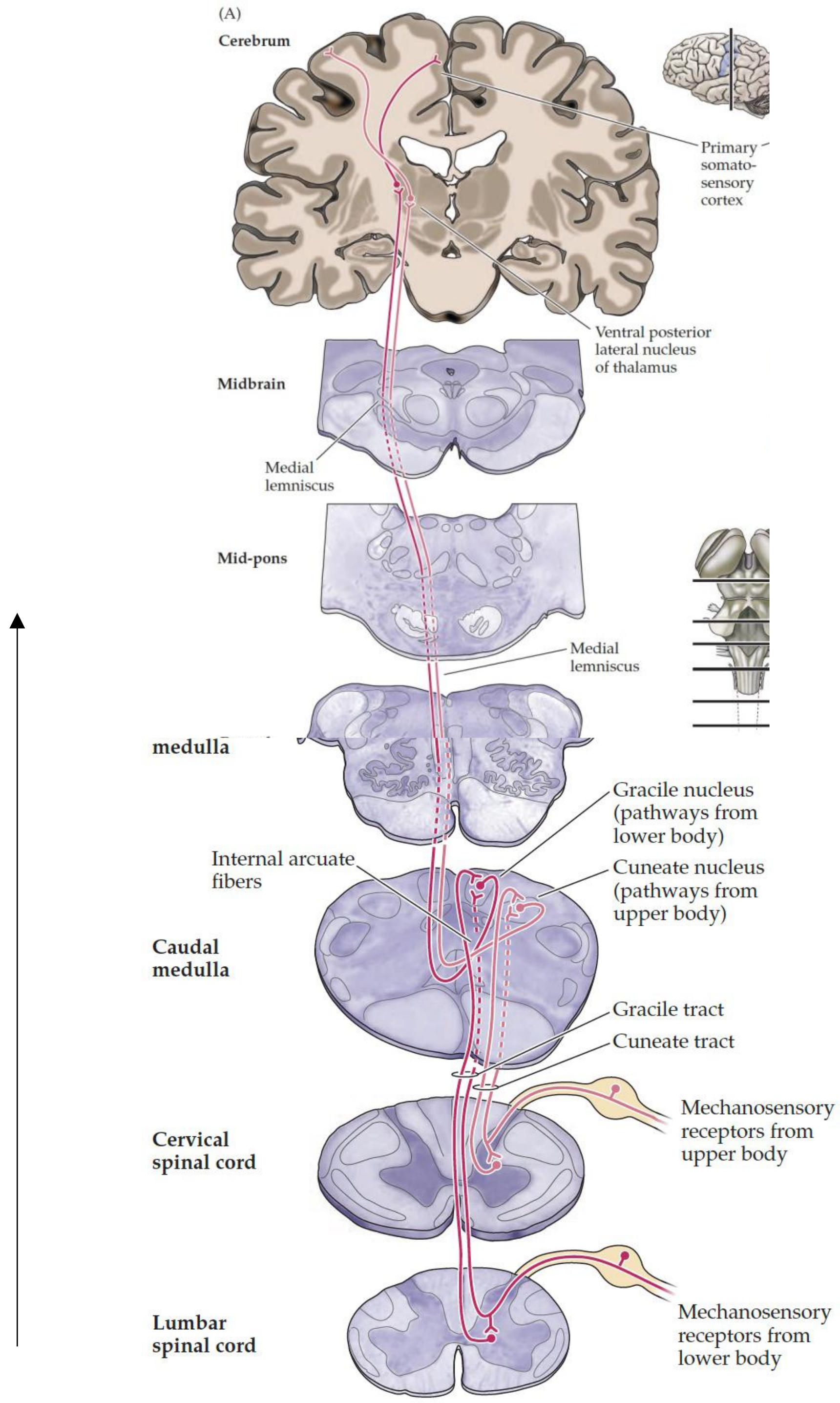


Pathway for mechanosensing

Touch information goes to the cortex

- Tertiary neurons in the thalamus
- Secondary sensory neurons in the brainstem
- Primary sensory neurons



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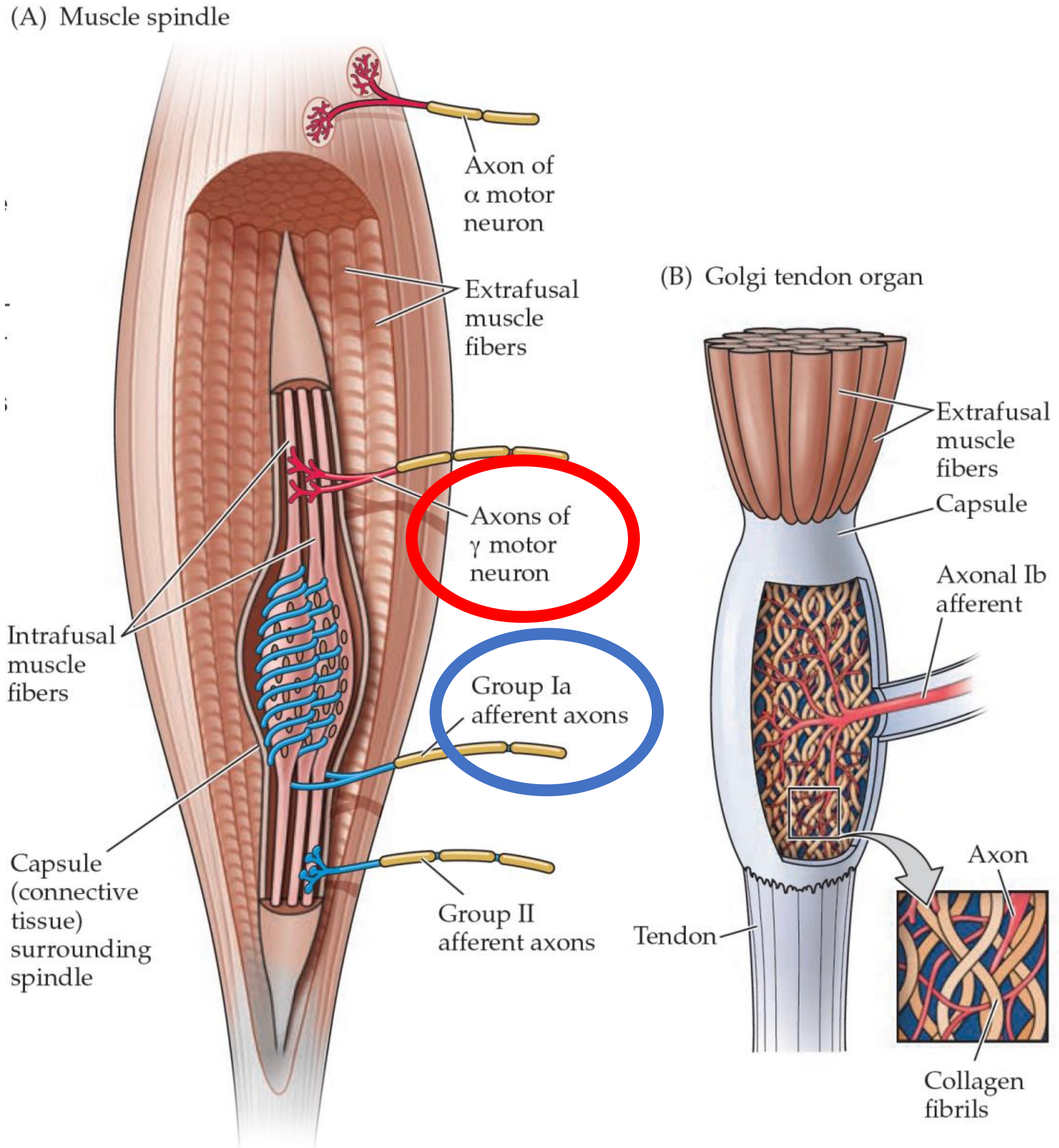
Proprioceptors in the musculoskeletal system

- Efferent fibers: signal from CNS towards periphery

- Afferent fibers: signal from periphery towards CNS



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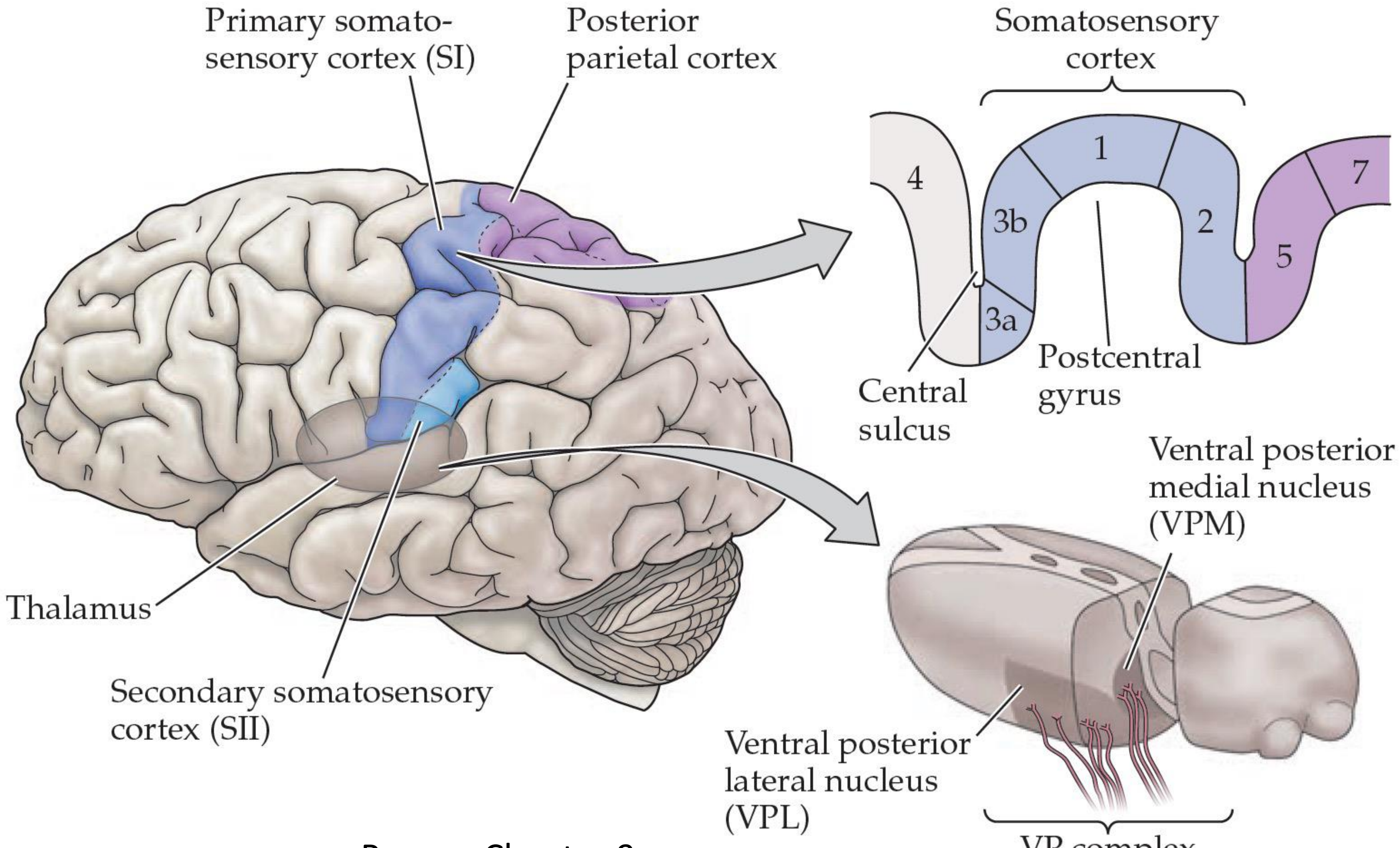
Somatosensory cortex



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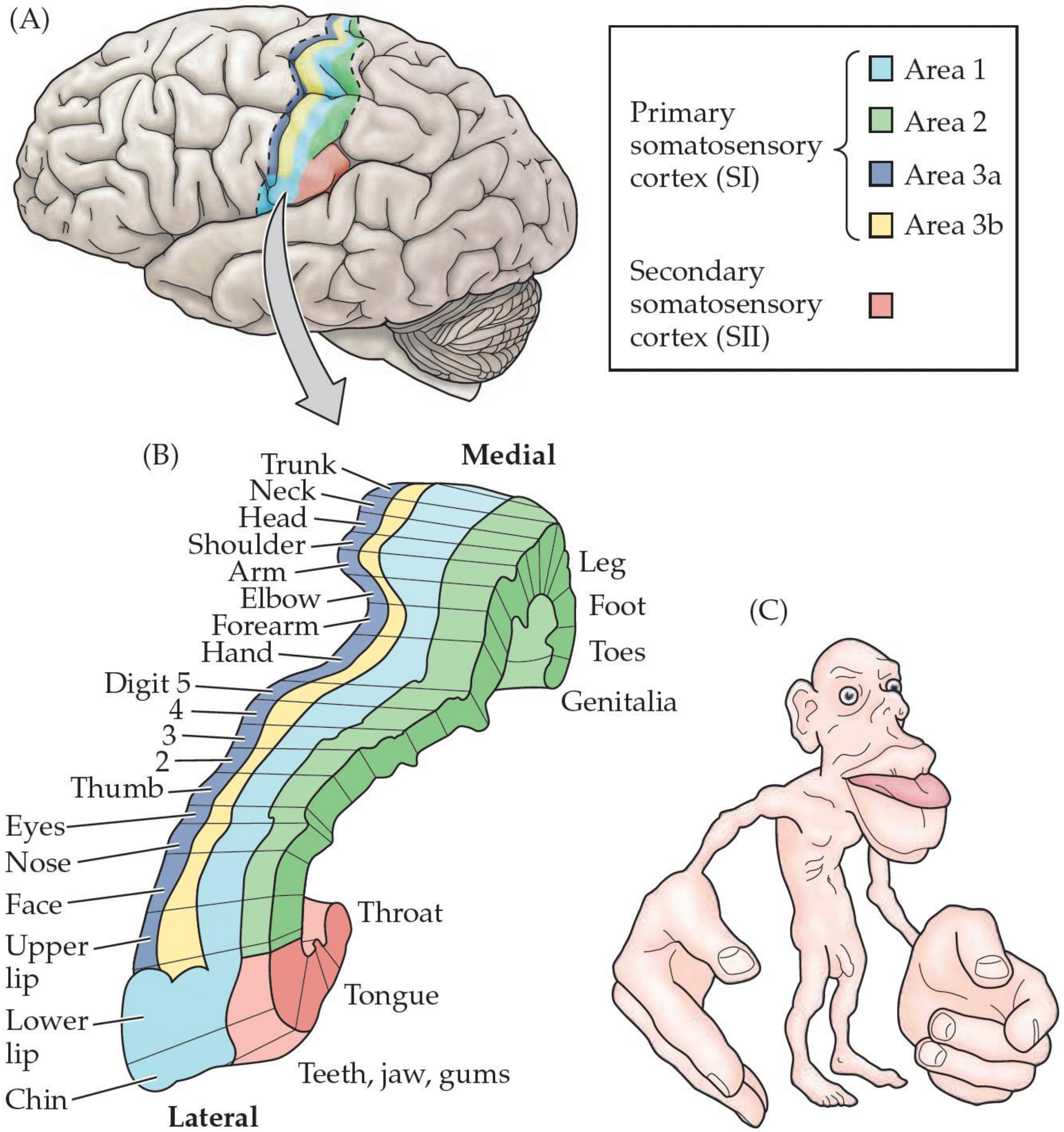
Somatotopic order in somatosensory cortex

Locations with high spatial resolution (hands, face, lips, toes) are strongly represented areas in the homunculus



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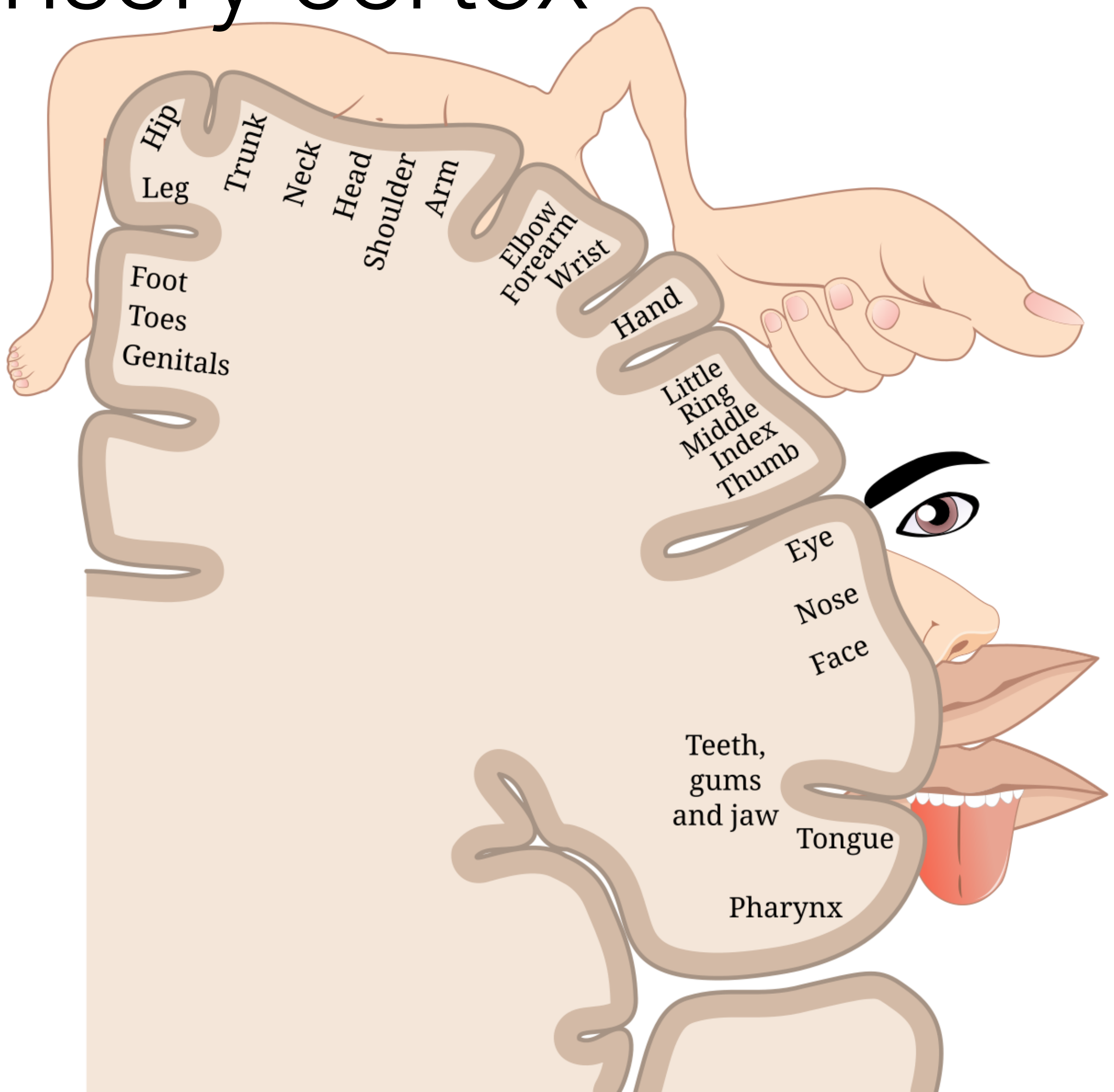
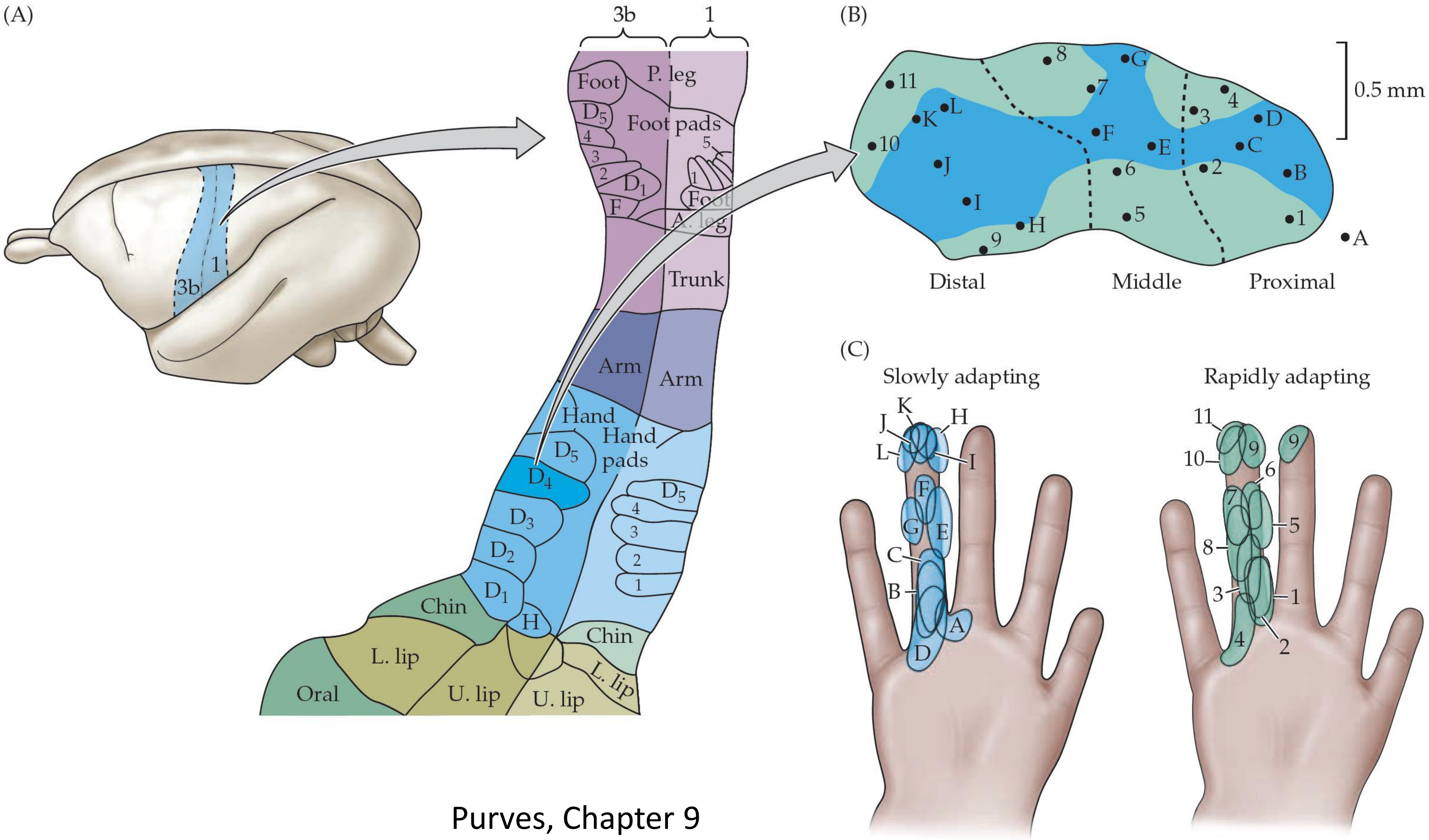
Somatotopic order in somatosensory cortex



Functionally distinct columns in primary somatosensory cortex



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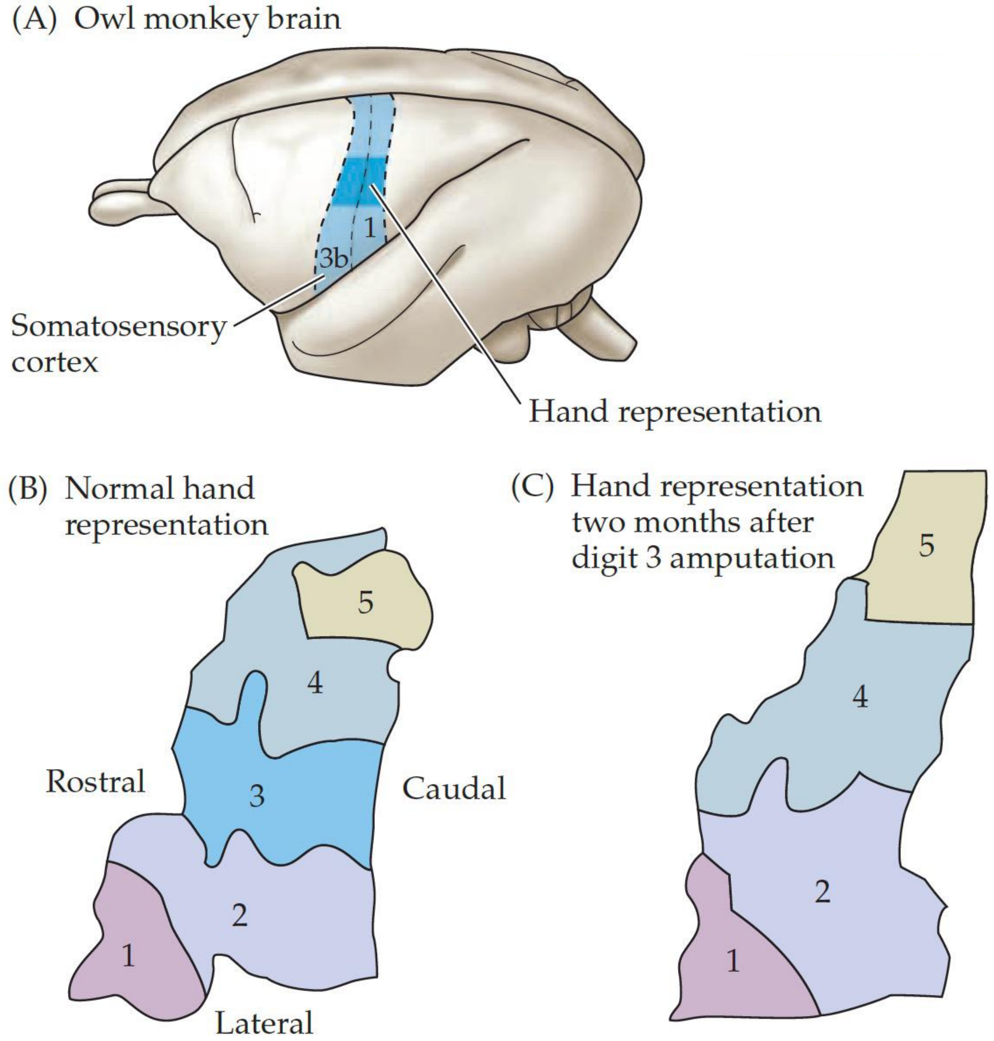
Functional changes in somatosensory cortex following amputation of a digit

Neuronal adaptation following peripheral changes



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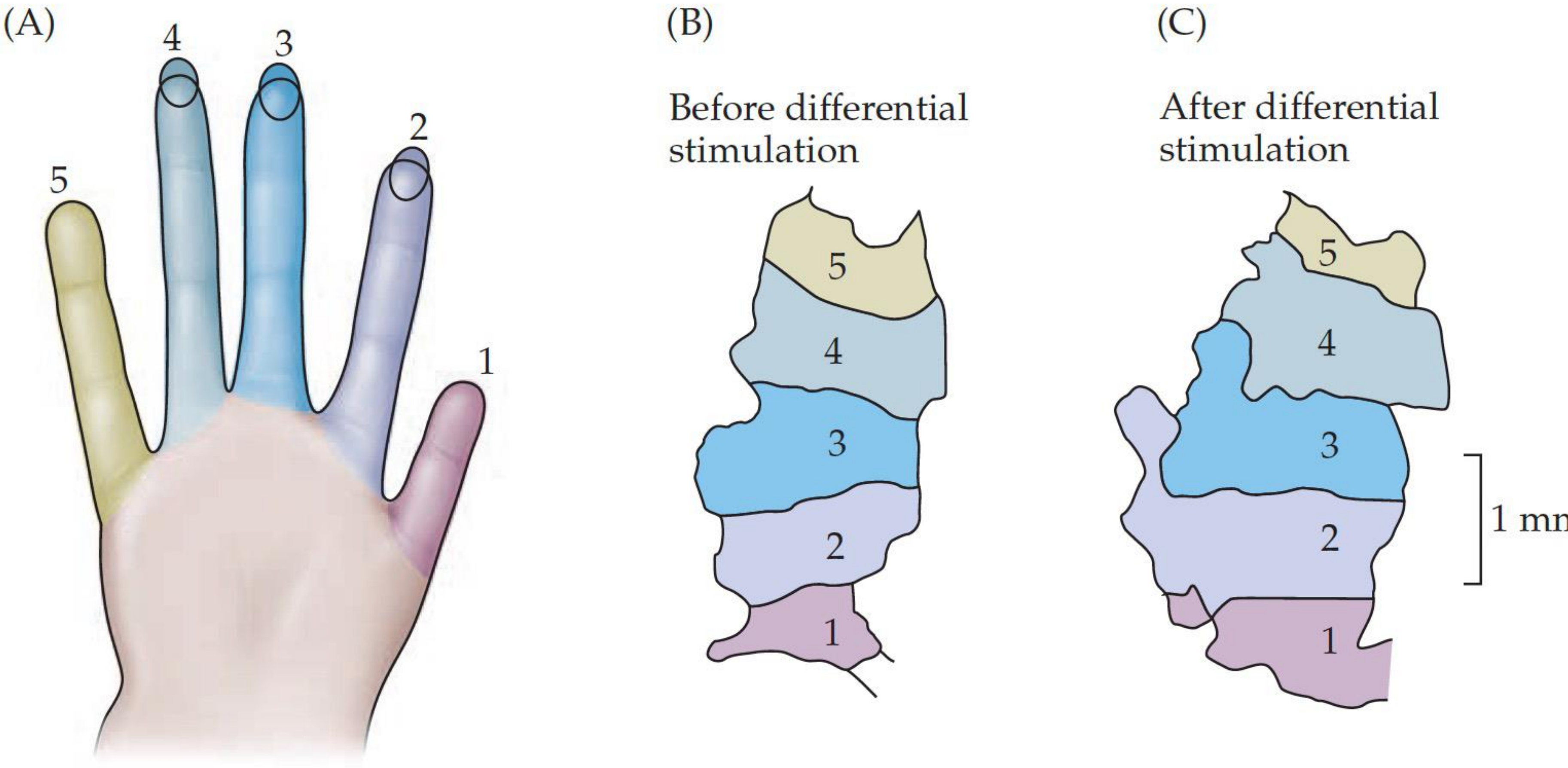
Functional changes in somatosensory cortex following repetitive behavior

Expansion of neural territory via repeated use



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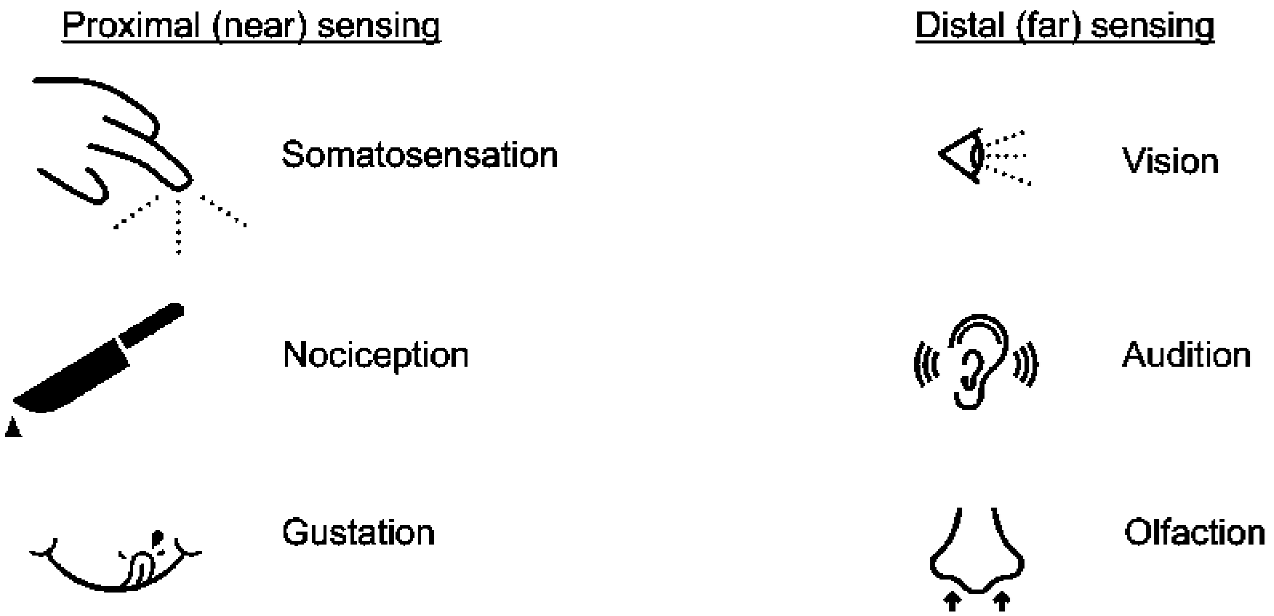
Sensory systems

- Vision: sense of sight
- Audition: sense of hearing
- Somatosensation: sense of touch

- Nociception: sense of pain
- Gustation: sense of taste
- Olfaction: sense of smell



Questions

- What are the key components of hearing?
- How does our brain localize sounds?
- What is tonotopic organization?
- What is somatotopic organization?
- Explain what the homunculus represents?
- What is the pathway for mechanosensing?