A few questions on the content of the previous lecture

slido

Visual acuity is the highest at the...

ⓘ Start presenting to display the poll results on this slide.

slido

The mapping of the visual input from the retinas to neurons within the visual stream is called...

ⓘ Start presenting to display the poll results on this slide.

slido

After the optic chiasm, the optic nerve becomes...., which then synapses in...., from which then emerges...., which finally reaches the....

ⓘ Start presenting to display the poll results on this slide.

Any questions/remarks before we begin today’s lecture?

Auditory Neuroscience

Dr. Lavinia Carmen Uscătescu

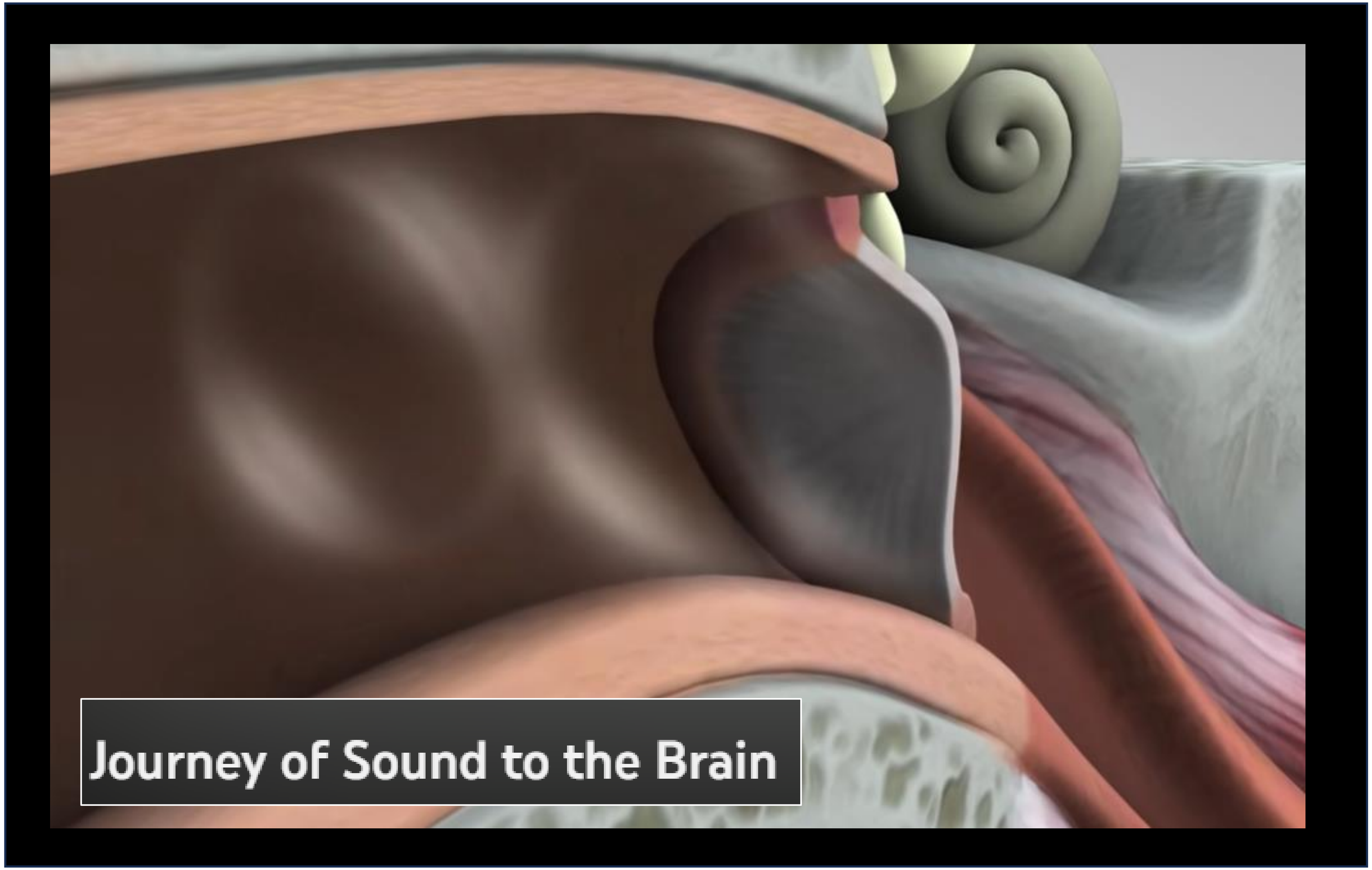
December 4th 2023

Outline

1. The ear
2. The auditory pathway
3. The auditory cortex

The ear

Overview



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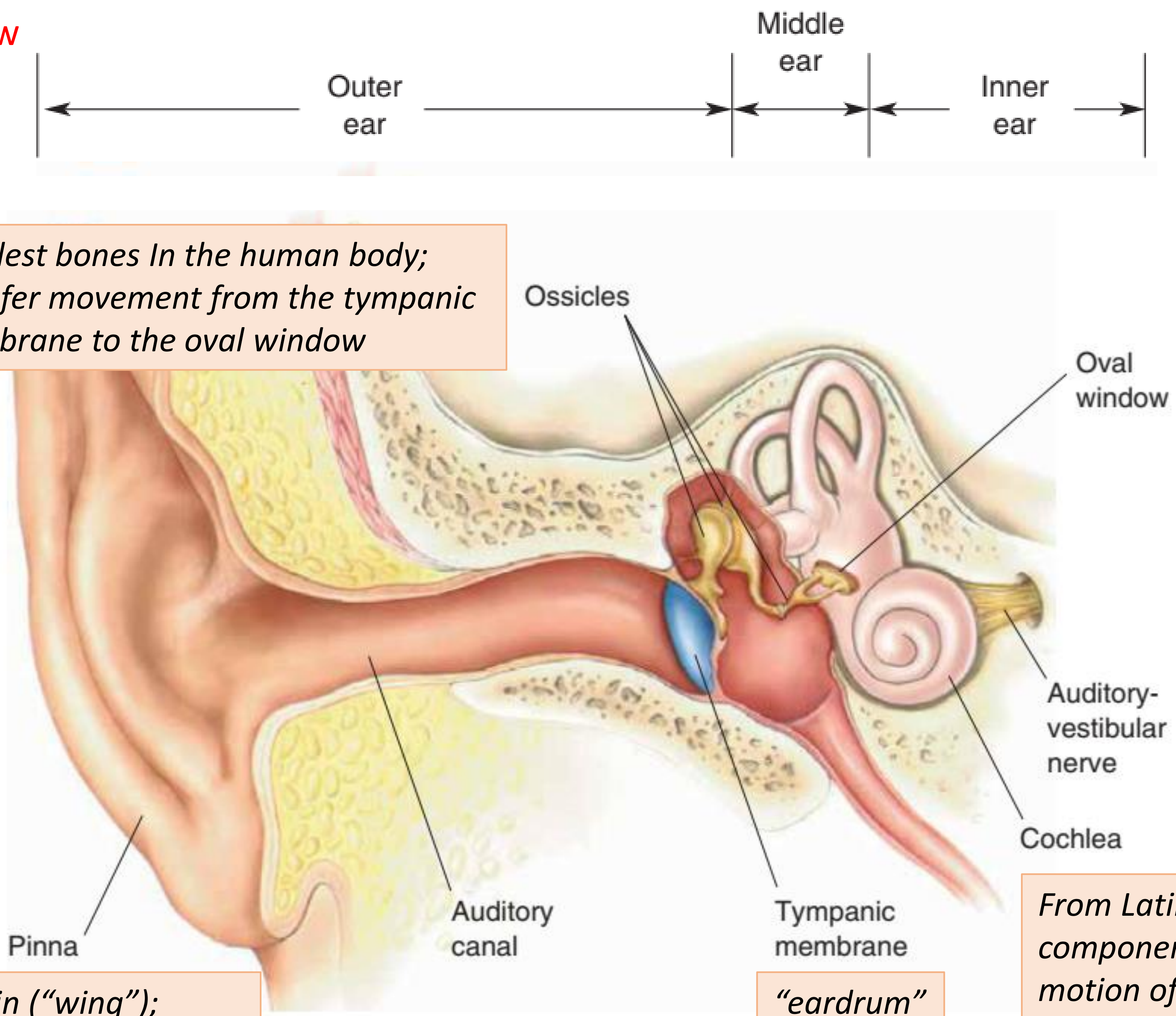
Overview



Smallest bones In the human body; transfer movement from the tympanic membrane to the oval window

From Latin ("wing"); helps collect sound mostly From in front of us

"eardrum"

From Latin: "snail"; fluid-filled; contains components that transform the physical motion of the oval window membrane into a neuronal response

Sound wave moves the tympanic membrane

⇩

Tympanic membrane moves the ossicles

⇩

Ossicles move the membrane at the oval window

⇩

Motion at the oval window moves fluid in the cochlea

⇩

Movement of fluid in the cochlea causes a response in sensory neurons

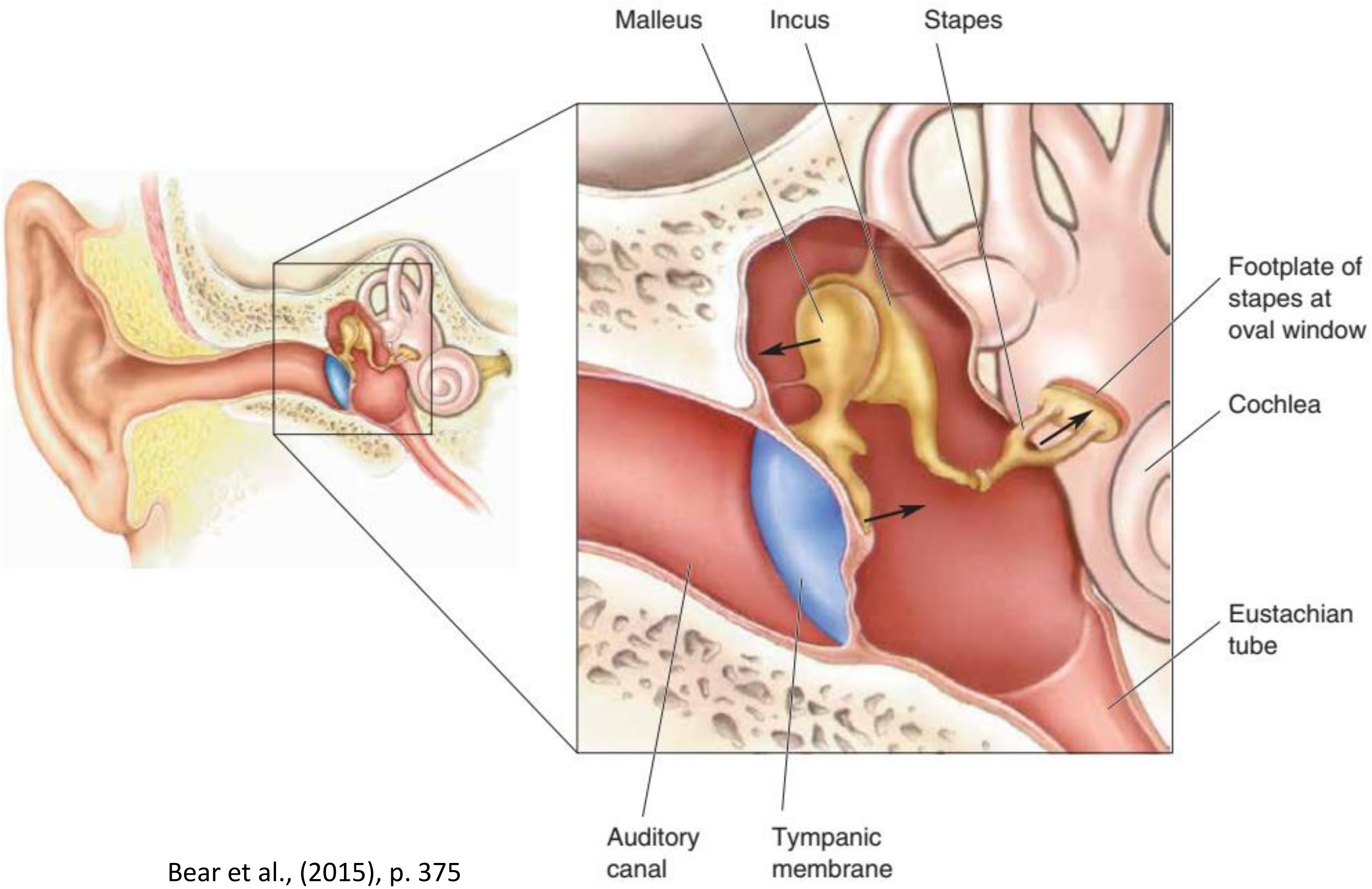
Bear et al., (2015), p. 373

The middle ear

Rigid connection

Flexible connection

From Latin: "hammer" "anvil" "stirrup"

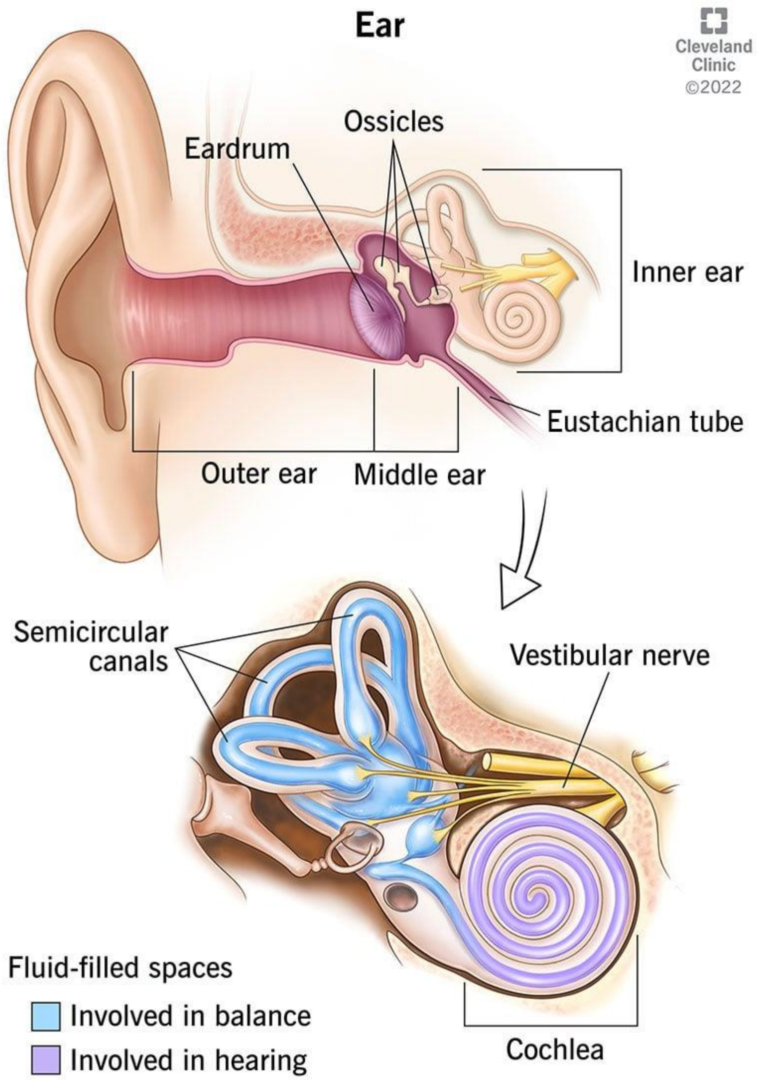


Bear et al., (2015), p. 375

The flat bottom portion of the stapes; moves in and out like a piston at the oval window; movements of the footplate transmit sound vibrations to the fluids of the cochlea (inner ear)

Connects the middle ear with the nasal cavities; usually closed by a valve; helps regulate pressure

The inner ear

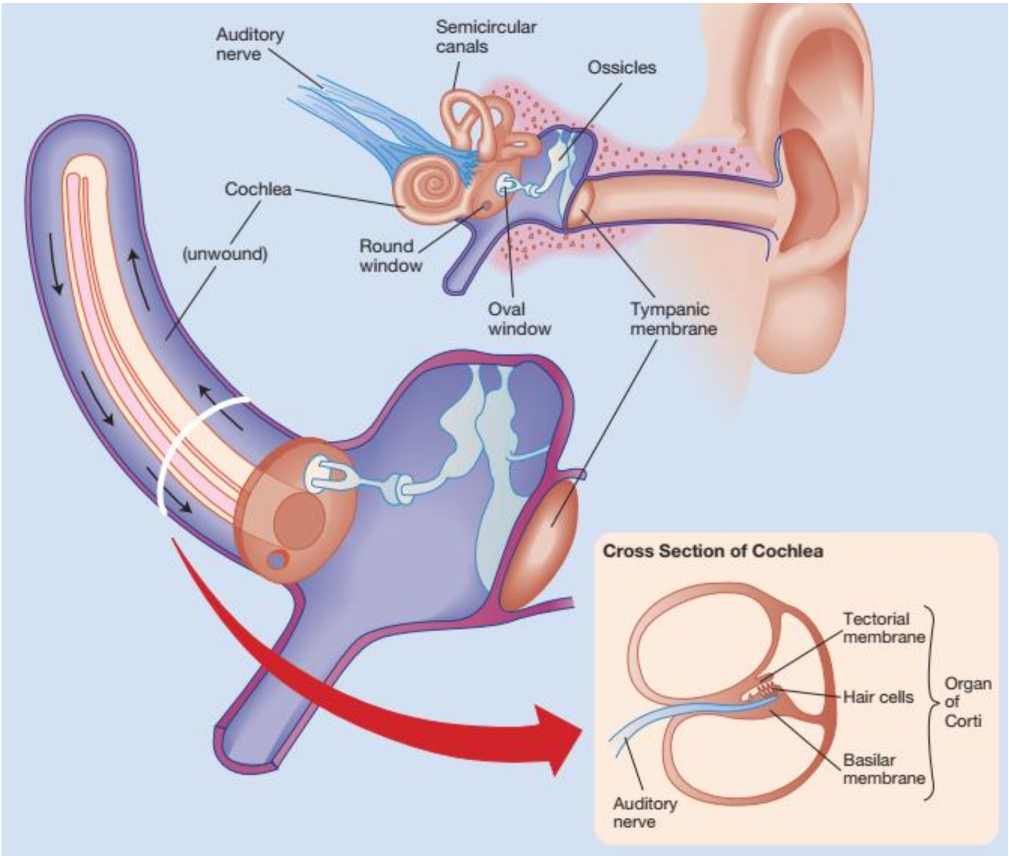


https://tinyurl.com/ycx2nah2

The inner ear:

(1) the **cochlea** => auditory system => hearing

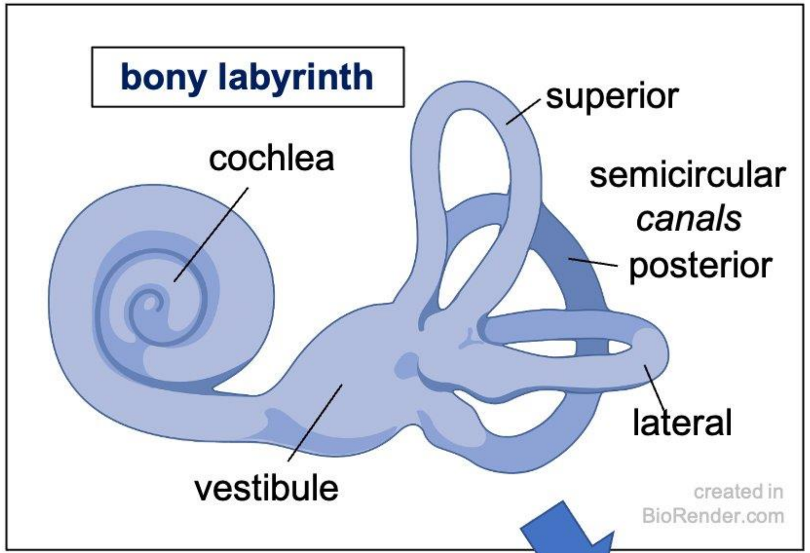
(2) the **labyrinth** => vestibular system => maintains balance

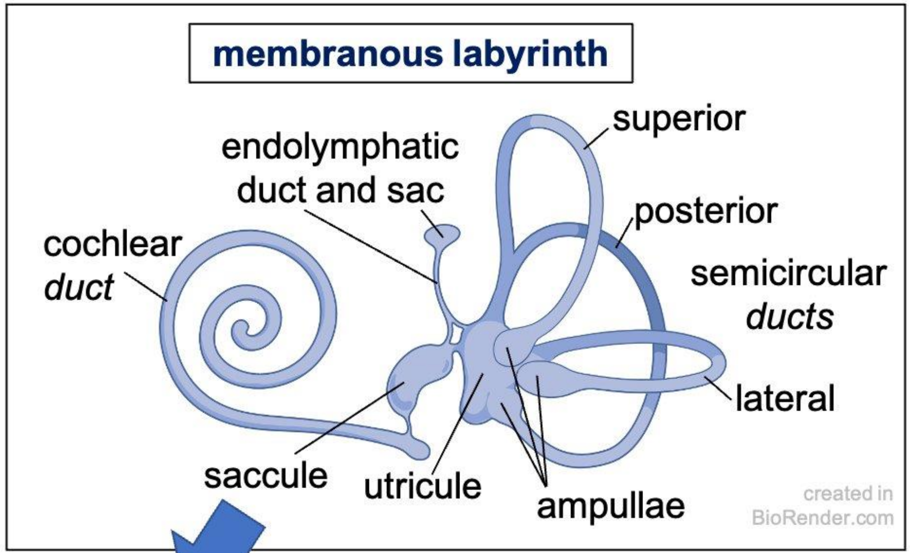


Pinel & Barnes, (2021), p. 187

also called “**otic capsule**”; surrounds and houses the membranous labyrinth, separated by a layer of **perilymph**

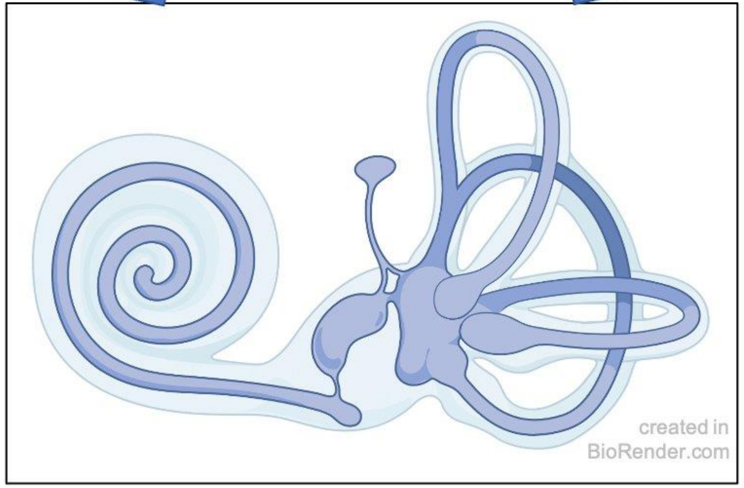
contains **endolymph** & **sensory epithelium**





perilymph

extracellular fluid located in the **scala tympani** and **scala vestibuli** of the cochlea; major cation is **sodium**

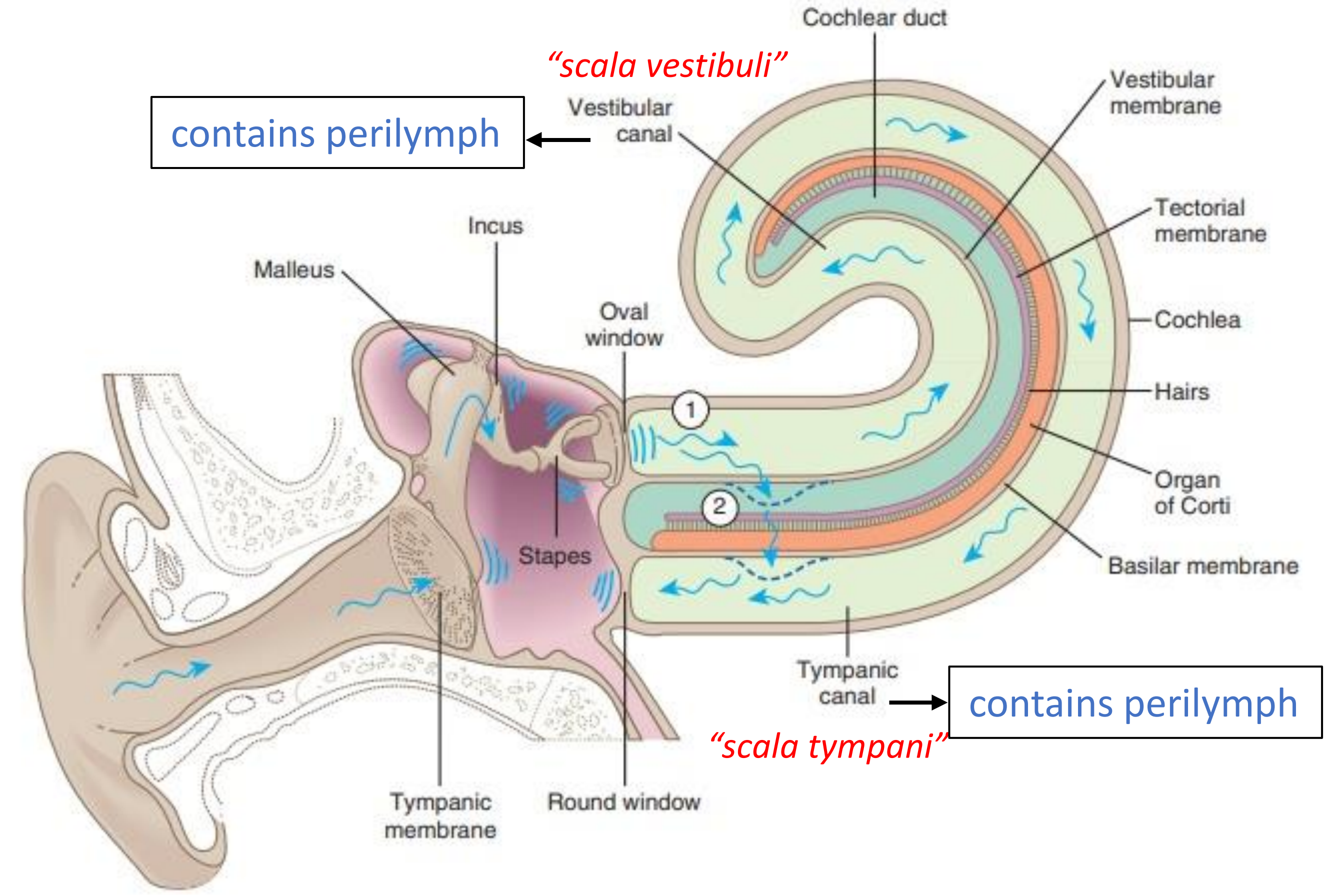


endolymph

fluid located in the **membranous labyrinth** of the inner ear; major cation is **potassium**

https://tinyurl.com/b37rx6wt

The cochlea



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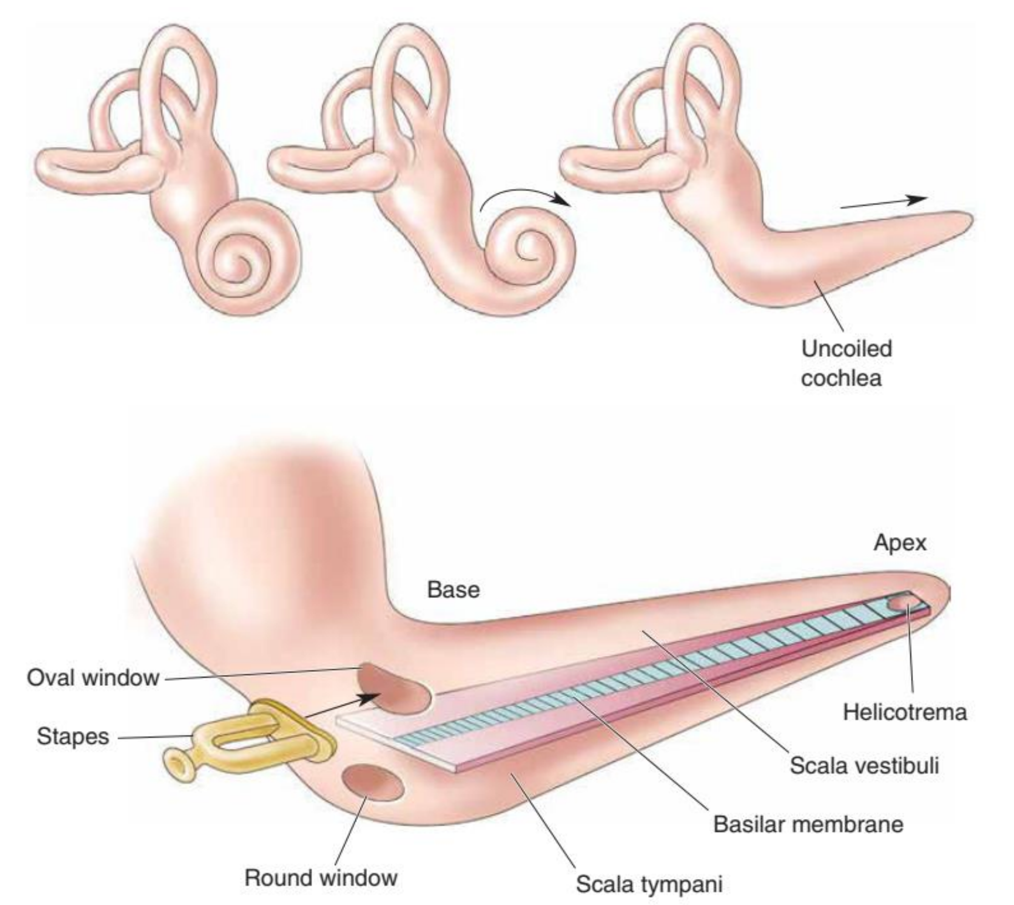
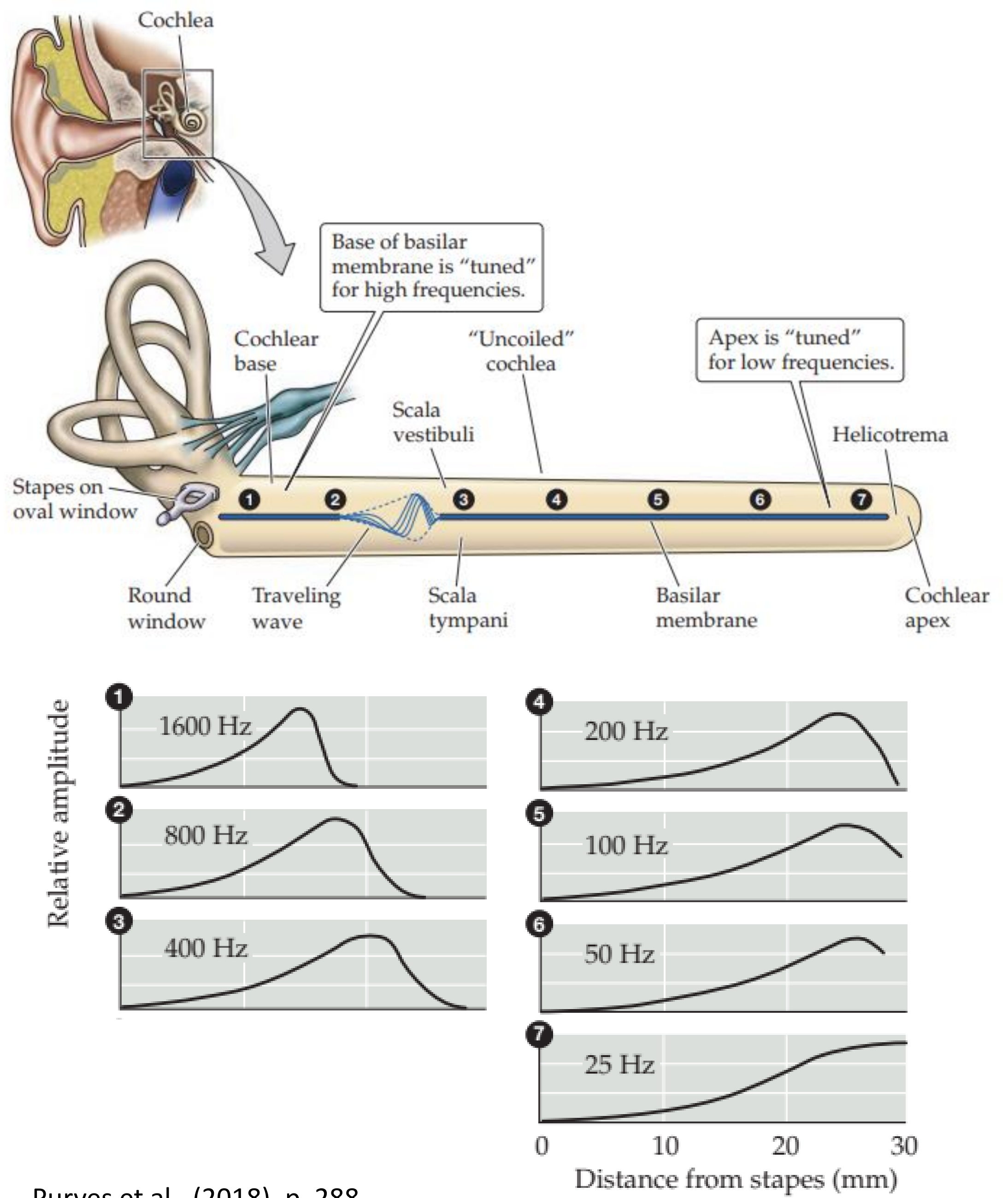


Bear et al., (2015), p. 378

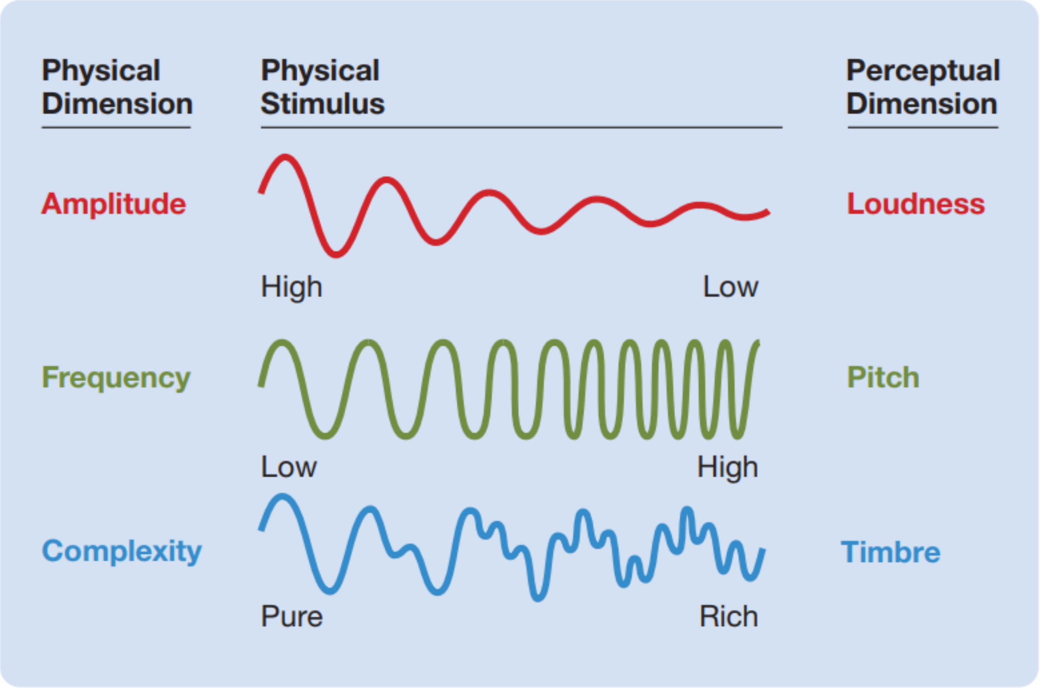
▲ FIGURE 11.8

The basilar membrane in an uncoiled cochlea. Although the cochlea narrows from base to apex, the basilar membrane widens toward the apex. Notice that the basilar membrane is the narrow blue band only. The helicotrema is a hole at the apex of the basilar membrane, which connects the scala vestibuli and scala tympani.

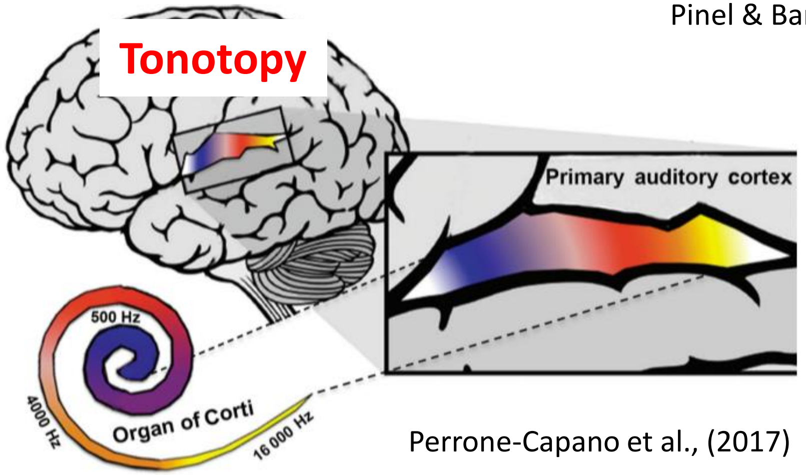


Purves et al., (2018), p. 288

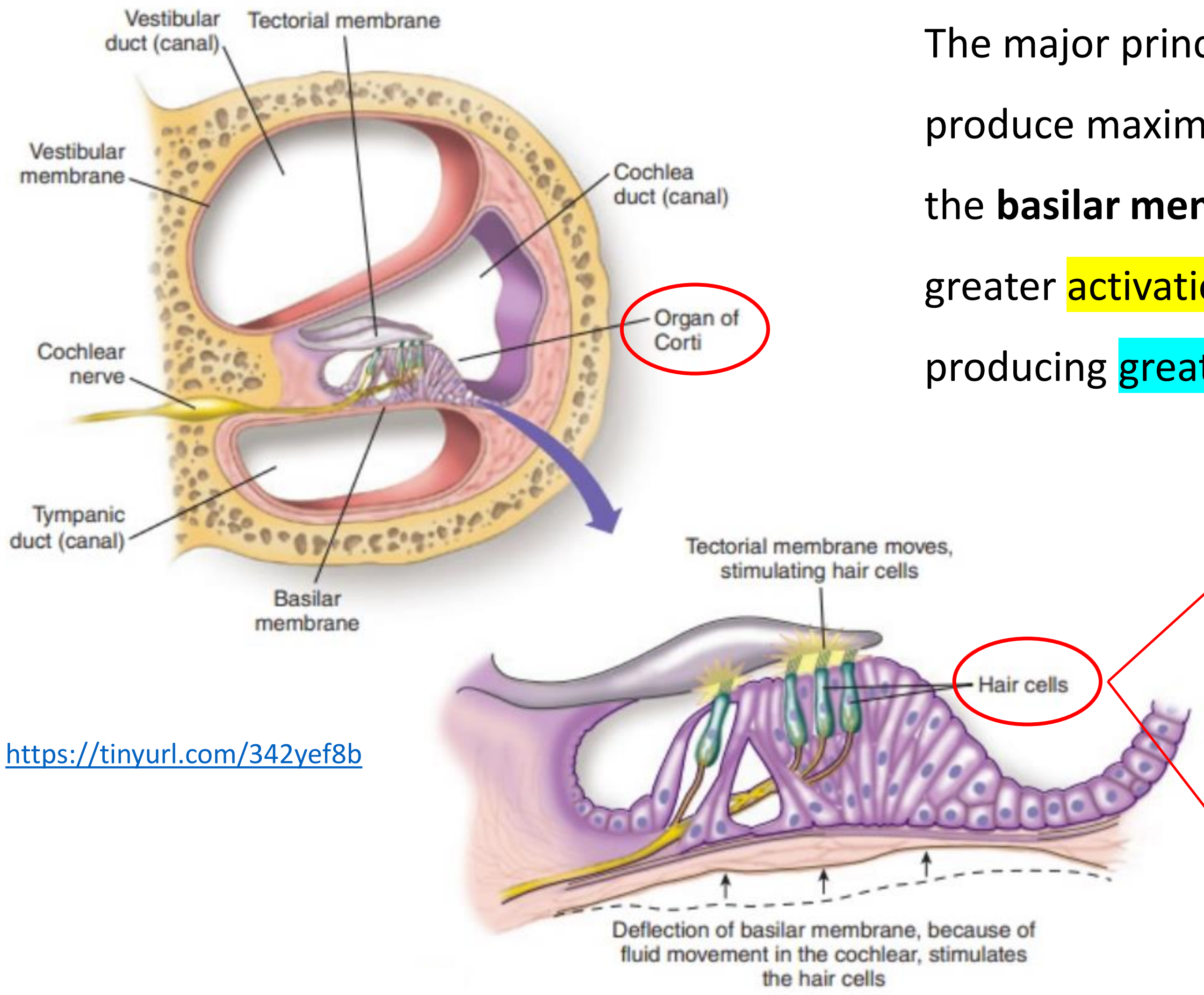
Figure 7.2 The relation between the physical and perceptual dimensions of sound.



Pinel & Barnes, (2021), p. 187



Perrone-Capano et al., (2017)



https://tinyurl.com/342yef8b

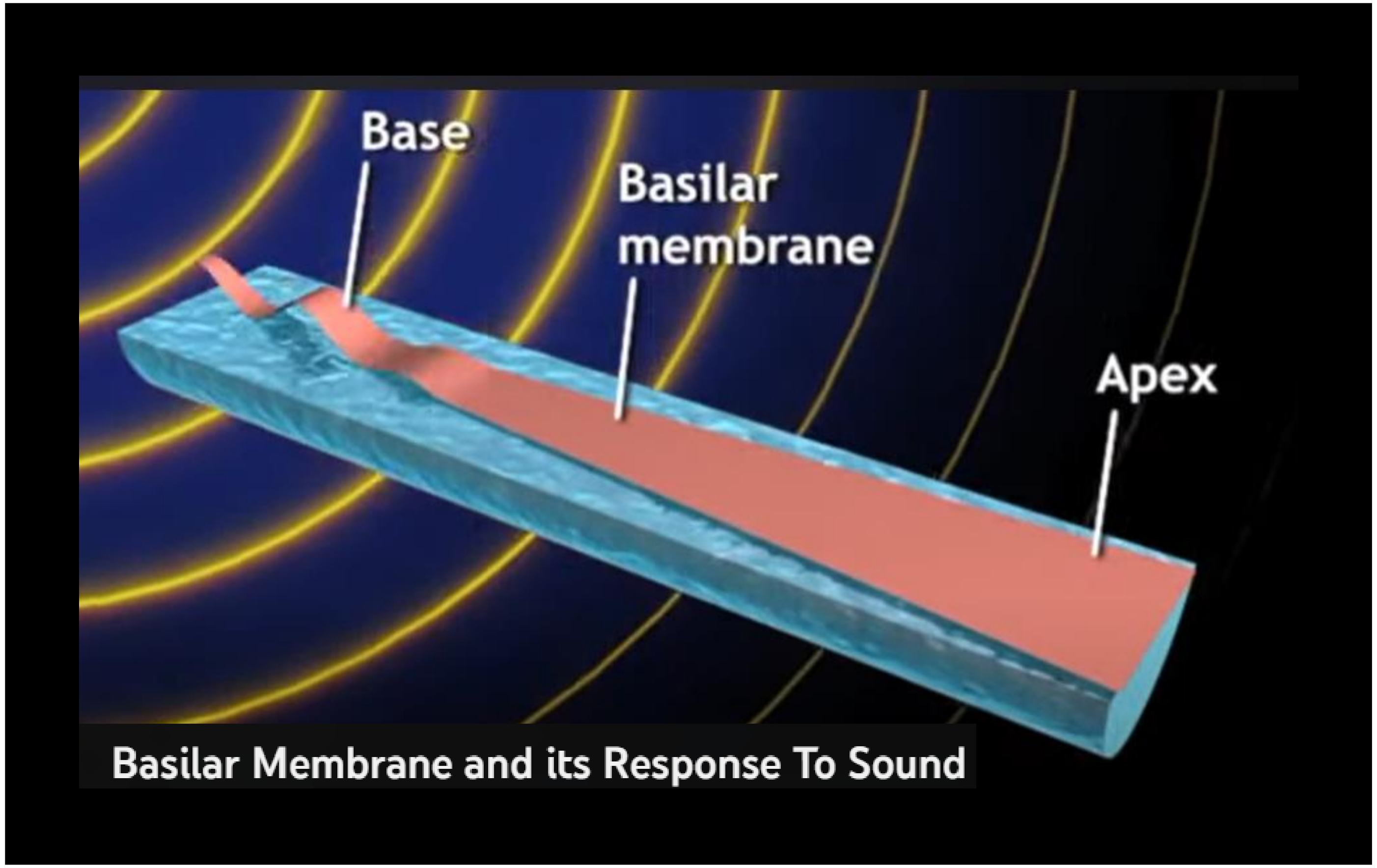
The major principle of **cochlear coding** is that different frequencies produce maximal stimulation of **hair cells** at different points along the **basilar membrane**—with higher frequencies producing greater activation closer to the windows and lower frequencies producing greater activation at the tip of the basilar membrane.

outer hair cells => **cochlear amplifier**, i.e., **amplify** the movement of the **basilar membrane** during **low-intensity sound** stimuli; **more numerous** than inner hair cells

inner hair cells

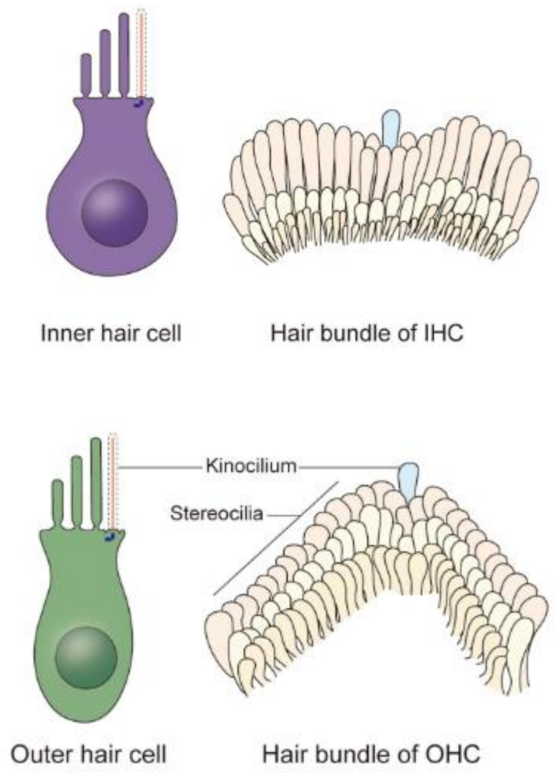
the actual **sensory receptors** => and 95% of the **fibers** of the **auditory nerve** that project to the brain arise from this subpopulation

Let’s visualize all this



https://www.youtube.com/watch?v=vhizzJApNV0

The hair cells



Wang & Zhou, (2021)

auditory receptors are called **hair cells** because each one has 10–300 hairy-looking **stereocilia** extending from its top

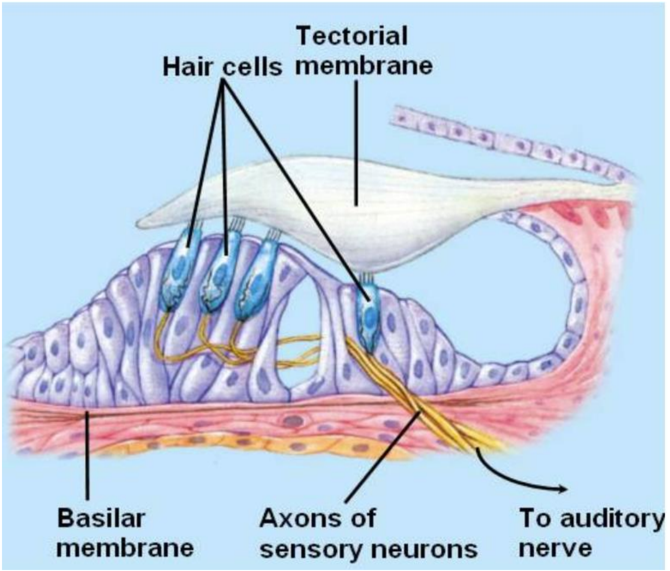
Hair cells lack axons => are **not neurons**, and **do not generate** action potentials. They are specialized **epithelial** cells.

(1) A tone initiates a **traveling wave** in the cochlea that propagates from the base toward the apex of the **basilar membrane**.

(2) The traveling wave initiates **sensory transduction** by **displacing** the sensory **hair cells** that sit atop the basilar membrane.

Because the **basilar membrane** and the **tectorial membrane** are anchored at different positions, the traveling wave causes a **shearing motion** between them.

This shearing motion bends the **stereocilia** => **electrical receptor potentials**.



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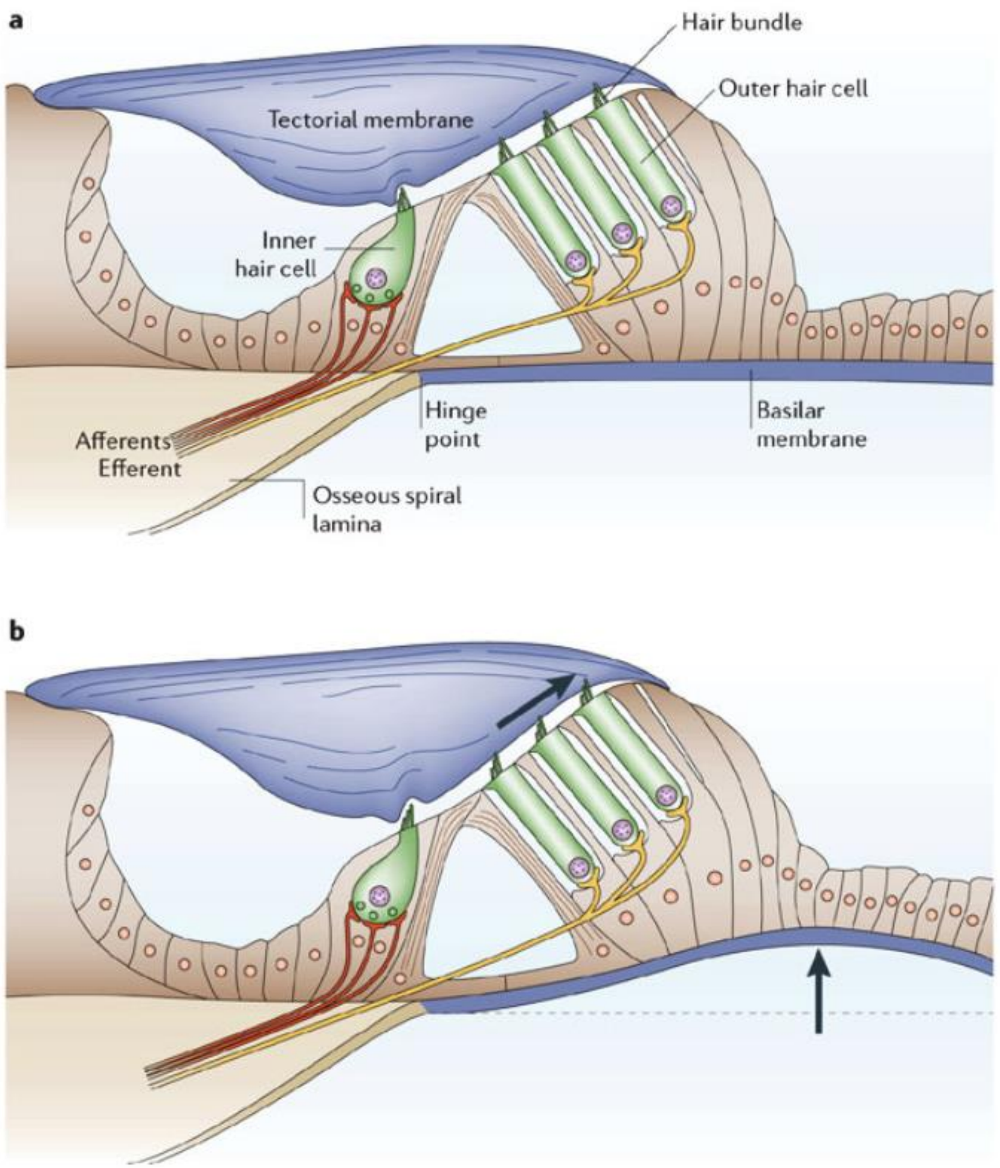
When the **basilar membrane** bends following a sound wave, the **hair cells** brush up against the **tectorial membrane**.



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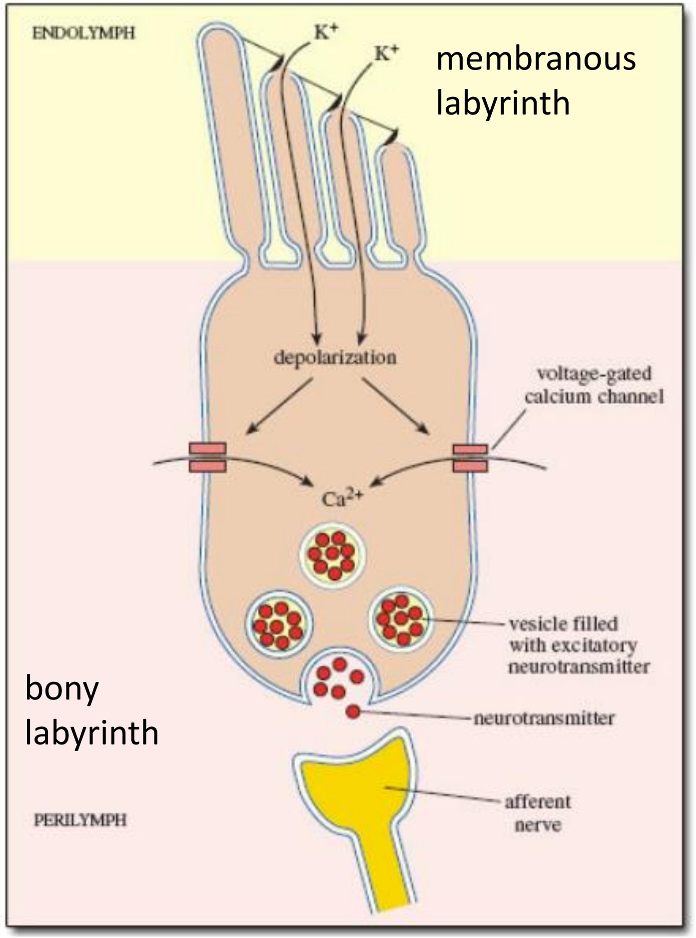

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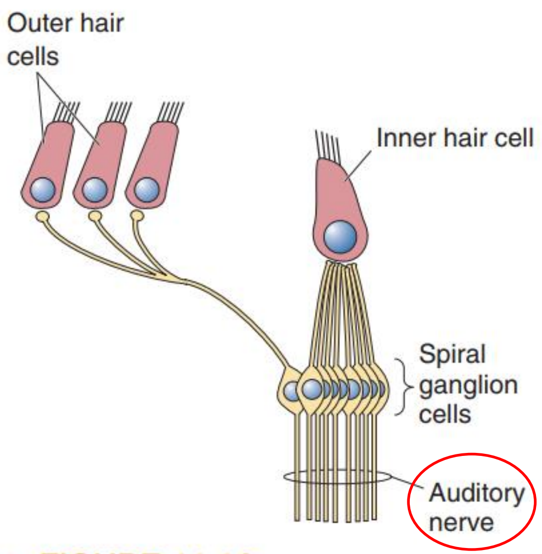
The bending of the stereocilia opens pores at their tips which allows **positively charged potassium ions** to enter and **depolarize** the cell. This receptor potential opens **voltage-gated channels** which allow **calcium ions** to enter the cell and trigger the release of **neurotransmitters** at the bottom of the cell.

The spiral ganglion cells



▲ FIGURE 11.16
The innervation of hair cells by neurons from the spiral ganglion.

Bear et al., (2015), p. 386

The initial bridge between the physical world of sound and perception of that sound is established by **neurons** of the **spiral ganglion**. These are the first cells in the **auditory pathway** to fire **action potentials**.

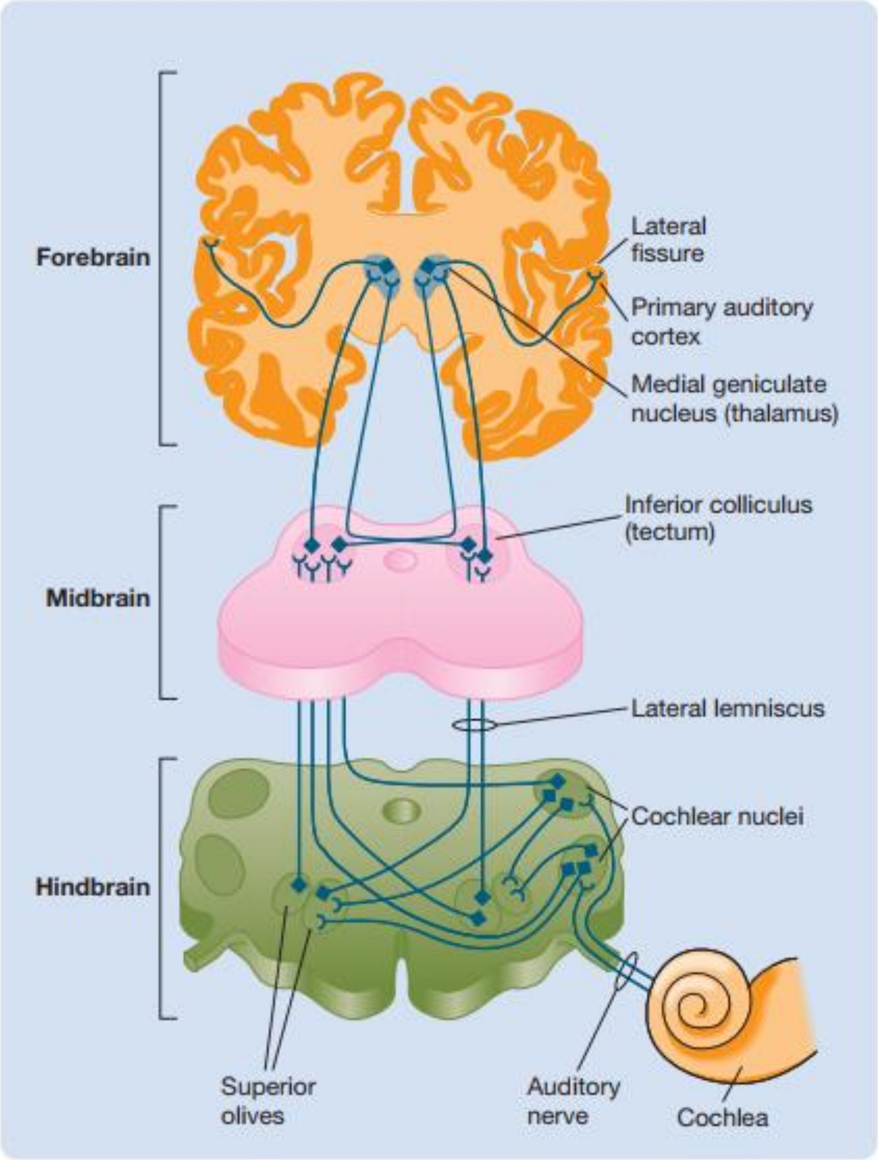
The **cell bodies** of these neurons give rise to **peripheral processes** that contact acoustic receptors in the organ of Corti (i.e., **hair cells**), and the **central processes** collectively form the **auditory nerve** that projects into the brain.

One spiral ganglion fiber receives input from **only one inner hair cell**; moreover, each inner hair cell feeds about 10 spiral ganglion neurites. The situation is the opposite with outer hair cells. Because they outnumber their spiral ganglion cells, **one spiral ganglion fiber** synapses with **numerous outer hair cells**.

*Note: the **vestibulocochlear nerve (VIII)**, contains: the **acoustic/auditory nerve**, and the **vestibular nerve**.*

The auditory pathway

Figure 7.5 Some of the pathways of the auditory system that lead from one ear to the cortex.



Pinel & Barnes, (2021), p. 190

Auditory cortex

⇧

Medial geniculate nucleus

⇧

Inferior colliculus

⇧

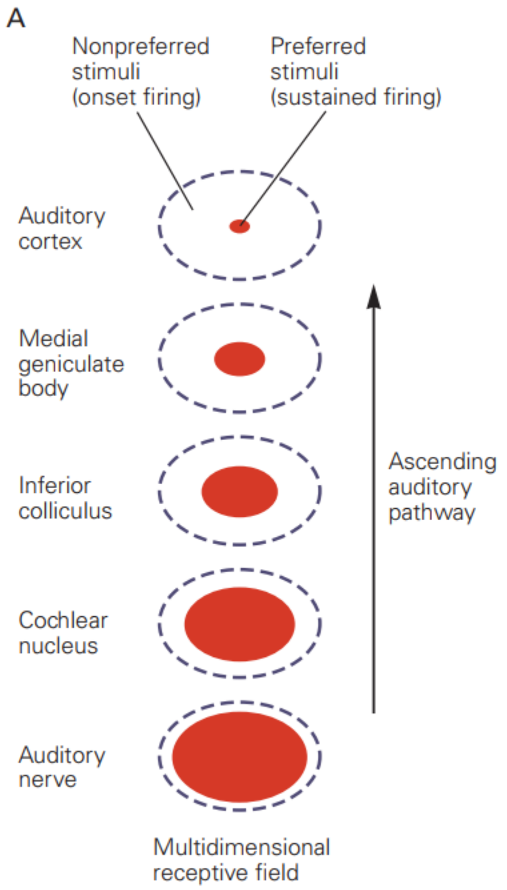
Superior olivary complex

⇧

Cochlear nucleus

⇧

Cochlear nerve

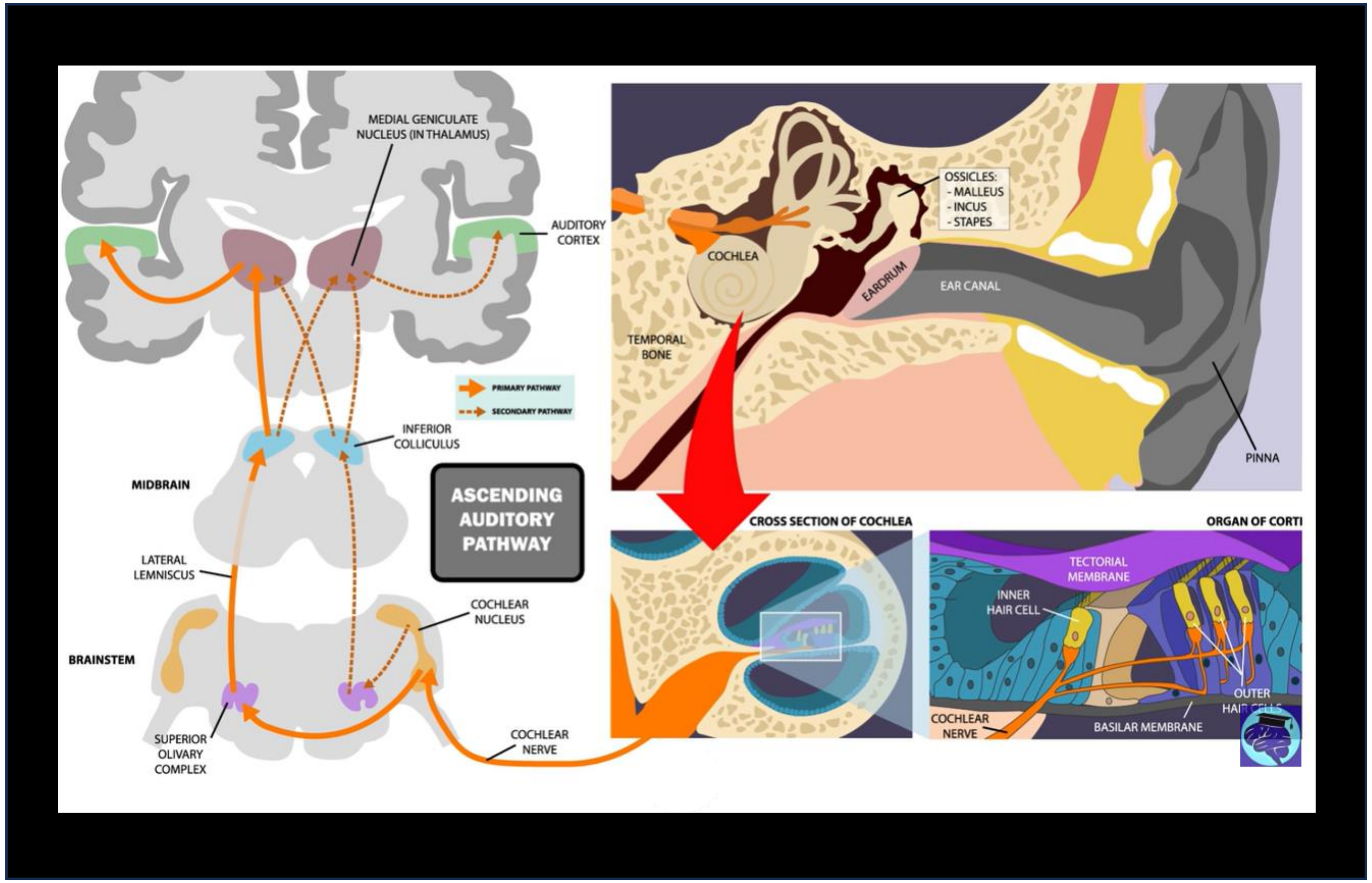


Kandel et al., (2021), p. 667

ascending pathway/ ascending tract

sensory pathway that carries

peripheral sensations to the **brain**



https://tinyurl.com/ce2ayav9

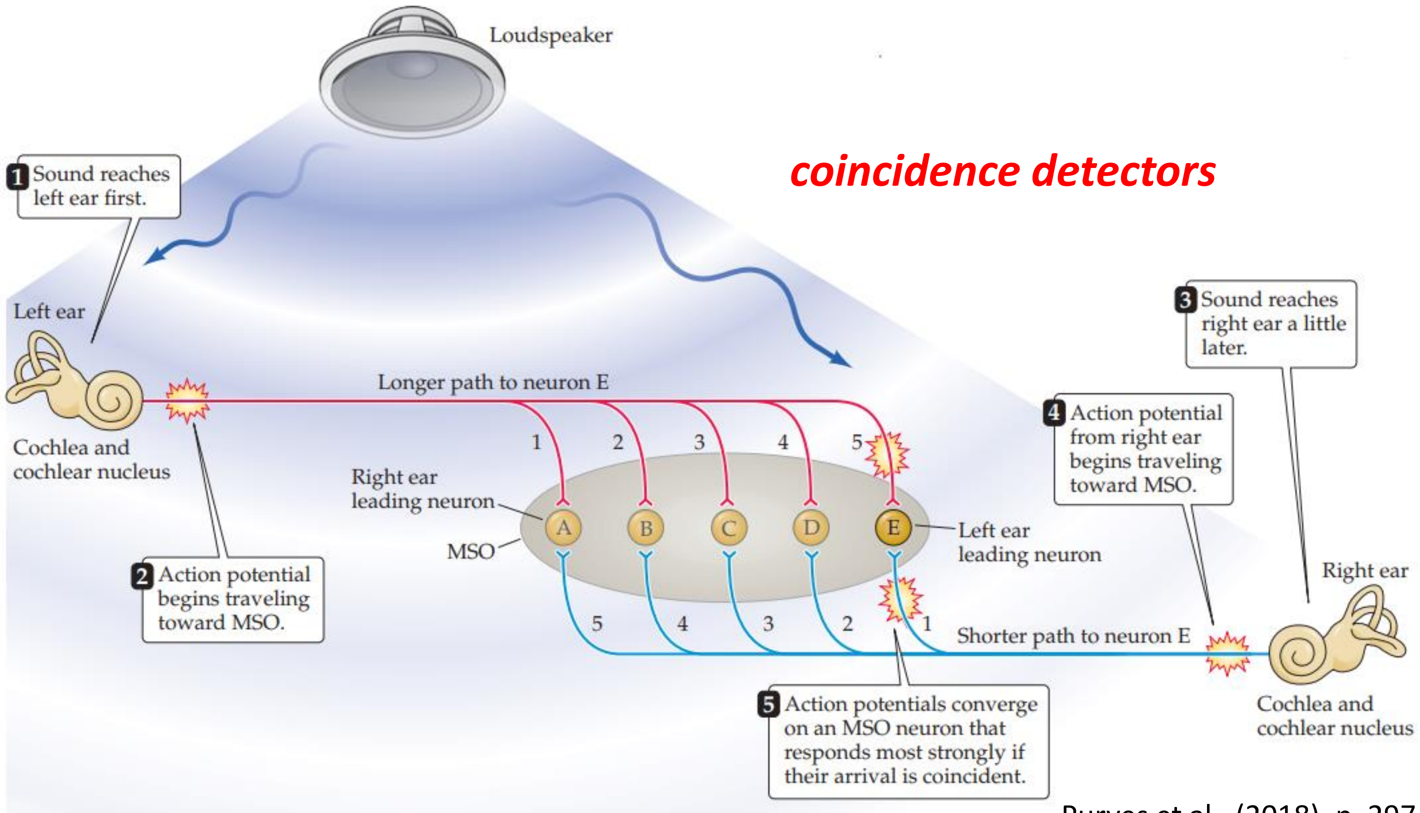
High degree of **bilateral connectivity** of the **ascending projections** of the auditory brainstem => **damage** to **central** auditory structures => almost **never monaural hearing loss** => monaural hearing loss strongly implicates unilateral **peripheral damage** (i.e., to the middle or inner ear or to the auditory nerve).

Sound localization

The **medial superior olive (MSO)** contains cells with **bipolar dendrites** that extend both **medially** and **laterally**. The **lateral** dendrites receive excitatory input from the **ipsilateral** anteroventral **cochlear nucleus**, and the **medial** dendrites receive excitatory input from the **contralateral** anteroventral **cochlear nucleus**.

The **axons** that project from the anteroventral cochlear nucleus **vary systematically in length** to create **delay lines**. These anatomical differences **compensate** for sounds arriving at slightly **different times** at the two ears, so that the resultant neural impulses arrive at a particular **MSO neuron** simultaneously, making each cell especially **sensitive** to **sound sources** in a particular place.

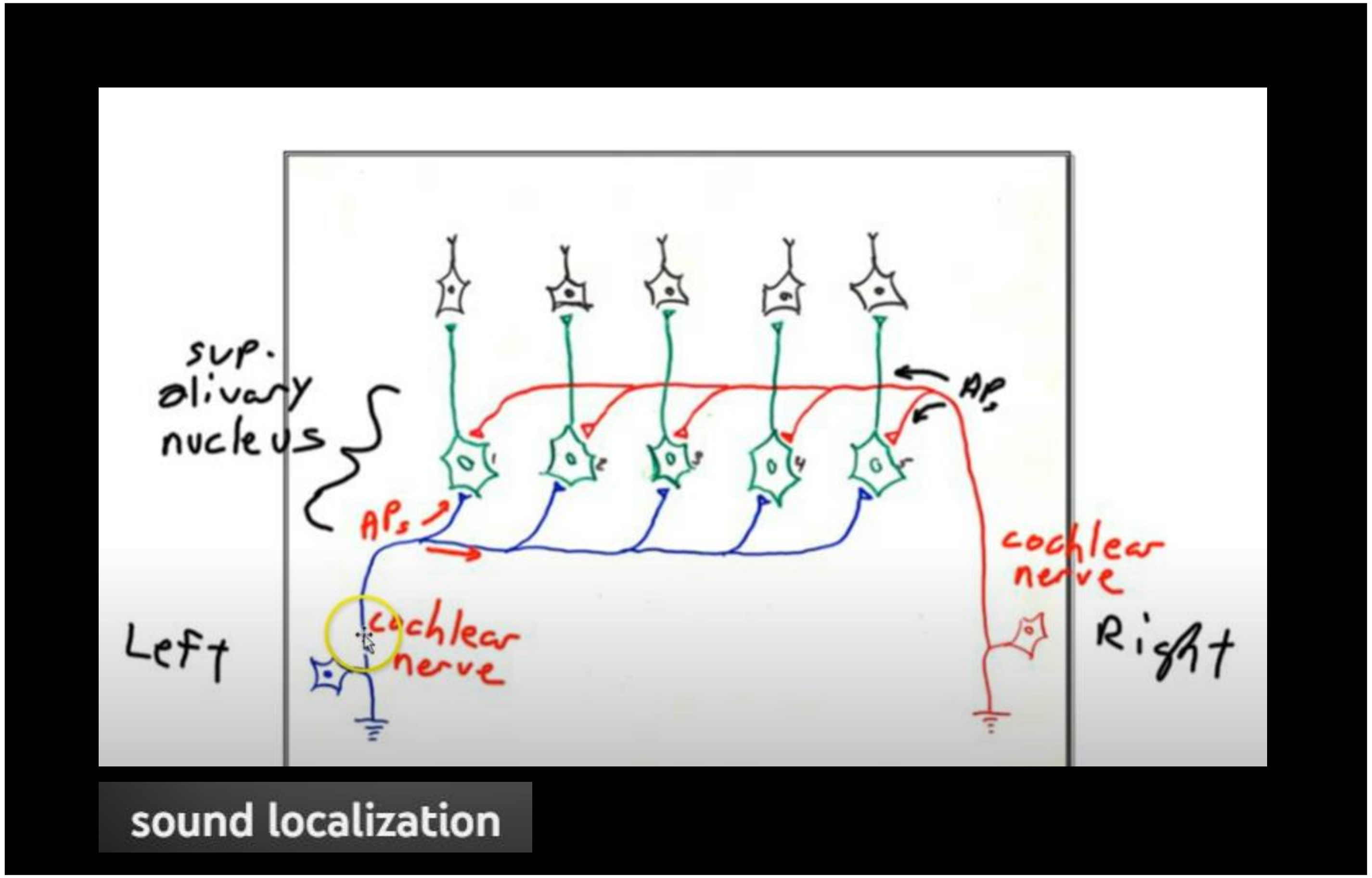
coincidence detectors



Purves et al., (2018), p. 297

FIGURE 13.14 A model of how the MSO computes the location of a sound by interaural time differences. A given MSO neuron responds most strongly when the two inputs arrive simultaneously, as occurs when the contralateral and ipsilateral inputs precisely compensate (via their different lengths) for differences in the time of arrival of a sound at the two ears. The systematic (and inverse) variation in the delay lengths of the two inputs creates a map of sound location. In this model, neuron E in the MSO would be most sensitive to sounds located to the left, and neuron A to sounds from the right; neuron C would respond best to sounds coming from directly in front of the listener. (After Jeffress, 1948.)

Let's visualize all this

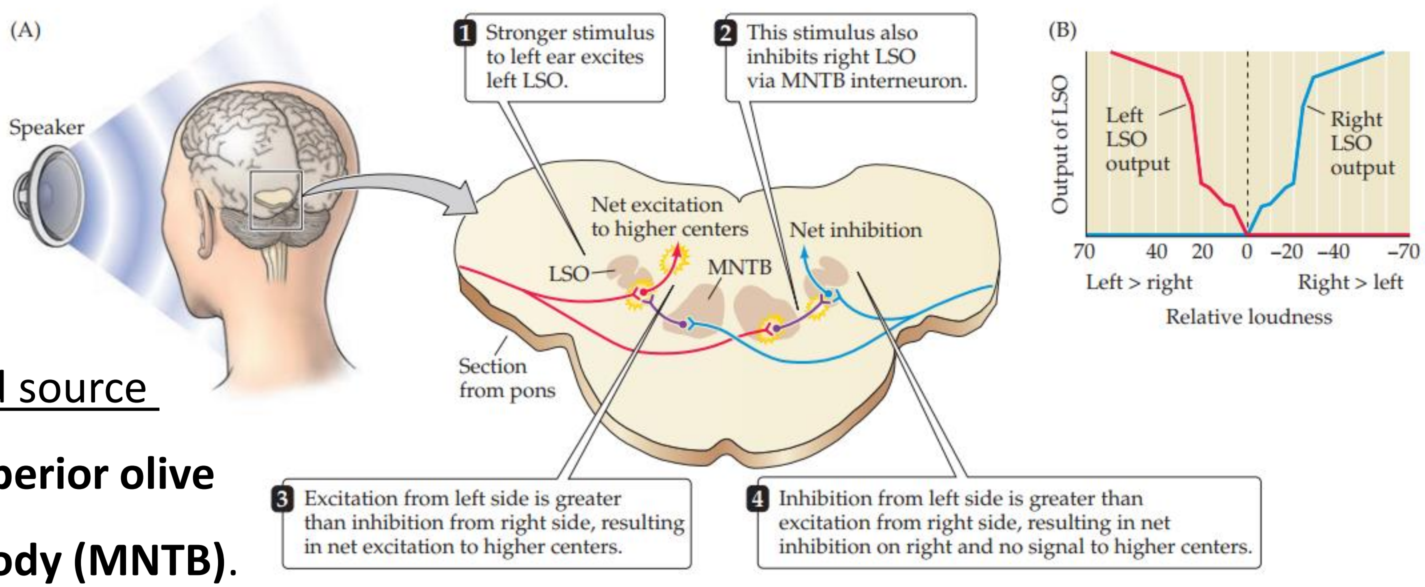


https://www.youtube.com/watch?v=yza-hpIubxQ

Sound localization perceived via **interaural time differences** works only for frequencies **below 3 kHz** => second mechanism must come into play at **higher frequencies**.

The circuits that compute the position of a sound source based on its **loudness** are found in the **lateral superior olive (LSO)** and the **medial nucleus of the trapezoid body (MNTB)**.

Excitatory axons project from the **ipsilateral** anteroventral cochlear nucleus to the **LSO**. The LSO also **receives inhibitory input** from the **contralateral** ear via an **inhibitory neuron** in the **MNTB**. This **excitatory–inhibitory** interaction results in a **net excitation** of the **LSO** on the same side of the head as the sound source => **firing rates** will be **highest** in the **ipsilateral LSO**. Sounds closer to the listener's **midline** will elicit **lower firing rates** in the **ipsilateral LSO**.



Purves et al., (2018), p. 298

FIGURE 13.15 LSO neurons encode sound location through interaural intensity differences. (A) LSO neurons receive direct excitation from the ipsilateral cochlear nucleus; input from the contralateral cochlear nucleus is relayed via inhibitory interneurons in the MNTB. (B) This arrangement of excitation–inhibition makes LSO neurons fire most strongly in response to sounds arising directly lateral to the listener on the same side as the LSO, because excitation from the ipsilateral input will be great and inhibition from the contralateral input will be small. In contrast, sounds arising from in front of the listener, or from the opposite side, will silence the LSO output, because excitation from the ipsilateral input will be minimal, but inhibition driven by the contralateral input will be great. Note that LSOs are paired and bilaterally symmetrical; each LSO encodes only the location of sounds arising from the ipsilateral hemifield.

The inferior colliculus and the medial geniculate nucleus

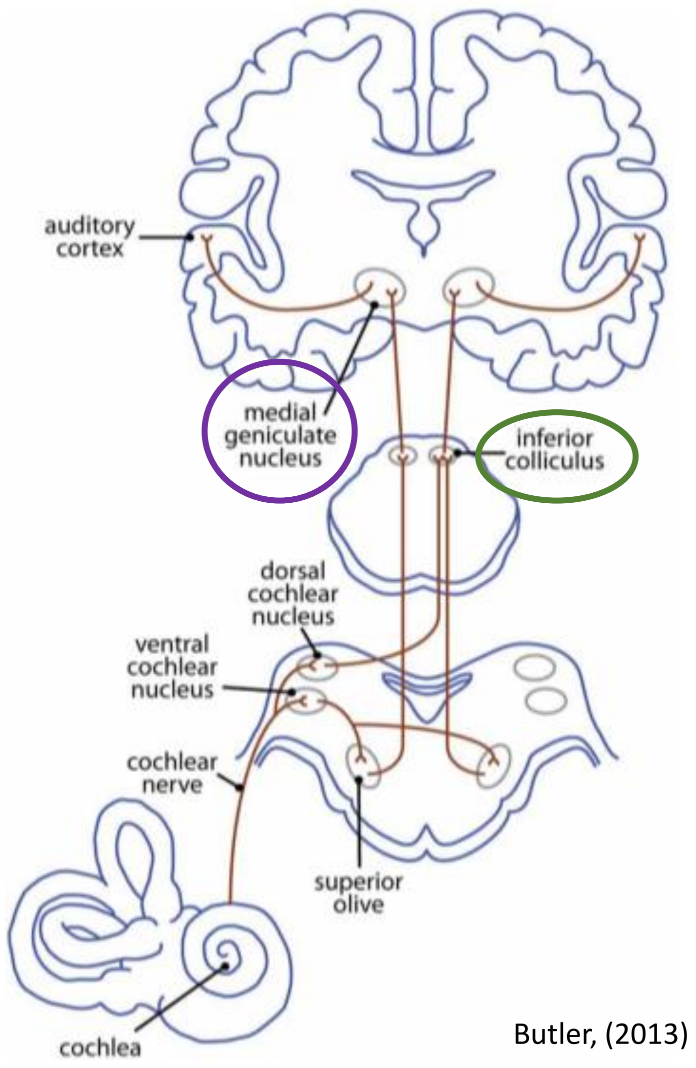


FIGURE 3 | The ascending mammalian auditory pathway—from cochlea to cortex.

The **inferior colliculus** can process sounds with **complex temporal patterns**, because many of its respond only to frequency-modulated sounds, while others respond only to sounds of specific durations or in specific temporal sequences => discriminating **pitch** and **rhythm**.

It also plays an important role in generating the **startle response** and **orienting** the body toward relevant stimuli.

The **medial geniculate nucleus** has three subdivisions: (1) the **ventral** division, which projects to the **core region of the auditory cortex**, and the (2) **medial** and (3) **dorsal** divisions, which are organized like a belt around the ventral division and **project to the belt regions** surrounding the core region of the **auditory cortex.**

Tonotopy characterizes both the **inferior colliculus** and the **ventral division of the medial geniculate nucleus**.

The auditory cortex

Auditory cortical **lesions** => deficits in **speech** and **music perception**.

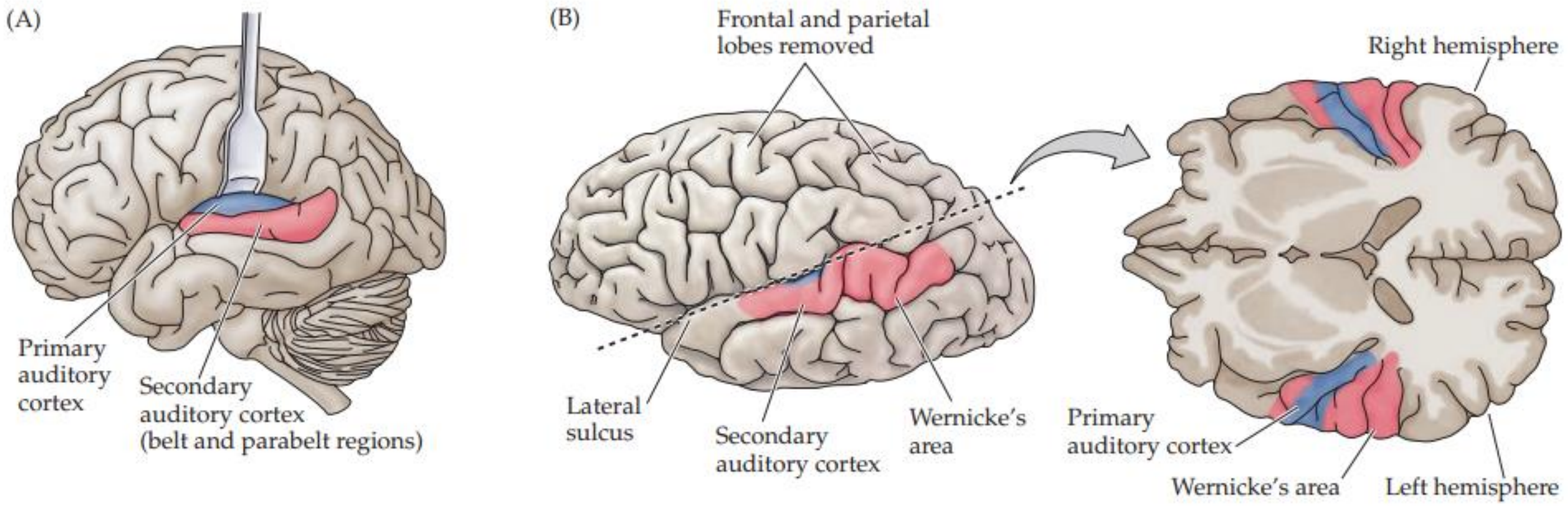
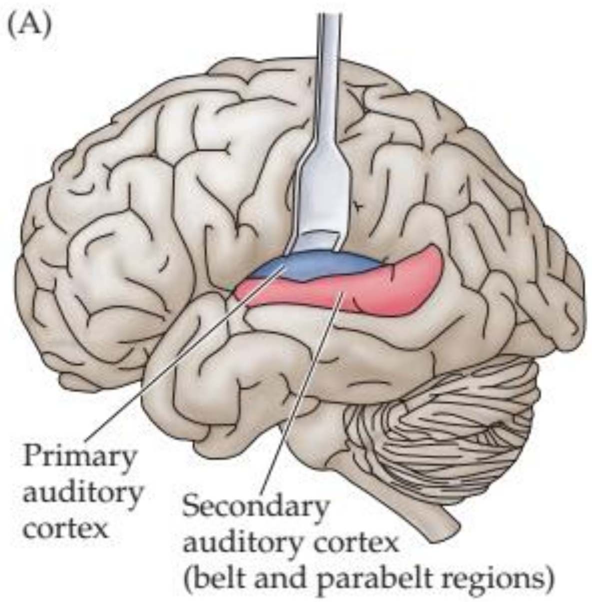


FIGURE 13.16 The human auditory cortex. (A) Diagram showing the brain in left lateral view, including the depths of the lateral sulcus, where part of the auditory cortex occupying the superior temporal gyrus normally lies hidden. The core region is shown in blue; the surrounding belt regions of the auditory cortex are in red. (B) Diagram of the brain in left lateral view, showing locations of human auditory cortical regions related to processing speech sounds in the intact hemisphere. Right: An oblique section (plane of dashed line) shows the cortical areas on the superior surface of the temporal lobe. Note that Wernicke's area, a region important in comprehending speech, is just posterior to the primary auditory cortex.

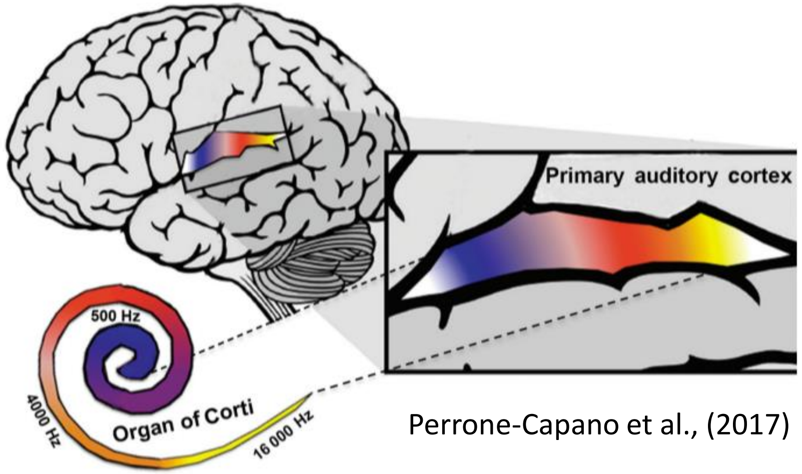
Purves et al., (2018), p. 301



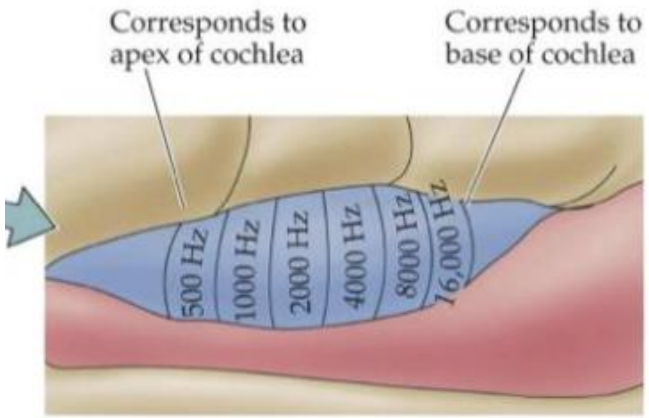
Primary (i.e., core) and secondary (i.e., belt and parabelt) regions.

The core region (i.e., **Heschl's gyrus**, or Brodmann's areas 41 and 42) is buried in the lateral sulcus. It receives point-to-point input from the ventral division of the MGC => **precise tonotopic** maps.

The belt and parabelt regions of the auditory cortex receive more **diffuse input** from the MGC, as well as input from the primary auditory cortex => **less precise** in their **tonotopic** organization.



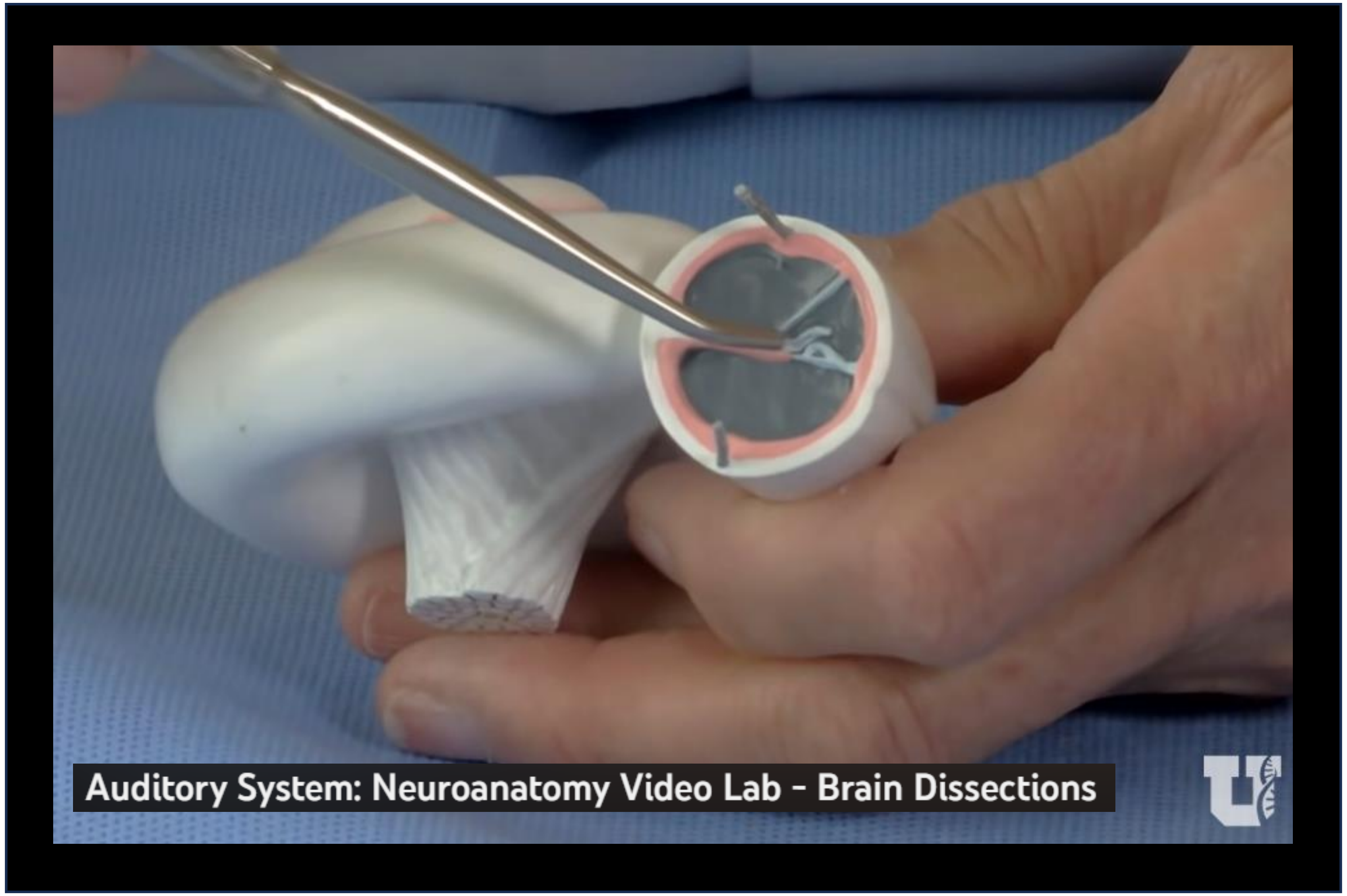
Perrone-Capano et al., (2017)



https://tinyurl.com/3mvvmp9f

Besides the tonotopic arrangement, there are irregular patches of neurons that are **excited by both ears** (and are therefore called **EE cells**) interspersed with patches of cells that are **excited by one ear and inhibited by the other ear (EI cells)**.

Extensive overview and anatomical localization



https://www.youtube.com/watch?v=4c4h3WfF3kA

Further resources

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