Lecture 9
Dorsal Stream & Hearing

PSYC 304

Announcements

Midterm 1 Review

- Next week, last 40 minutes of last class

Midterm 2

- June 26th, 2025
- SWING FLOOR 1 ROOM 121
- 7 pm

Schedule for next few weeks

- Vestibular system, olfaction, gustation & somato-sensation next week before optional exam review
- May need to push motor systems to next term. Will determine.

Reminders

- Magazine articles due tomorrow by midnight

Learning objectives

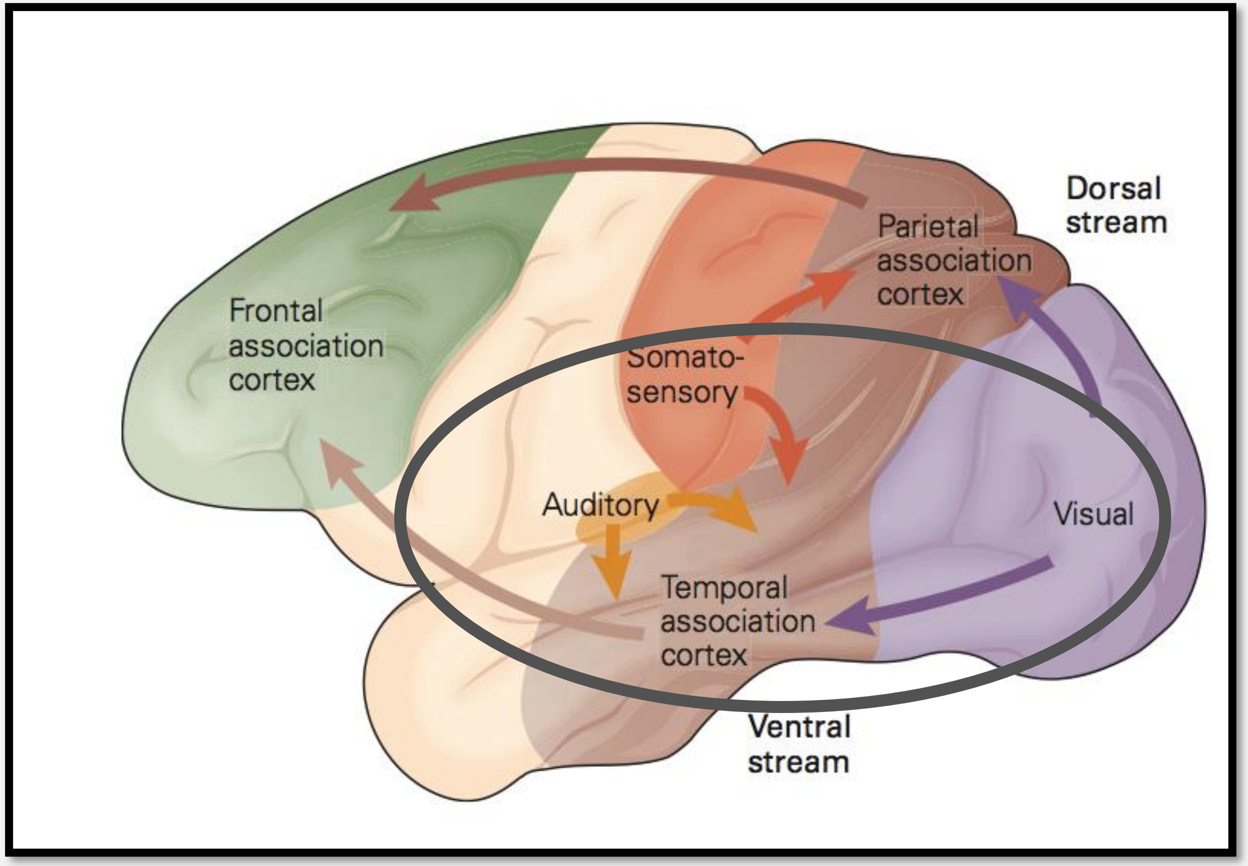
By the end of this lecture, you will be able to…

1. Describe what researchers have learned from individuals with damage to various aspects of the dorsal stream.
2. State two functions of hearing.
3. Describe 3 physical properties of sound waves
4. Understand the pathway of a sound wave from the environment to the cochlea within the inner ear.
5. Appreciate the structure of the cochlea.
6. Describe what is meant by a tonotopic map, from the basilar membrane to the primary auditory cortex.
7. Understand sensory transduction at the hair cell.
8. Conceptualize “coincidence” detectors as they relate to interaural time differences and detecting the location of sound
9. Recognize the key stops along the olfactory pathway
10. Provide two examples of how experience can impact one’s auditory system

Summary – The ventral stream

Ventral stream

- Related to object identity
- Uses shape, colour, touch, sound information to consciously identify objects
- Important for *semantic* knowledge (i.e., facts about the world)
- Neurons in the posterior portion exhibit more perceptual properties
- Neurons in the anterior portion exhibit more associative/memory properties



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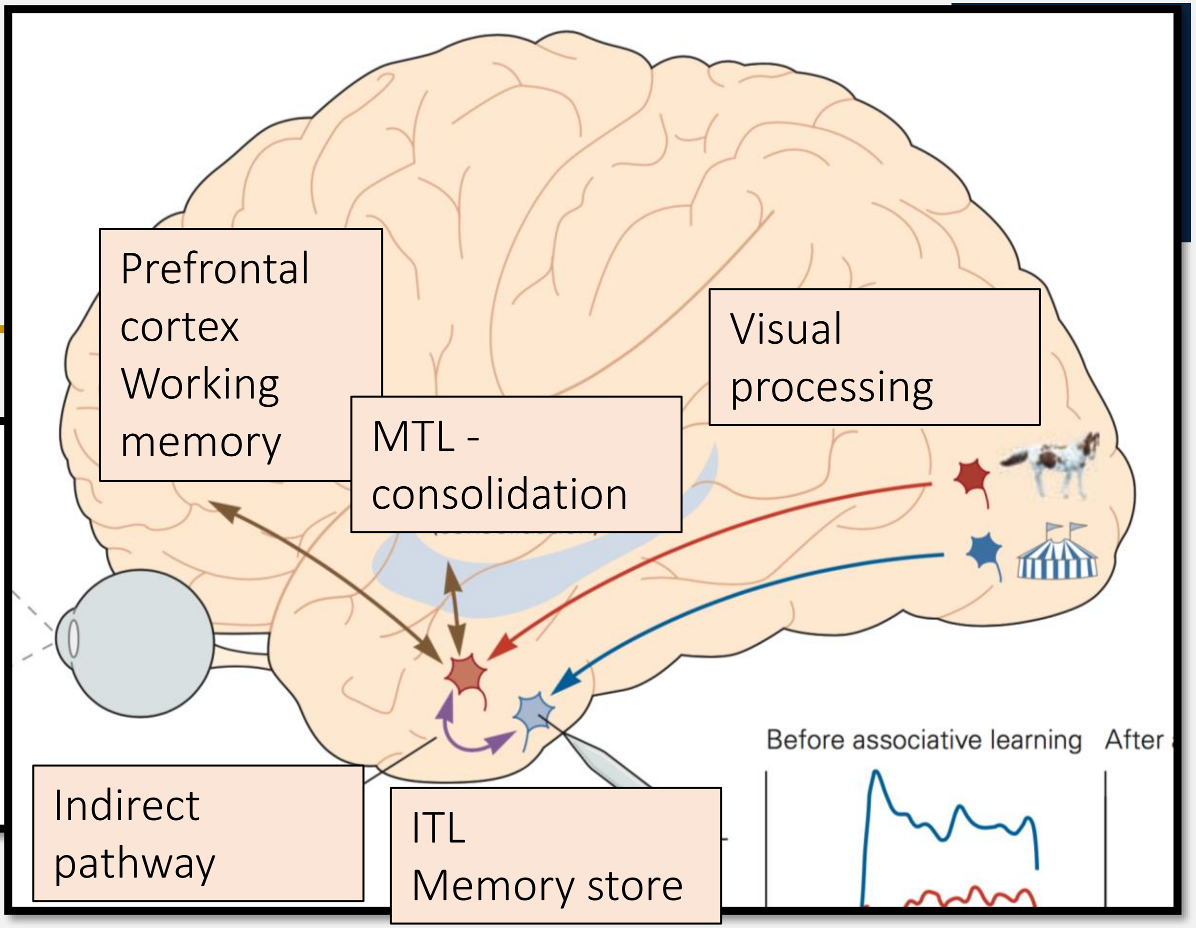
Associative learning

Inferior temporal lobe

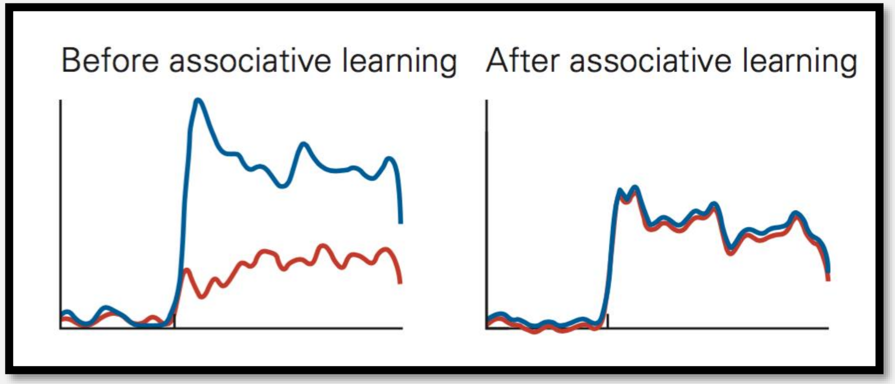
- Association of sensory inputs
- Distinct representation of separate stimuli



Medial temporal lobe

- (MTL) includes hippocampus
- Links neocortical representations

Tent presentation



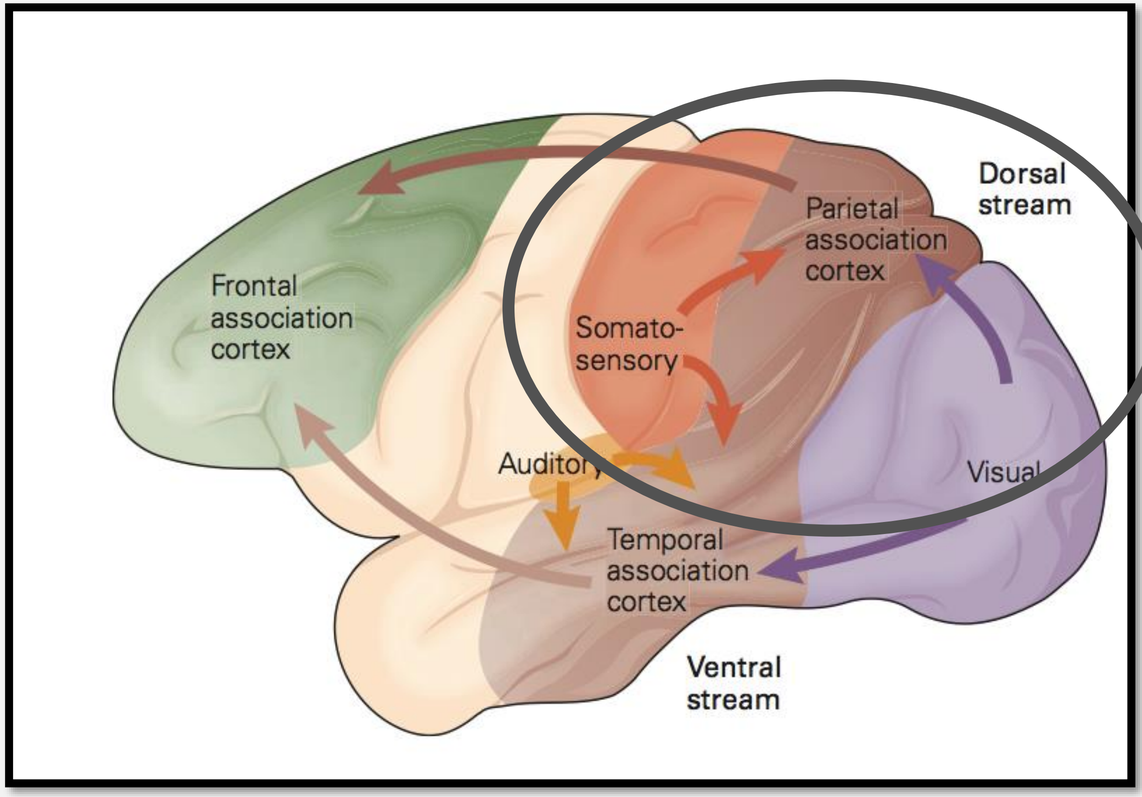
What do you think is the function of this??

Kandel Fig 28-13

Part II – The Dorsal Stream

Dorsal stream

- Parietal association cortex
- Processes information about space and movement
- Convergence of visual, somatosensory, vestibular information
- Guide attention and movement related to objects and spatial environments



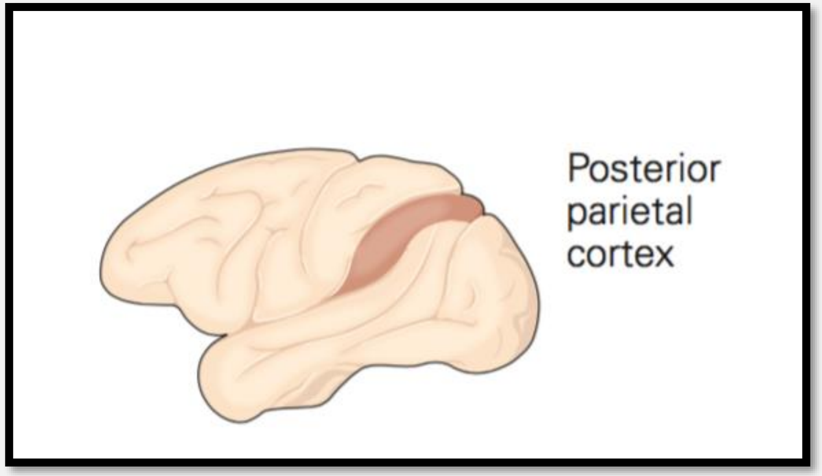
Approaches to understanding the function of a brain region

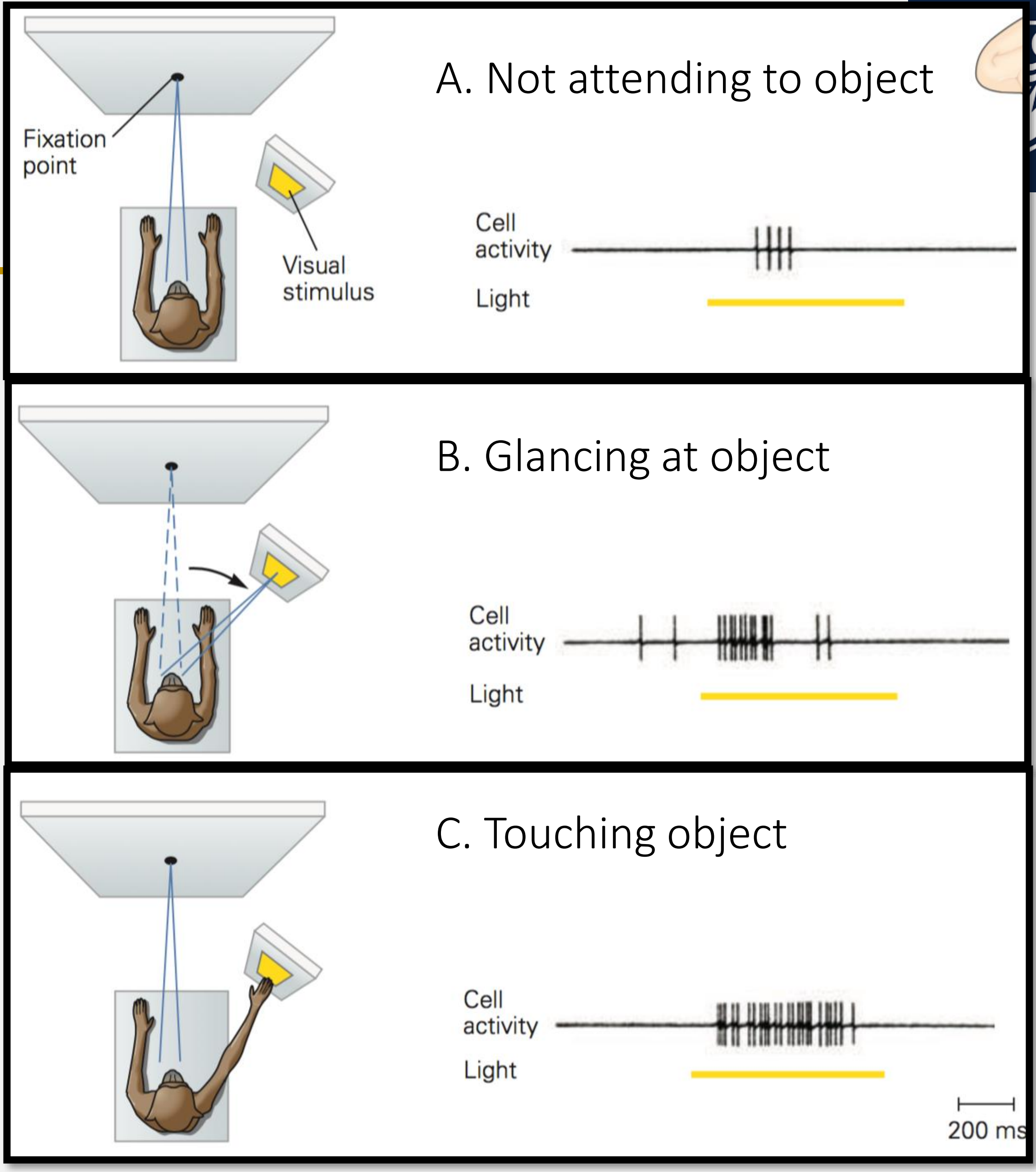
Models of investigating the “dorsal stream”

Dorsal stream

Posterior parietal neuron function

- *Animal models*
- RFs for stimuli in visual space
- Greater activity when engaging with a stimulus (glancing & reaching - attention)



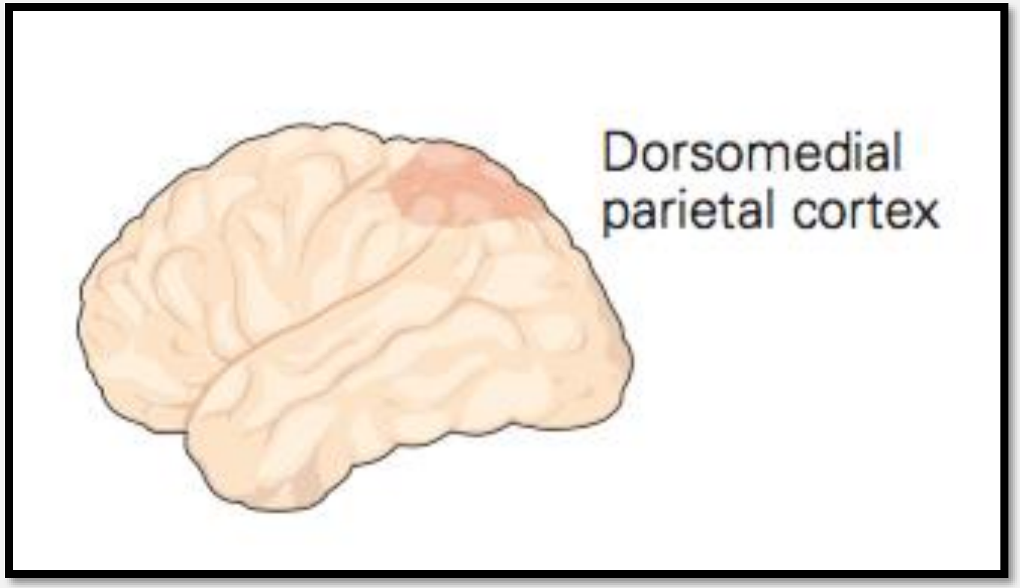


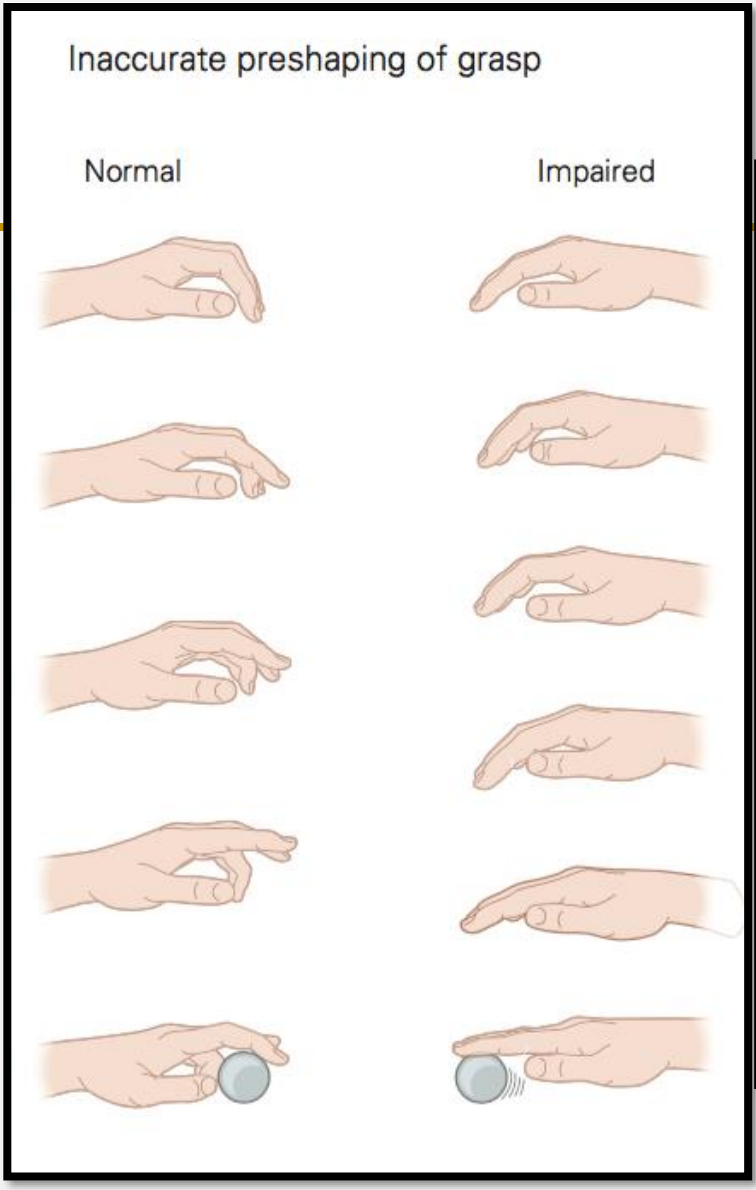
Kandel Fig. 17-15

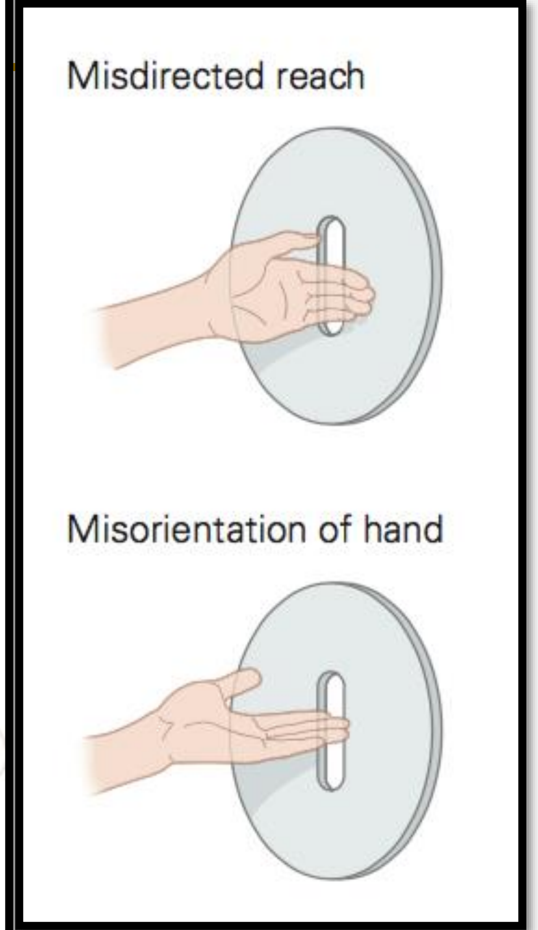
Dorsal stream

Dorsomedial parietal damage

- Motor deficits
- Shaping, grasping, orientation







Kandel Fig. 18-4

Dorsal stream

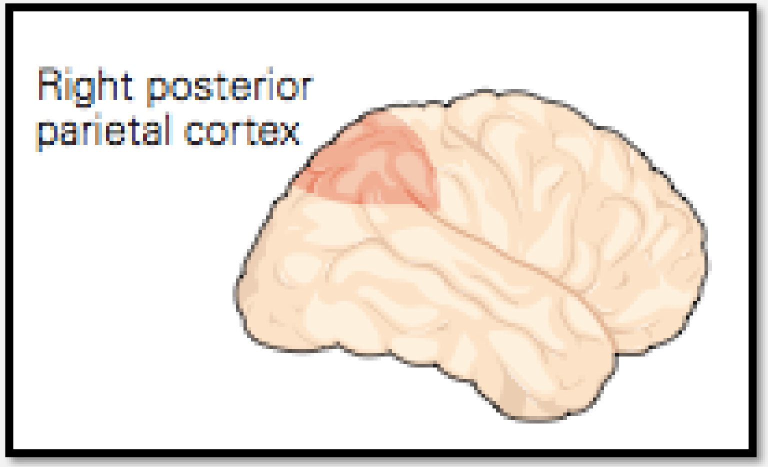
Parietal damage (dorsal area)

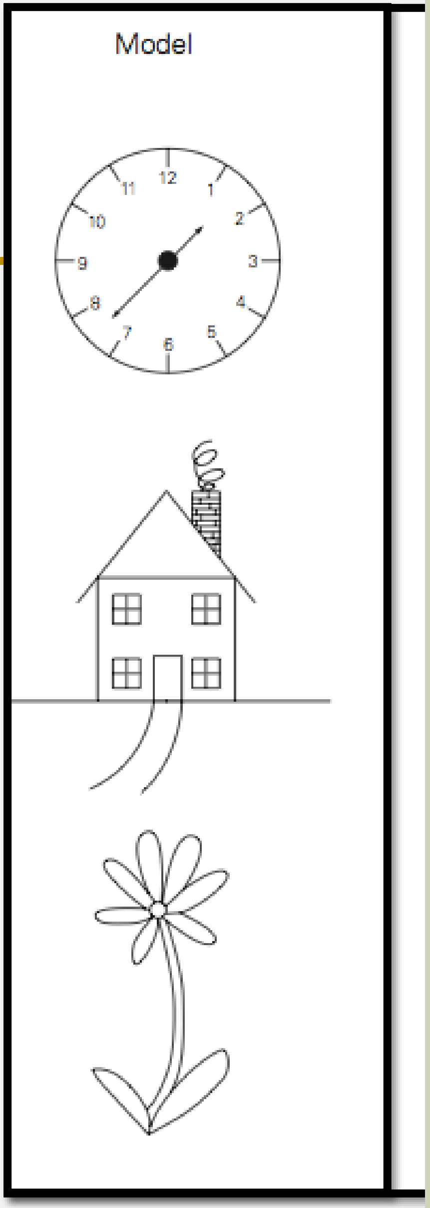
- Unilateral neglect
- Ego-centric neglect- *Personal neglect syndrome*
  - Asomatognosia
  - “Why is my ring on someone else’s hand!”
  - “Why is this leg in bed with me!”
- Ideomotor apraxia
  - Unable to execute certain movements
- Peri-centric neglect - Optic Ataxia
  - Difficulty reaching for an object in peripheral visual field

Dorsal Stream

Parietal associate cortex damage

- Dorsal stream, ventral area
- Sensory perceptual spatial neglect
- *How might someone with unilateral visual neglect following a lesion to the right posterior parietal cortex draw these images?*



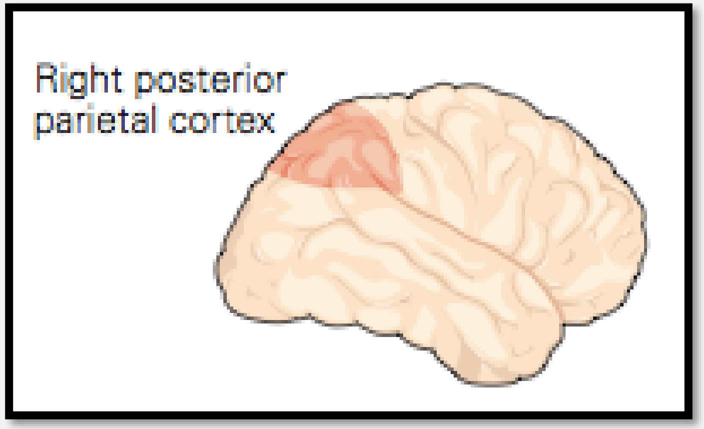


Kandel Fig. 17-11

Dorsal Stream

Parietal associate cortex damage

- Dorsal stream, ventral area
- Different stages of left neglect (hemi-neglect) for a patient recovering from a stroke to the right posterior parietal cortex



2 mos

3.5 mos

6 mos

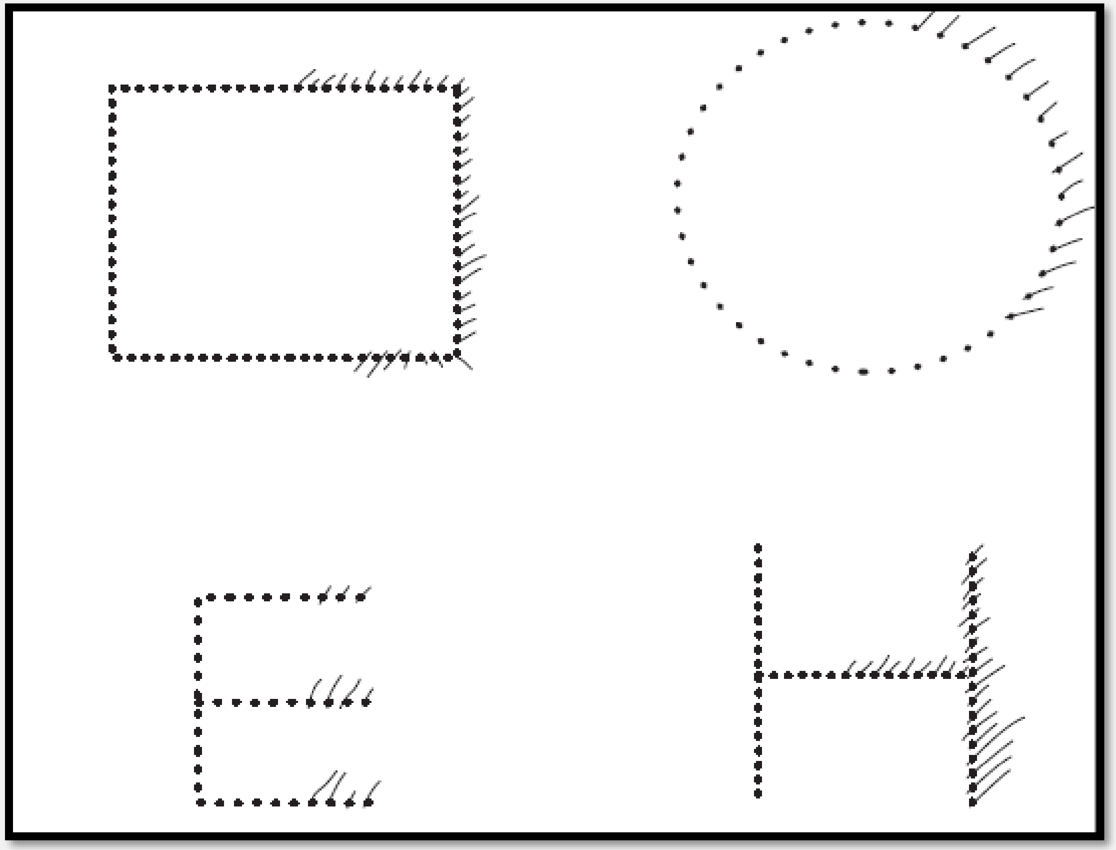
9 mos

Kandel Fig. 17-12

Dorsal Stream

Right posterior parietal cortex lesion

- Left spatial neglect

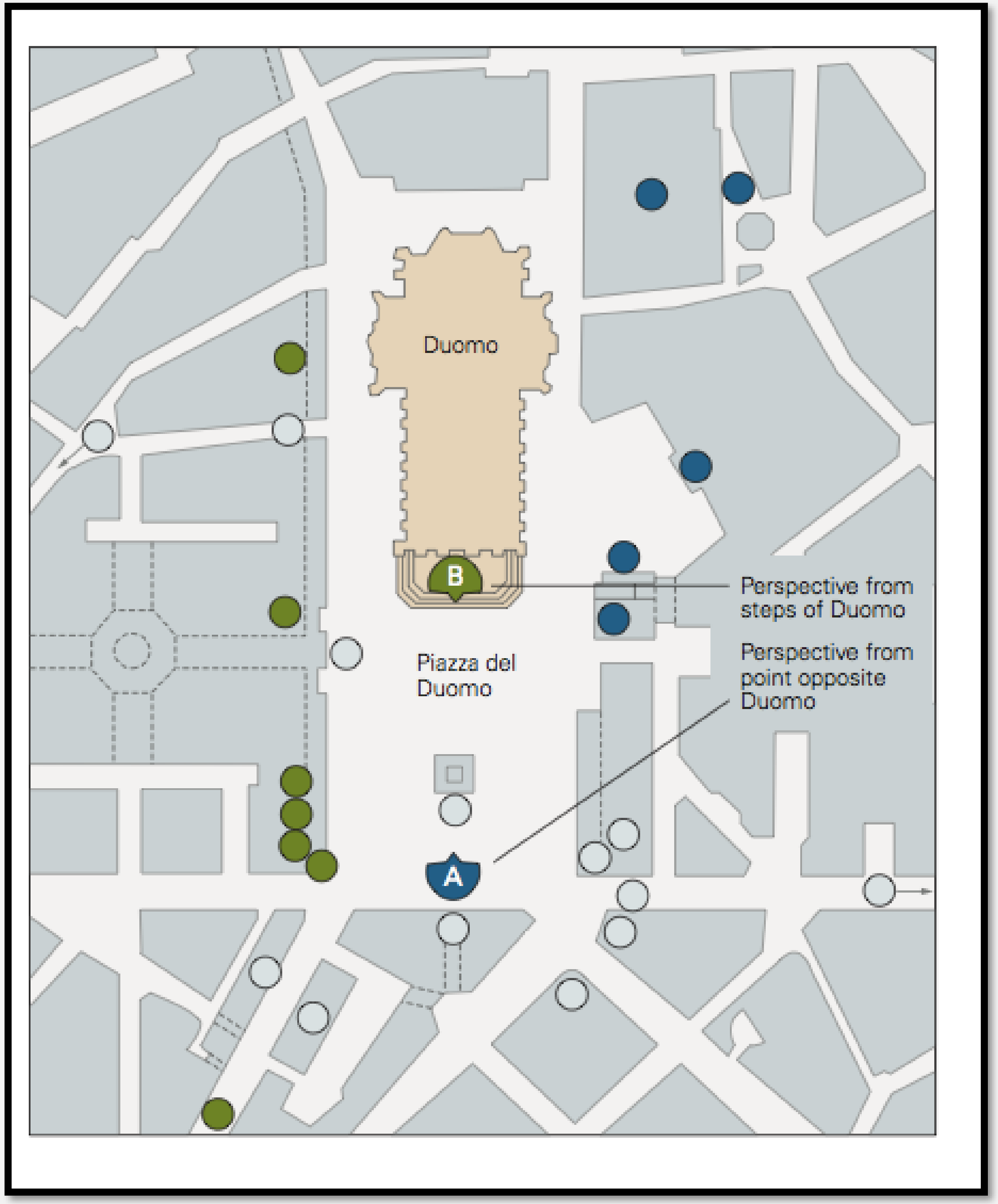


Kandel Fig. 17-13

Posterior parietal damage

Representational neglect

- ventral area of the dorsal stream
- Spatial neglect of recalled memories
- All patients had damage to the right parietal lobe
- ***Instruction:*** *Imagine you are standing the main square looking at the cathedral – describe from memory all the buildings around you*
- ***Results:*** *participants named all the buildings on the right-hand side!*
- ***Question:*** *How can you get them to remember the buildings on the left side?*



Kandel Fig17-14

Summary

Which types of deficits are associated with damage to each brain region?

Dorsal areas of parietal lobe

- Body awareness, visual guidance, motor behaviour
- (area close to the somatosensory cortex)

Ventral areas of the parietal lobe

- Spatial perception and cognition
- (areas closer to and connected to the visual cortex)

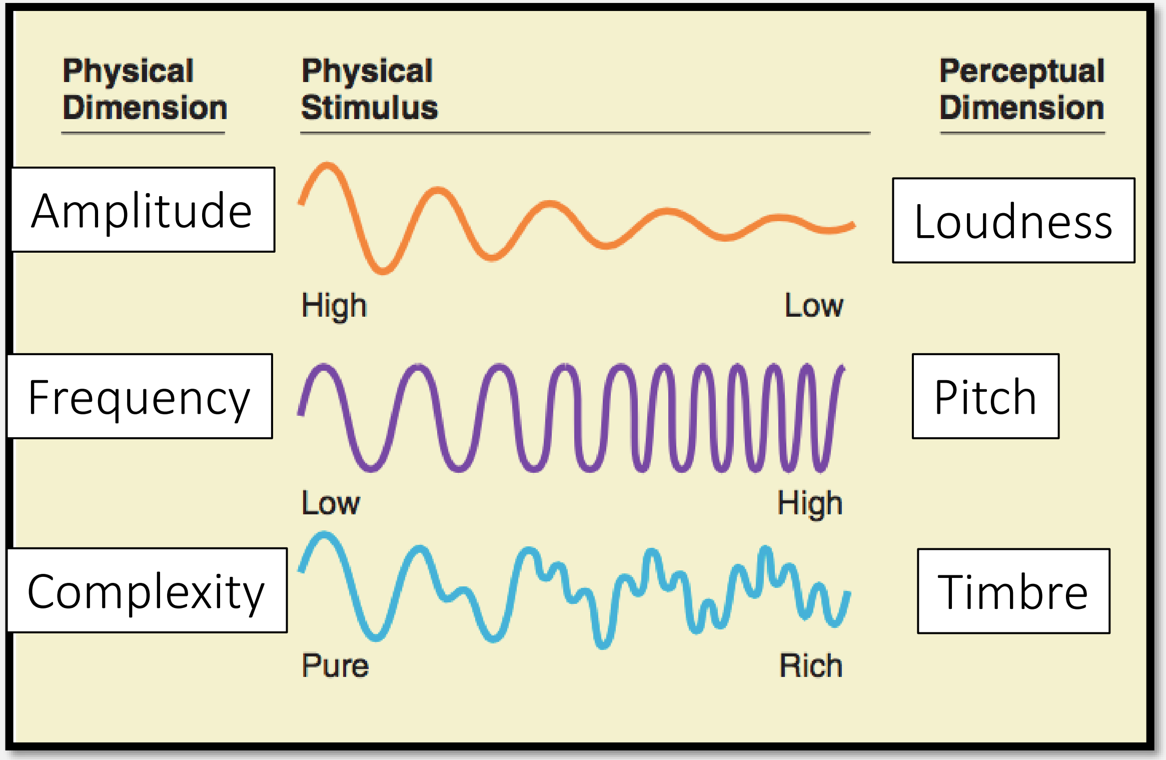
Hearing

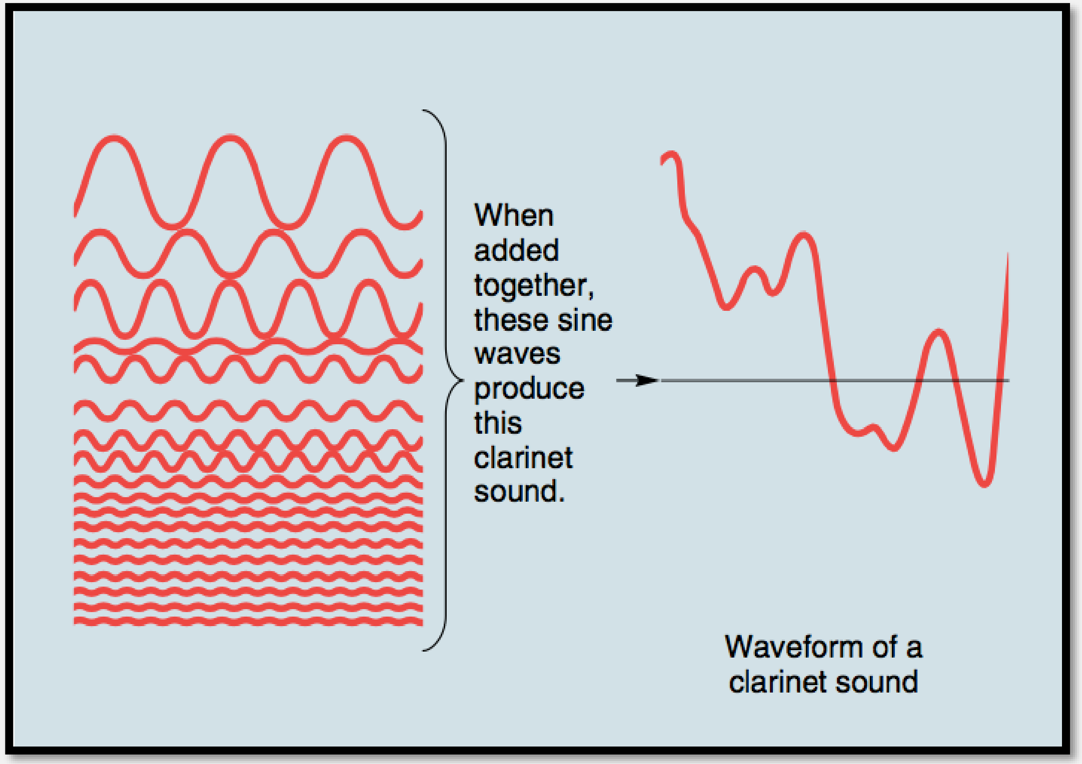
What is the purpose of hearing?

Sound localization in the wild

Top-down influence

Sound stimuli





20Hz 100Hz 250Hz 440Hz 1000Hz 10,000Hz 16,000Hz 20,000Hz

Everyday sounds

The ear (external and middle)

External Ear

- Captures and directs sound
- *SOUND:* pressure waves

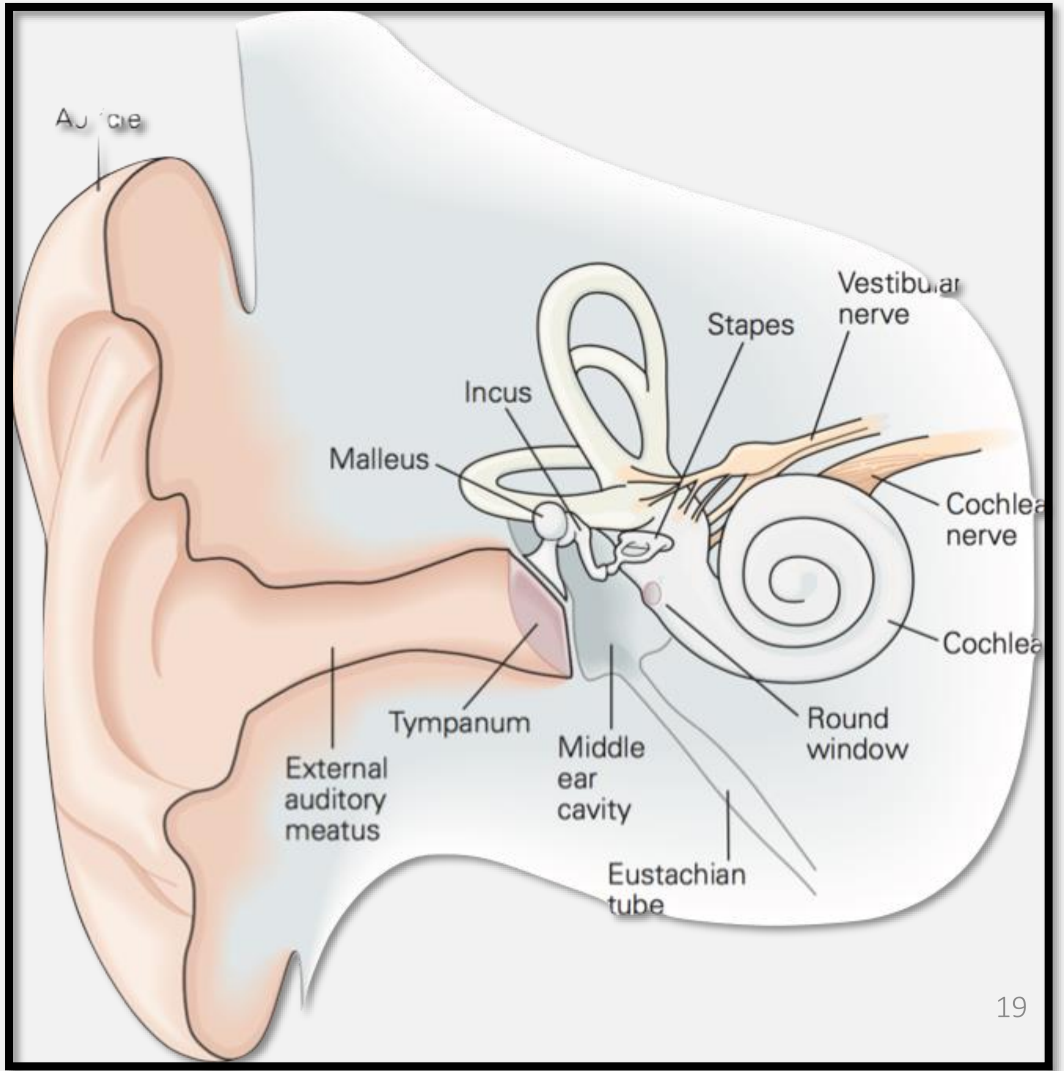
Ear Drum (tympanic membrane)

- Converts and air sound waves to vibrations in the ossicles

Ossicles

- Amplify and transfer vibrations to the oval window

Kandel Fig 30-1



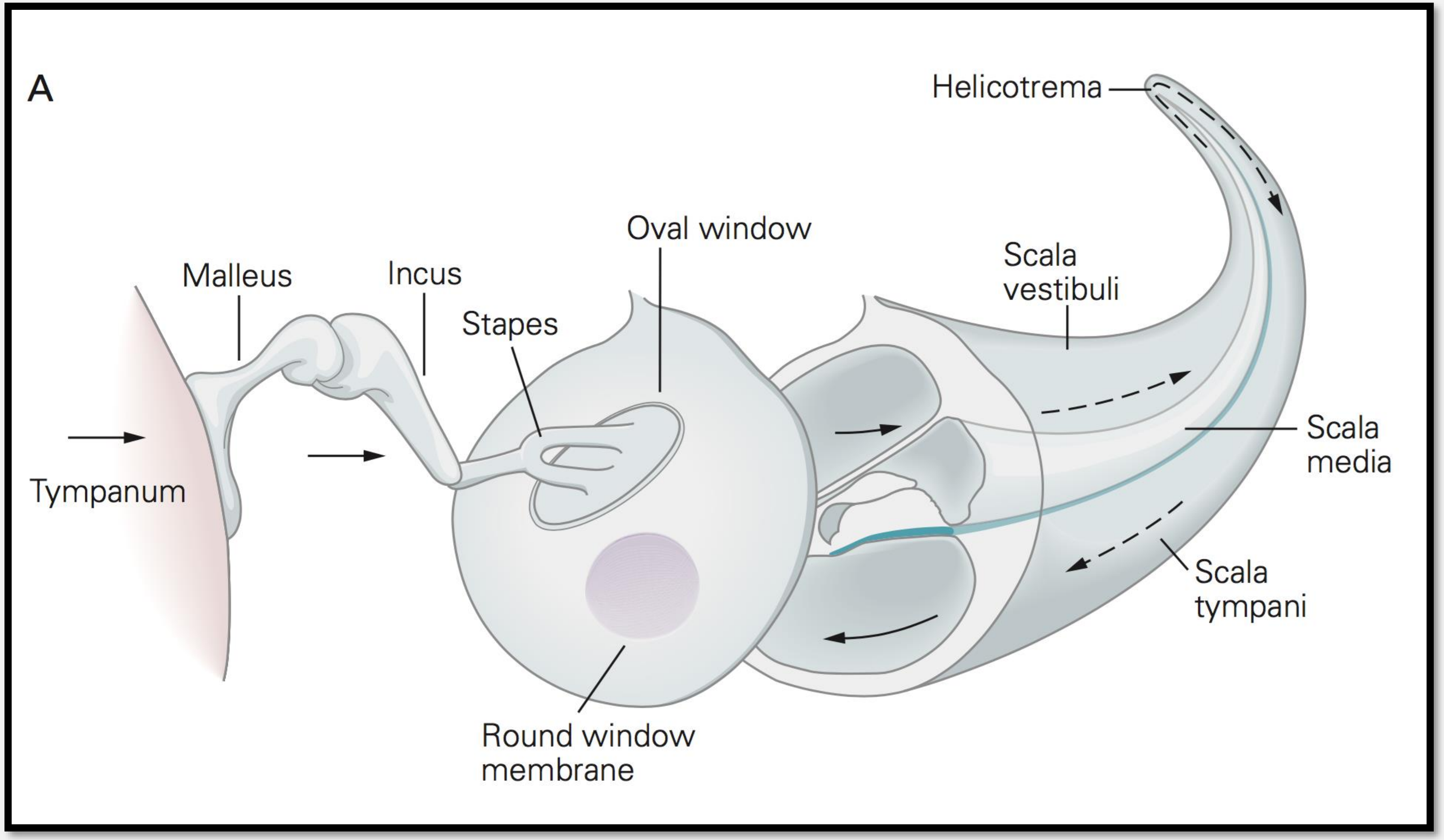
Inner Ear

Oval window

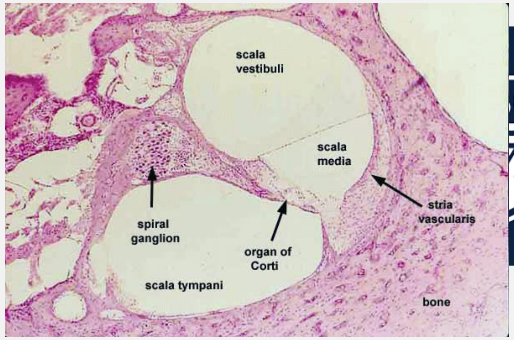
- Converts the vibrations to pressure waves in the cochlea
- Cochlea filled with incompressible fluid

Round window

- Allows movement of fluid



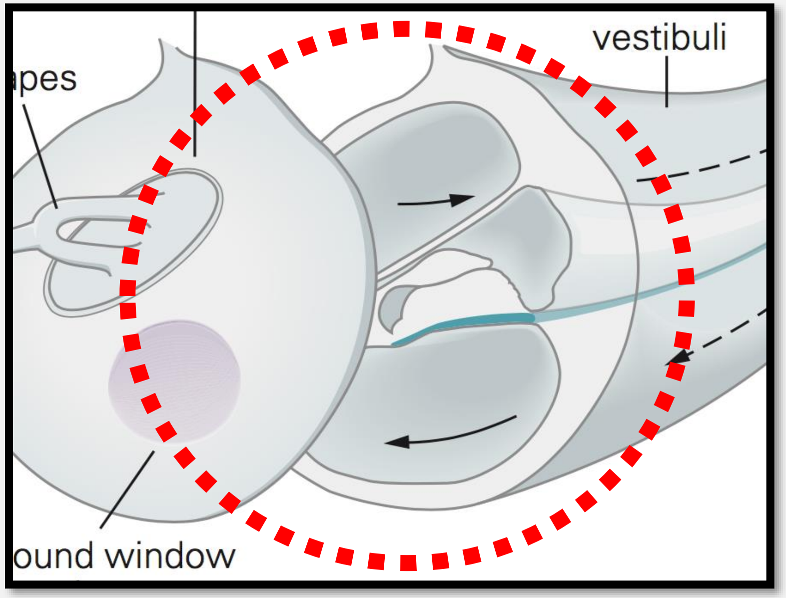
Kandel Fig 30-3

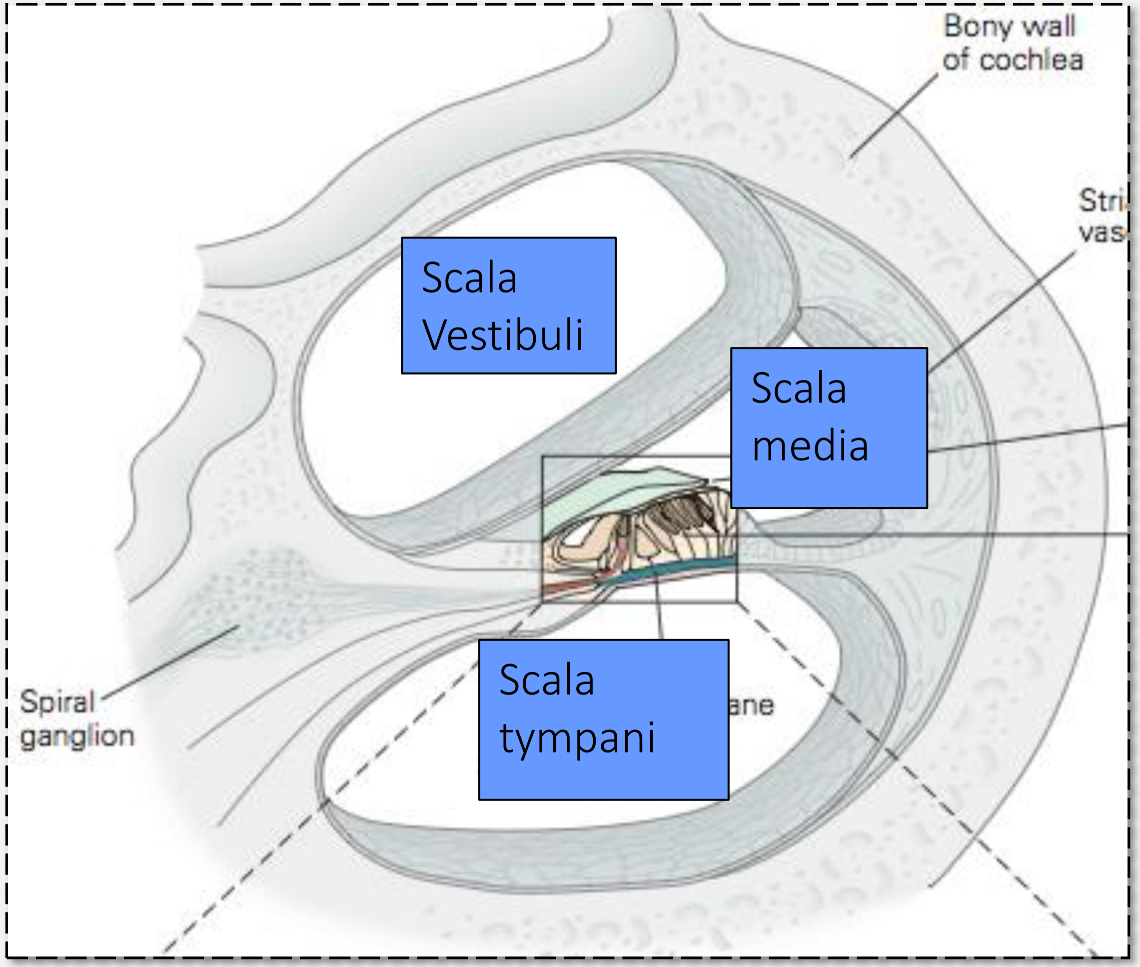


Inner Ear

Cochlea

- Incompressible fluid – Scala vestibuli and tympani
- Basilar membrane, hair cells, tectorial membrane – **Organ of Corti**



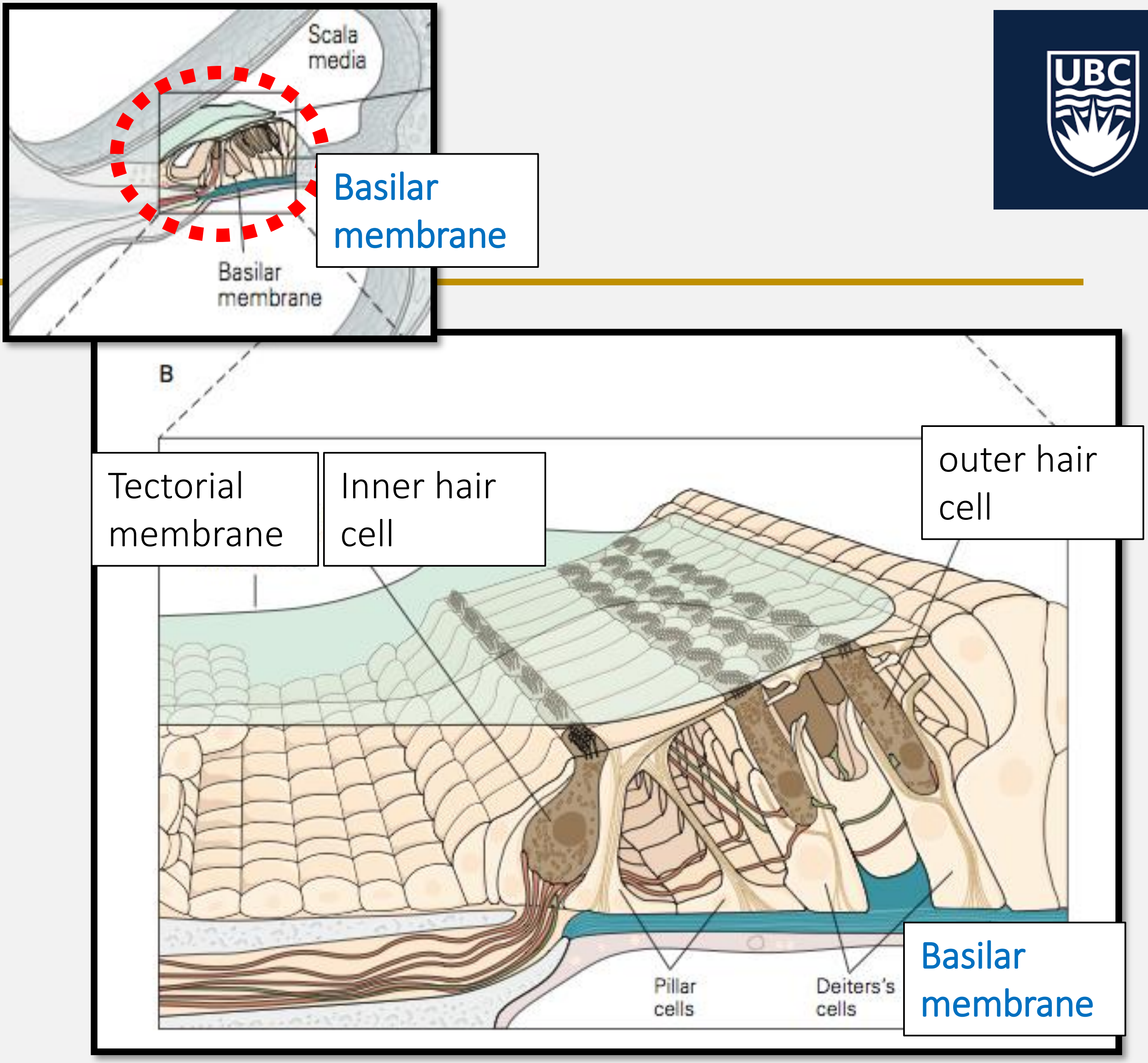


Kandel Fig 30-4

Inner ear

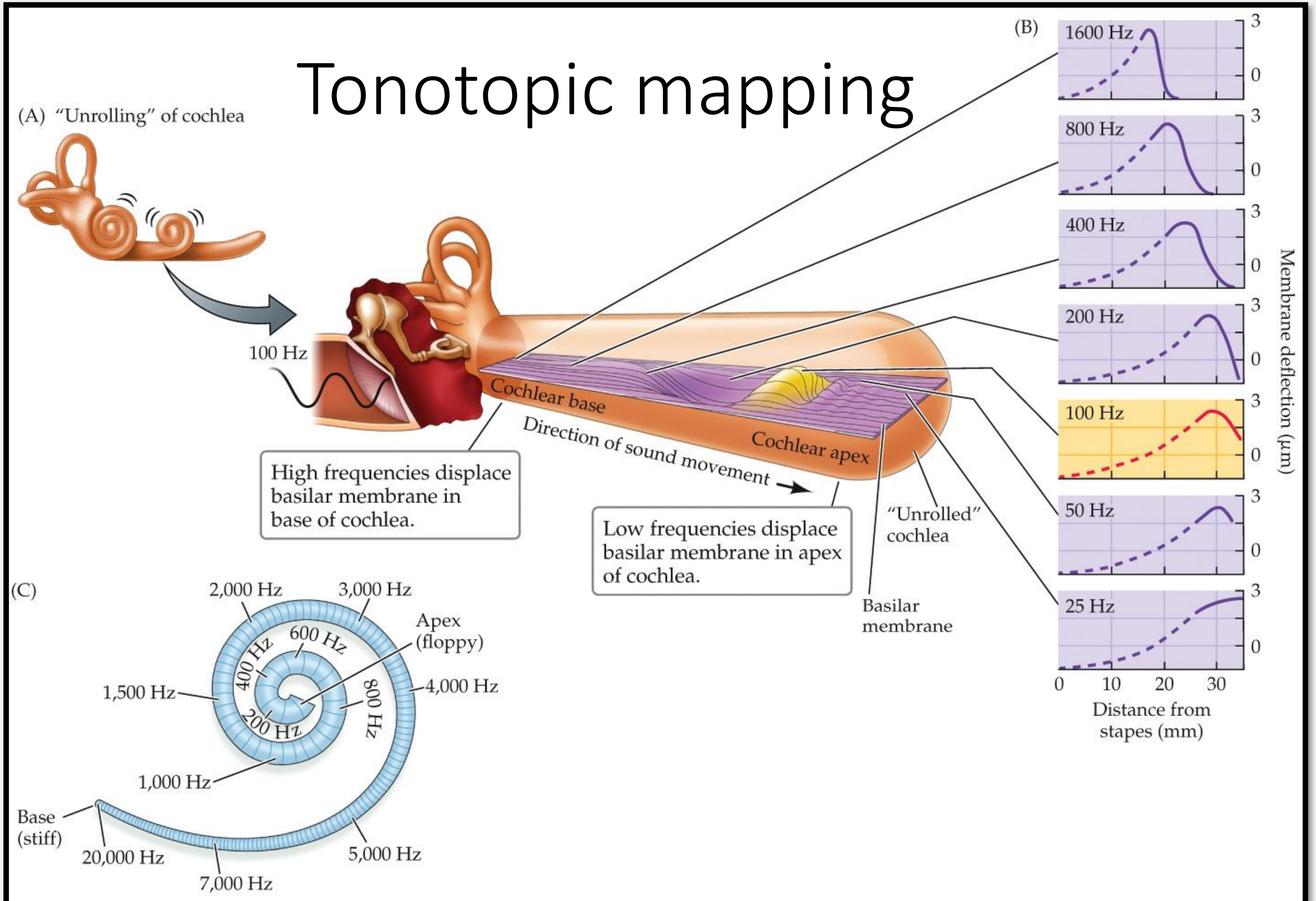
Basilar membrane

- Vibrates in response to movement of cochlear fluid
- Two sets of sensory cells: **inner hair cells** (IHCs) and **outer hair cells** (OHCs)
- **Stereocilia** protrude from each hair cell and extend into the **tectorial membrane**.



Kandel Fig 30-4

Tonotopic mapping

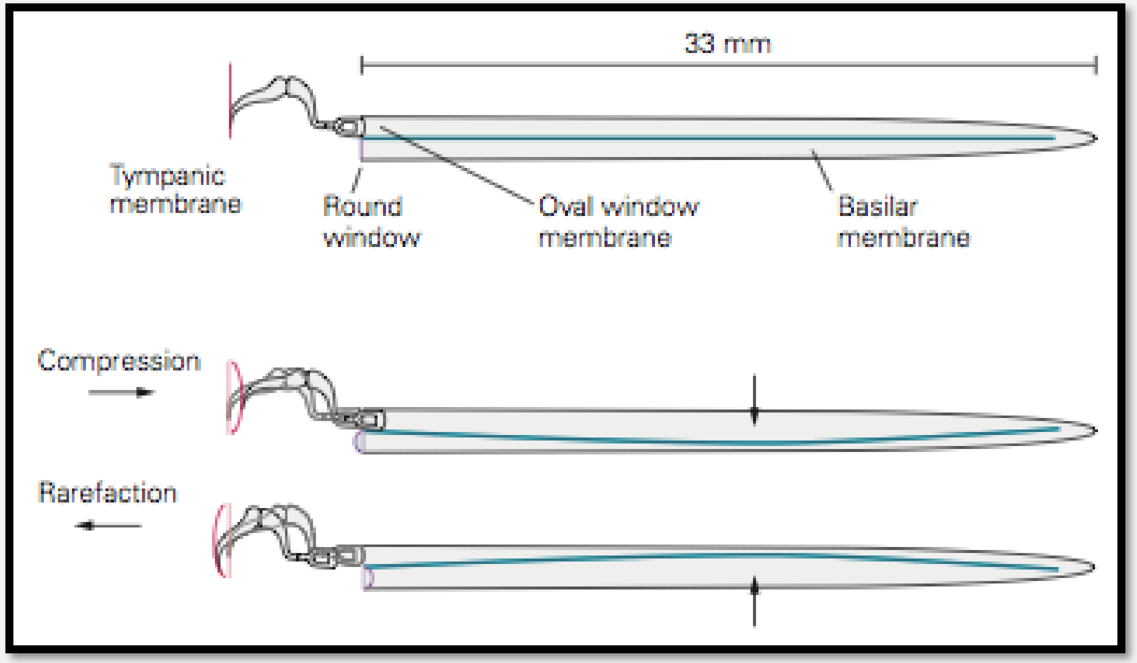


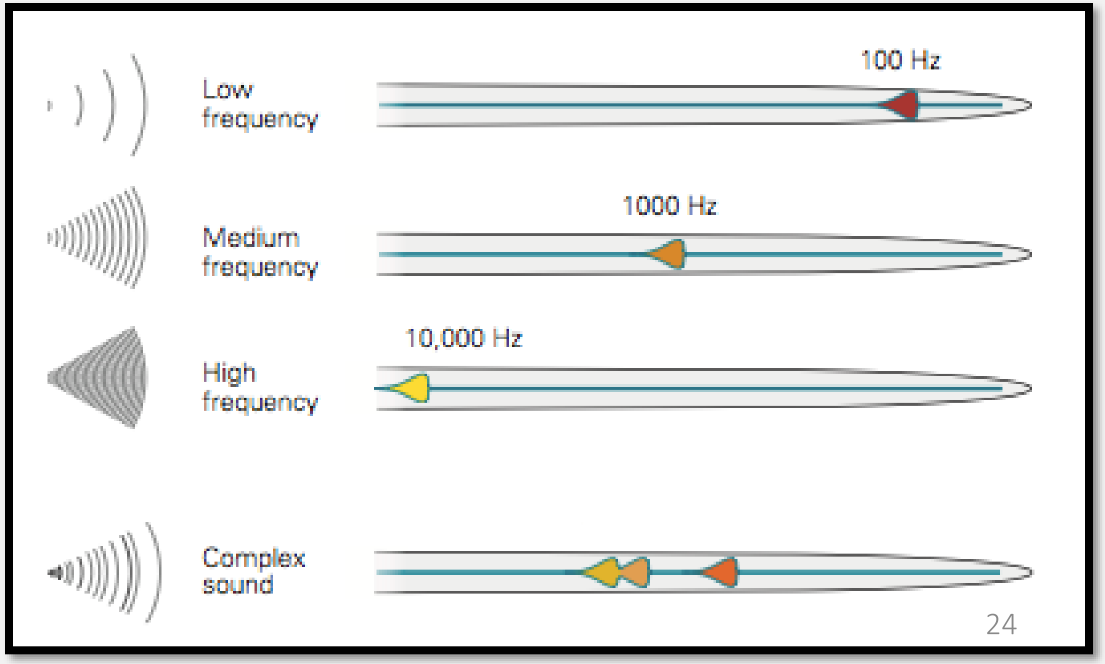
BEHAVIORAL NEUROSCIENCE 10e, Figure 9.4

Sensory transduction:

Basilar membrane (tonotopic map)

- bends in response to sound
- Base – thick and rigid – peak sensitivity to high frequency vibrations
- Apex – thin and floppy – peak sensitivity to low frequency vibrations





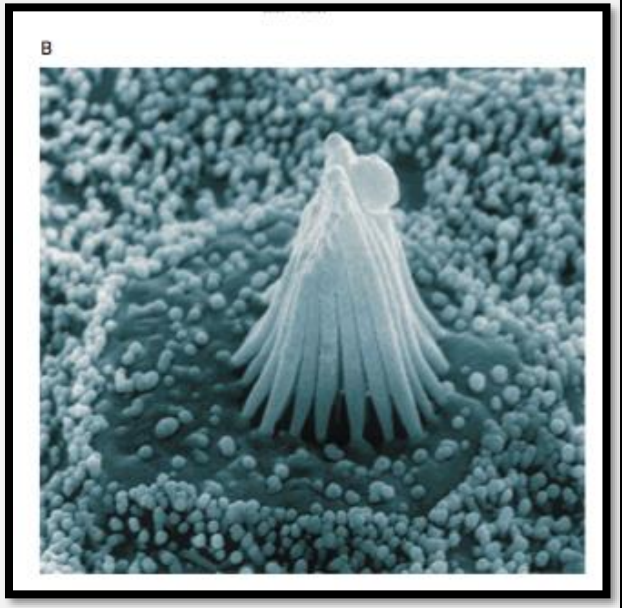
Summary – Anatomy

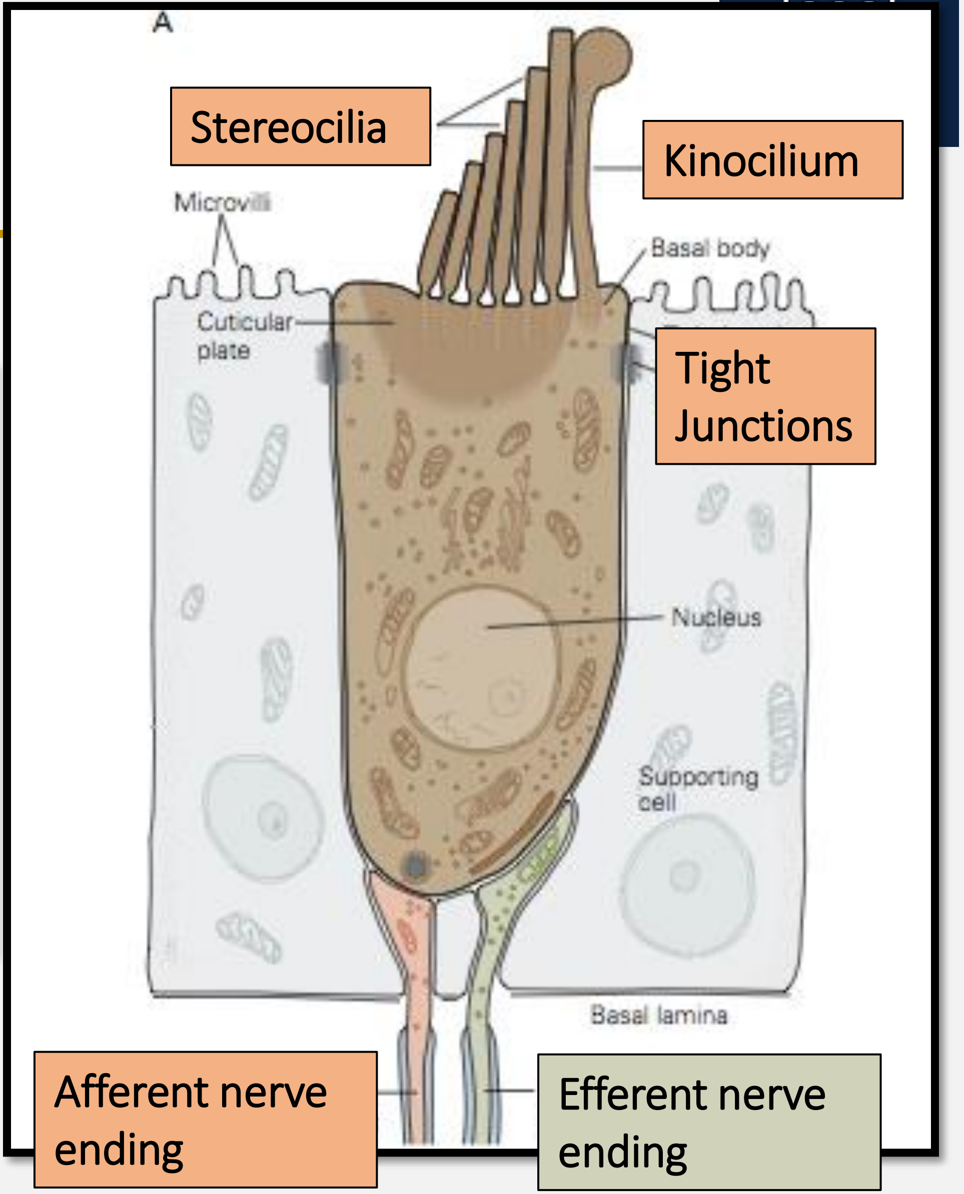
- Sound (pressure waves) is directed to the **tympanic membrane** where it is converted to physical vibrations of the ossicles
- The **ossicles** amplify the signal to the oval window
- Compression of the oval window displaces the fluid filled perilymph of the cochlea which is turn causes vibrations of the basilar membrane
- The basilar membrane is **tonotopically organized** such that high frequency vibrations preferentially activate **hair cells** near the thick, rigid base and low frequency vibrations preferentially activate **hair cells** near the thin, floppy apex
- **Hair cells** are attached at the basal end to the basilar membrane structure.
- **Hair cells** stereocilia project into the potassium rich endolymph fluid of the scala media
- **Stereocilia tips** are lodged into the stiff **tectorial membrane**
- When the basilar membrane moves, it causes a sheering force on the hair cell cilia attached to the tectorial membrane above which opens mechanoelectrical channels near the tips

Sensory transduction

Hair cells

- No axons!
- Afferent and efferent nerve endings
- Vm ~ -45 - -60mV
- Release glutamate continuously (10% channels involved with stimulus transduction open at rest)
- Graded responses (depolarization or hyperpolarized) modulate NT release





Kandel Fig 30-16

Afferent and Efferent synapses

Afferent connections

- Remember afferent = arriving at the central nervous system = sensory
- Each **Inner hair cell** – associated with 16-20 auditory nerve fibres
    - 90-95% of all afferent auditory fibres – perception of sound
- **Outer hair cells =** receive relatively fewer nerve fibre contacts
    - Sensory feedback mechanisms

Experiment – knock out

- Knockout inner hair cells neurotransmission in mice, but leave outer hair cells
- Results – complete deafness
- Restore function (with gene therapy) = restore hearing!

Afferent and Efferent synapses

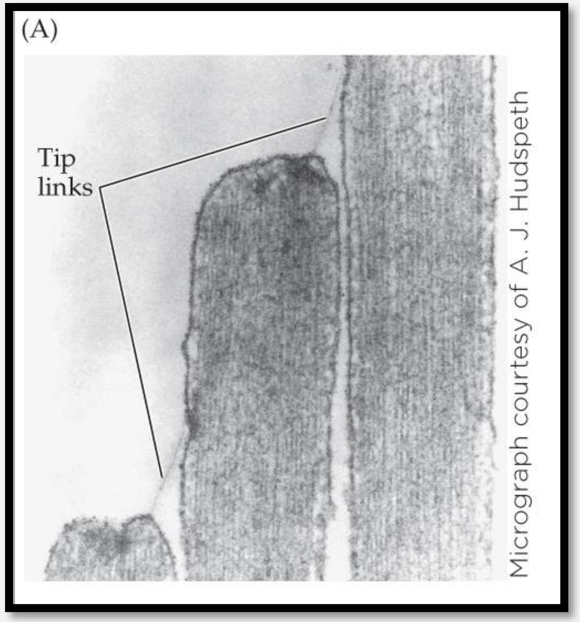
Efferent connections

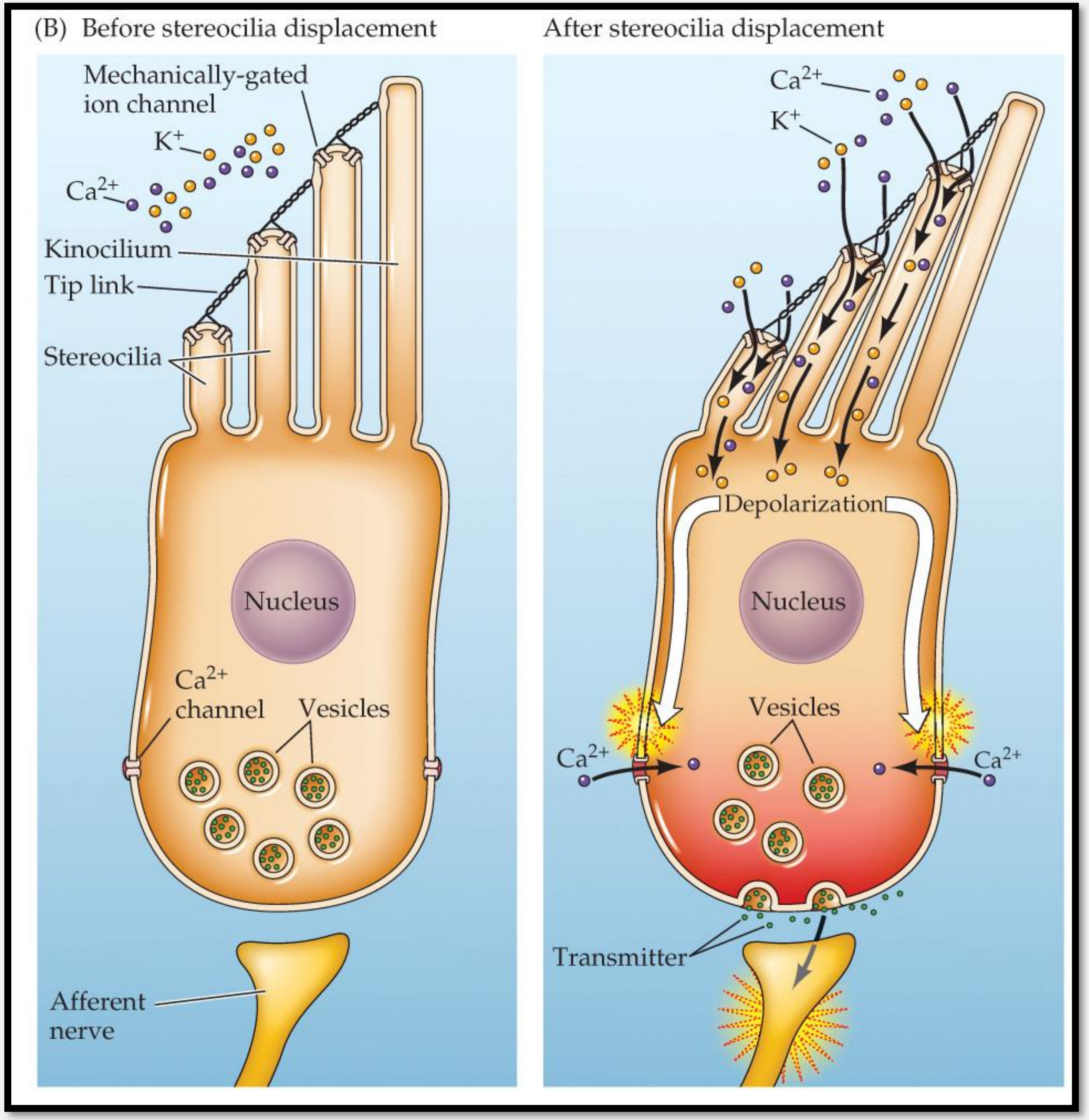
- Remember afferent = exiting the central nervous system = motor
- **Modulate inner hair cell sensitivity** (adjust for acoustic environment)
  - Protect against acoustic trauma to loud sounds
- Improve signal to noise ratio – inhibit certain inner hair cell afferent fibres to focus on relevant sounds
  - Feedback loop from brain to cochlea – attention and complex auditory tasks
- **Outer hair cells –** Can change length! WOW. Electromotility
  - Can amplify or restrict motion at the basilar membrane
  - Enhances (amplifies) signals at characteristic frequencies to enhance the signal that the inner hair cell detects and sends to brain
  - Restricts motion of basilar membrane in response to loud sounds or explosions – protective mechanism.

Sensory transduction:

Kinocilium

- Bending towards kinocilium opens channels, allows K+ entry
- Depolarization, and increased glutamate release





Kandel Fig 30-8

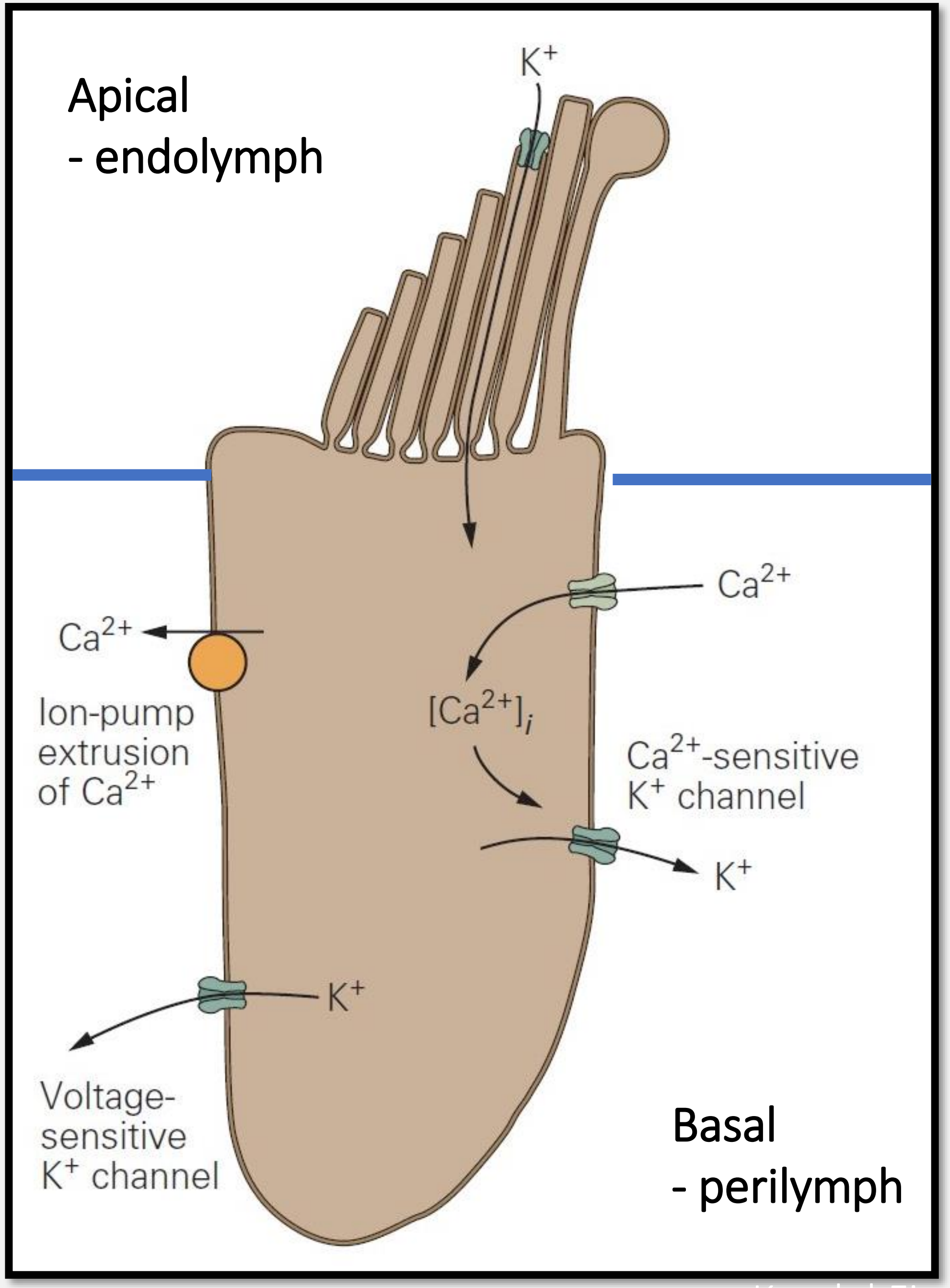
Hair cells (the environment)

Apical environment

- K+ rich (Na+ poor) scala media endolymph
- Vm ~ -125mV
- Opening of channels – K+ influx

Basal environment

- Na+ rich (K+ poor) perilymph
- Perilymph - ~ 80mV more negative than endolymph
- Vm ~ -45mV
- Depolarization from K+ influx → Ca2+ influx
  - Opens VG Ca2+ channels – Glu release
  - Open Calcium sensitive K+ channels – K+ efflux
  - Opens Voltage sensitive K+ channels – K+ efflux

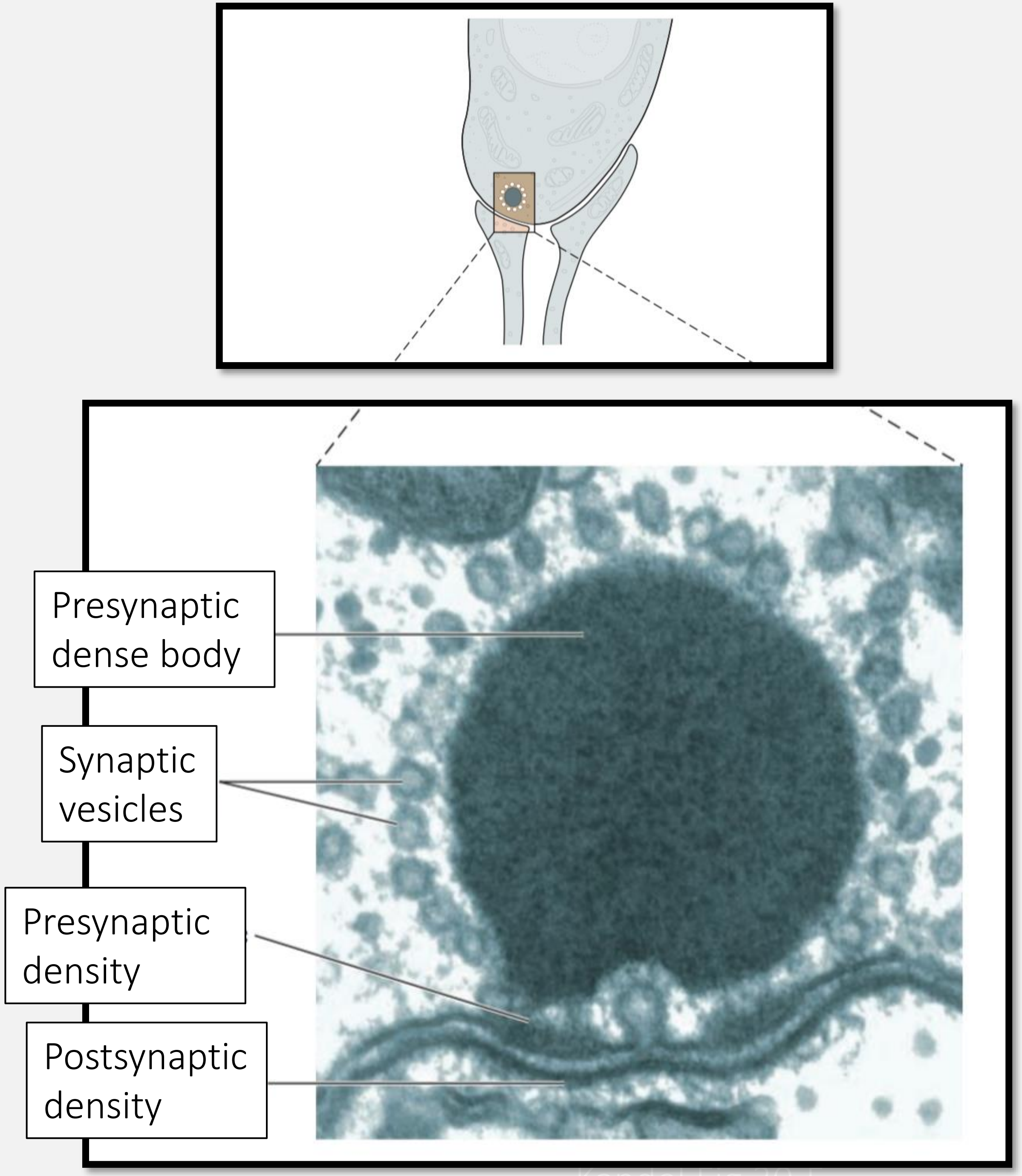


Kandel Fig 30-13

Sensory transduction

Hair cells – Active zone

- Presynaptic dense body
    - Surrounded by vesicles
- Presynaptic density
    - Ca2+ channels (10% activated at resting potential)
    - Continuous NT (glutamate) release
- Postsynaptic density
    - Continuously stimulated at rest



Kandel Fig 30-5

Summary – Hair cells

Sits in two different environments

- Apical end – where the cilia are – bath in a potassium rich endolymph – facilitate influx of K+ when channels open
- Basal end – Where the cell body and synapse are – perilymph fluid is more typical (Na+ high, K+ low concentration)

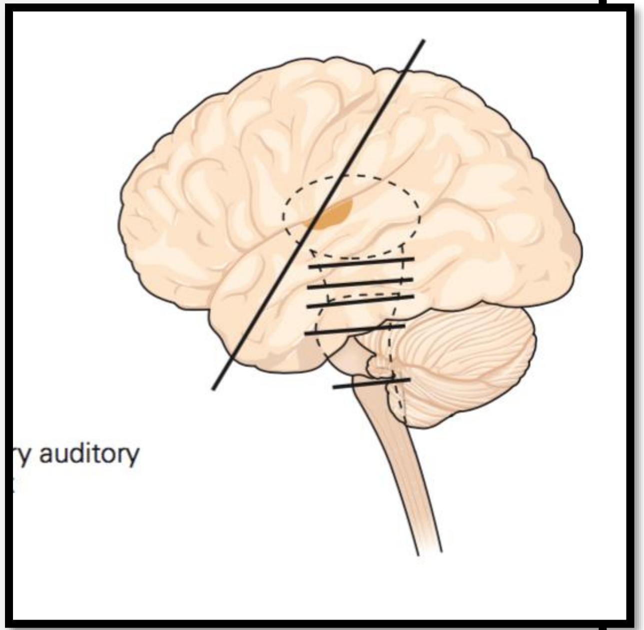
Tip links

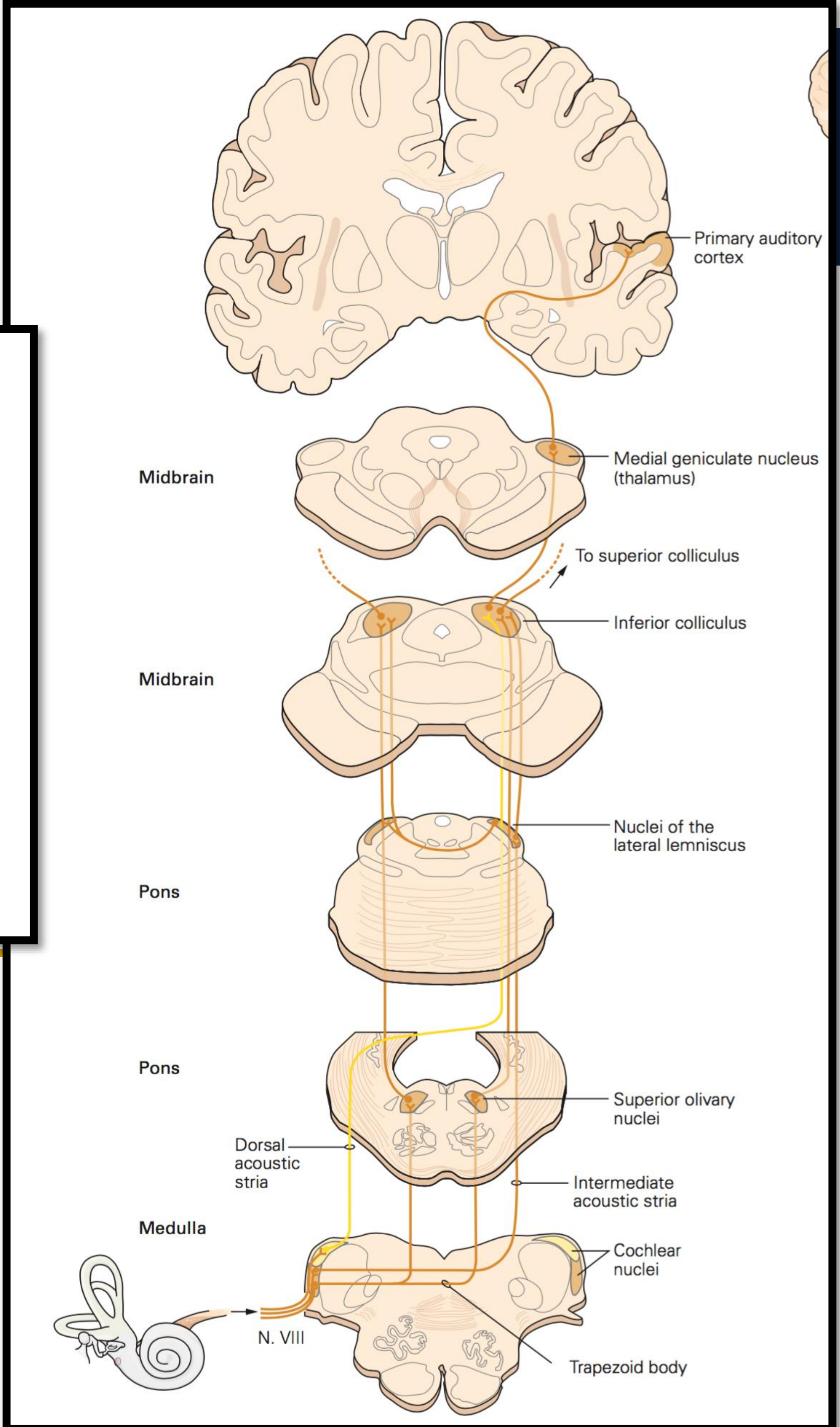
- Mechanically open potassium gates upon bending of the stereocilia towards the kinocilium (depolarizing event), close gates when bending is away from kinocilium (repolarizing/hyperpolarizing event)

Basal end ion channels

- Channels serve the purpose to allow Ca2+ influx (signalling increased neurotransmitter release) and allow rapid efflux of potassium to rapidly reset the ionic capacity of the neuron.
- Stereotyped synaptic machinery custom for hair cells

Hearing: higher level processing





Kandel Fig 31-2

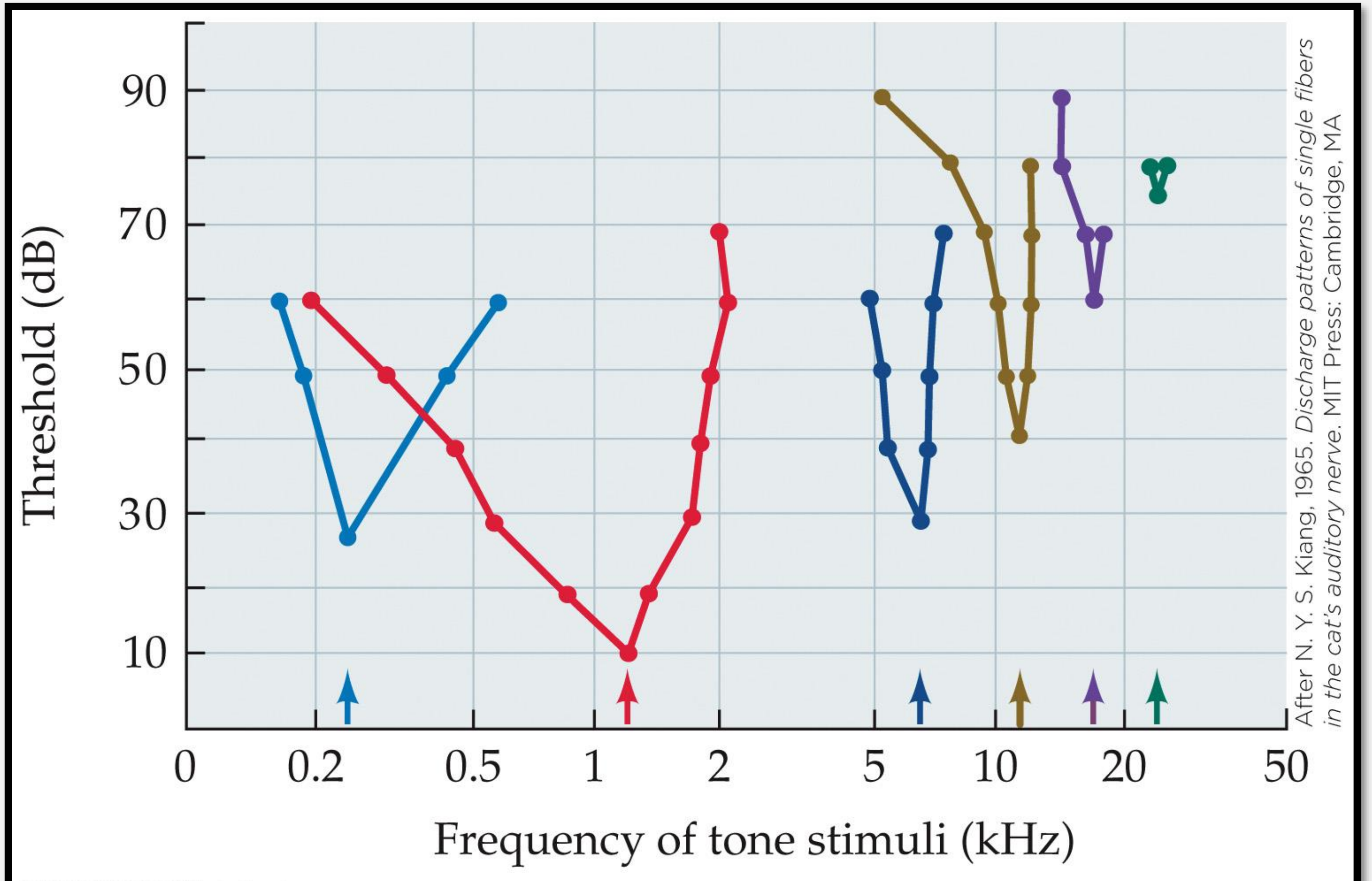
Auditory Signals Run from Cochlea to Cortex

Vestibulocochlear nerve (cranial nerve VIII):

- contains auditory fibers from the cochlea.

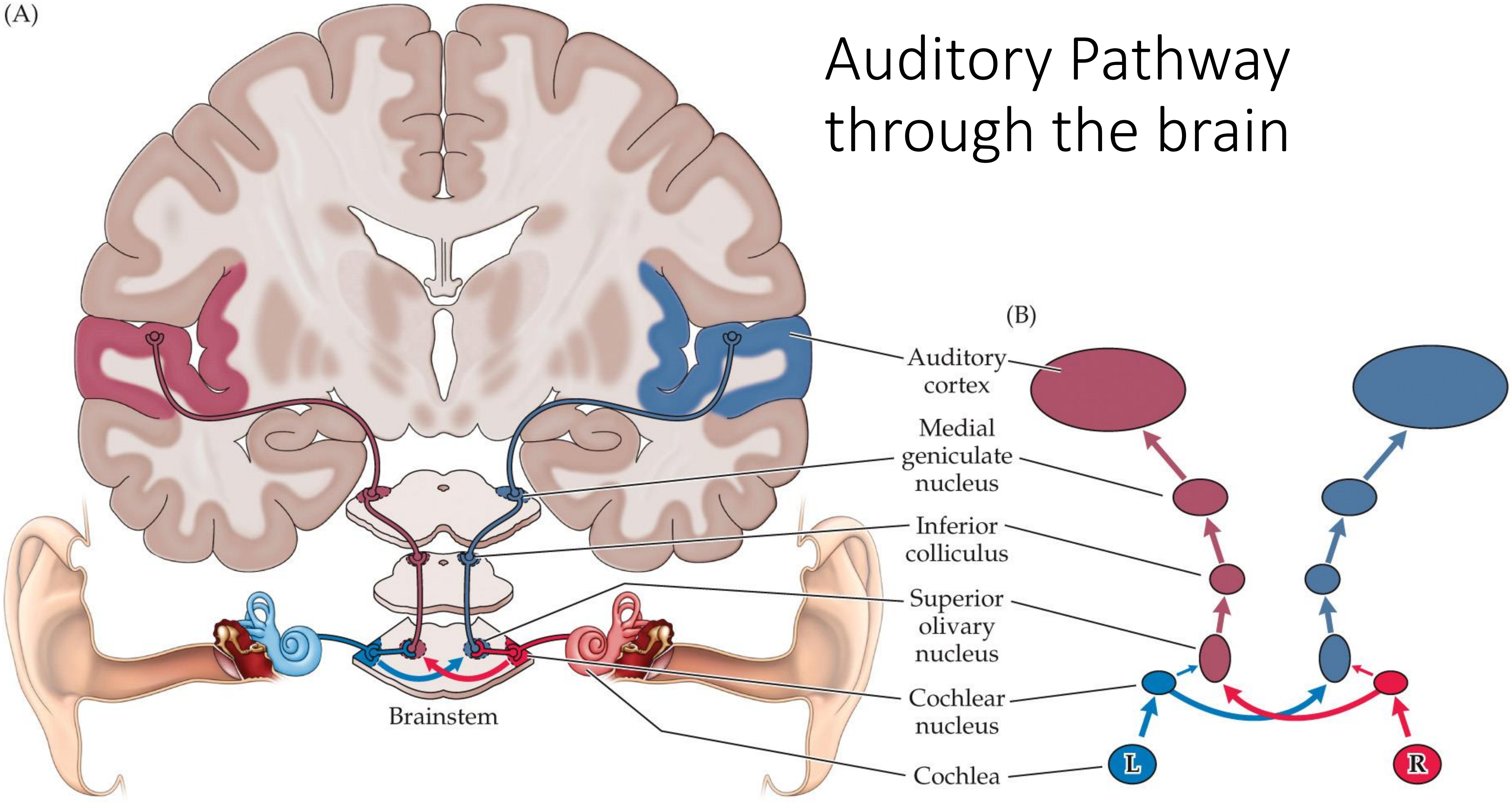
Tuning curves

- graphs of individual auditory nerve fiber responses—show a cell's response to various frequencies.



BEHAVIORAL NEUROSCIENCE 10e, Figure 9.7

Auditory Pathway through the brain



BEHAVIORAL NEUROSCIENCE 10e, Figure 9.8

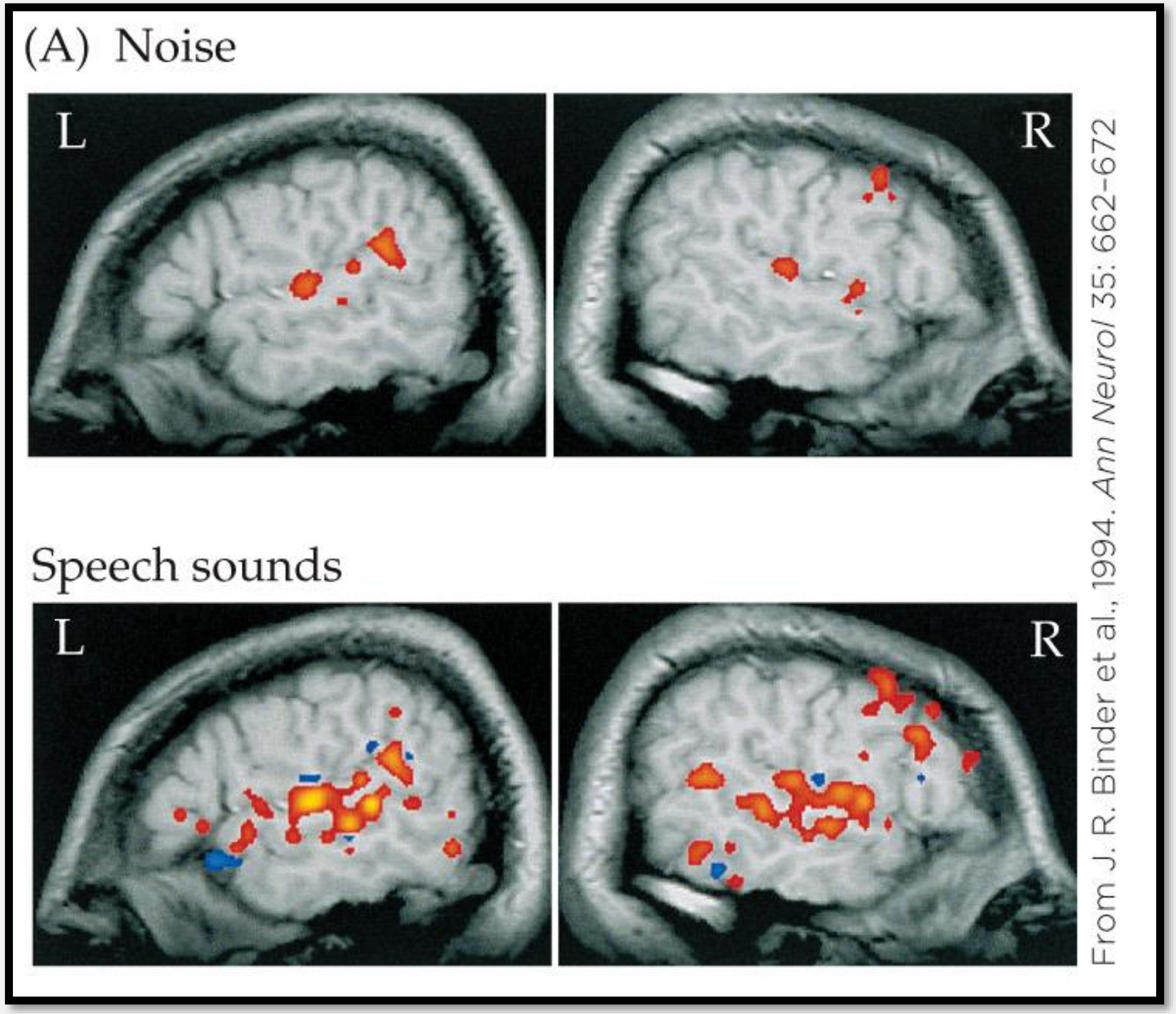
Auditory Signals Run from Cochlea to Cortex

tonotopic organization:

- All levels of the auditory pathway
- They are arranged in a map according to the frequencies to which they respond.

Brain imaging

- shows that main activation is in the **primary auditory cortex** (**A1**) on the superior temporal lobes.



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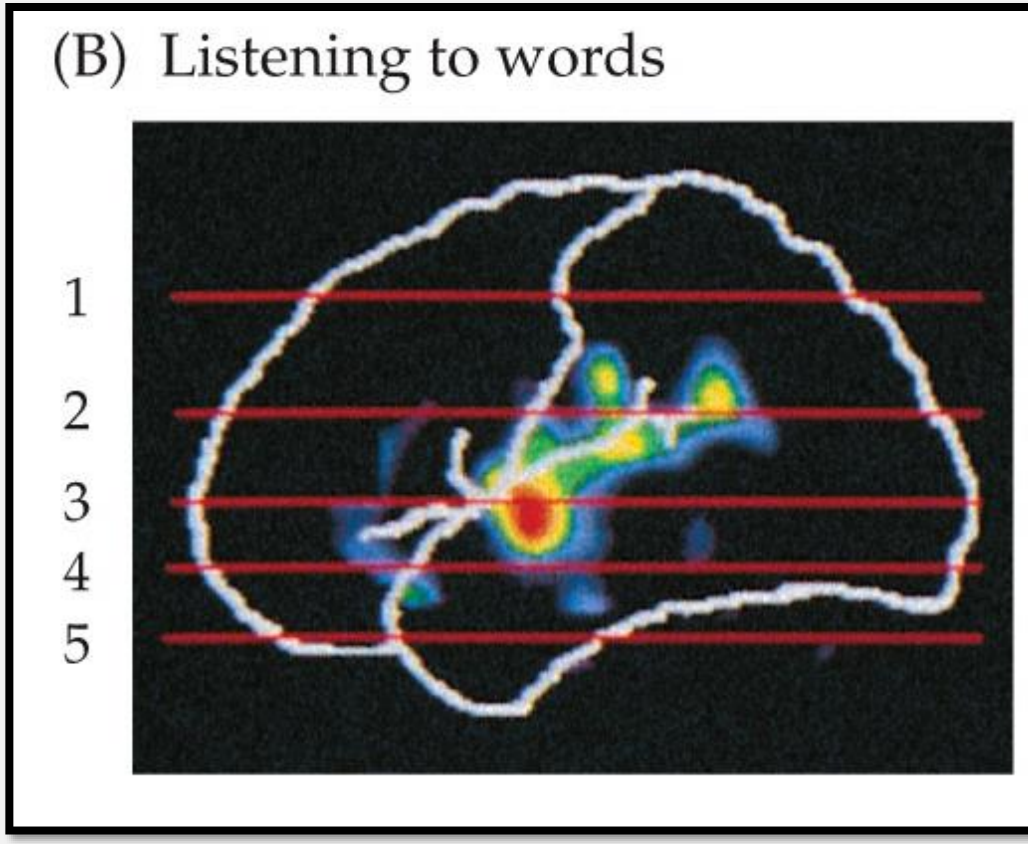
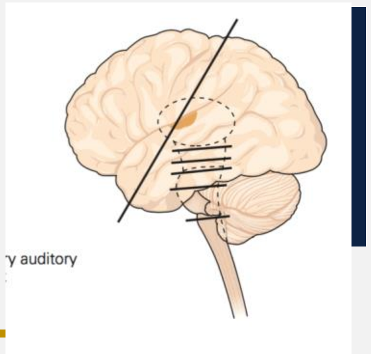


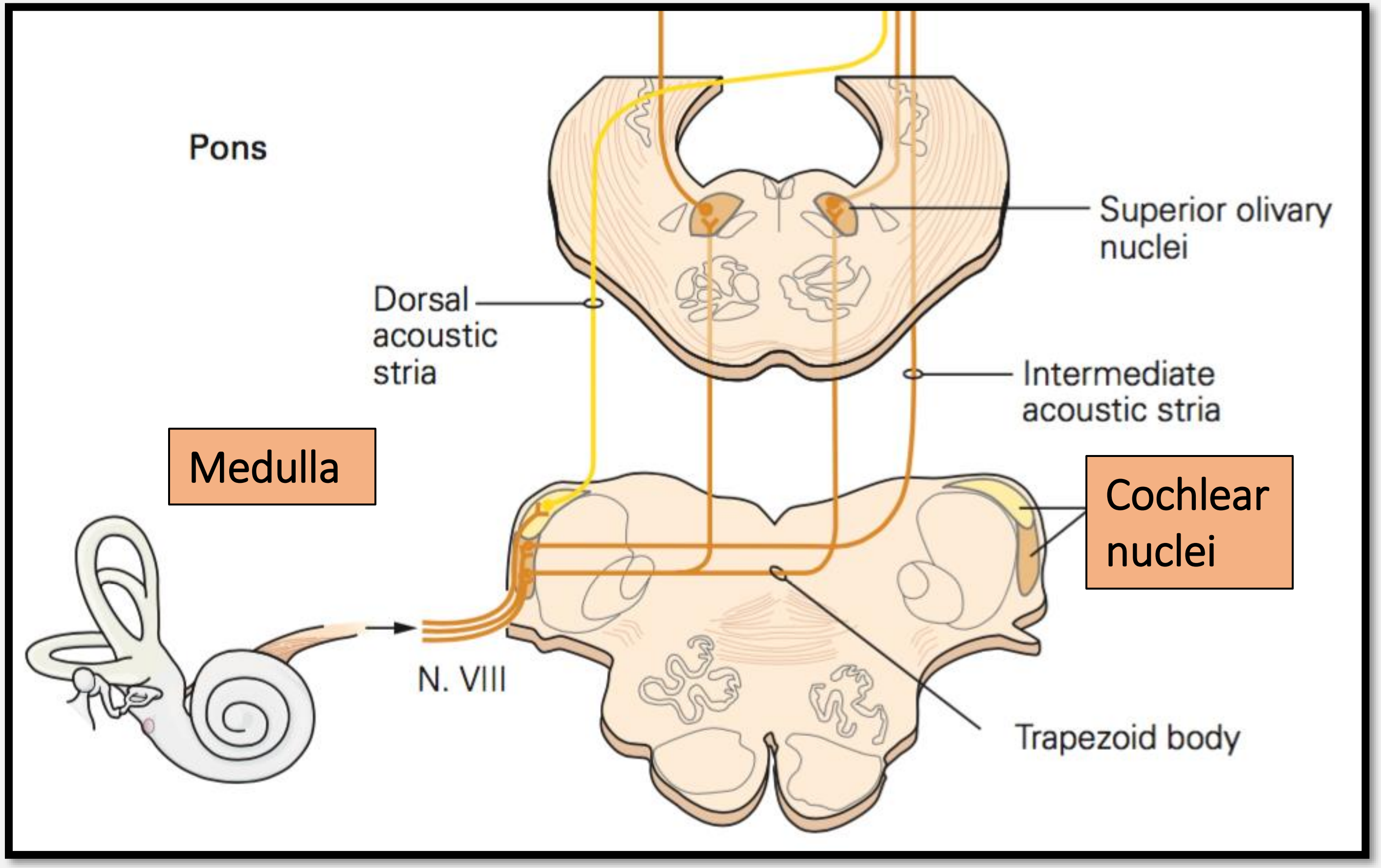
From M. I. Posner and M. E. Raichle, 1994. *Images of mind*. Scientific American Library: New York



Auditory pathways

Cochlear Nucleus

- Tonotopic map
- Integration of acoustic and somatosensory information
- Localize sound and distinguish self from non-self stimuli

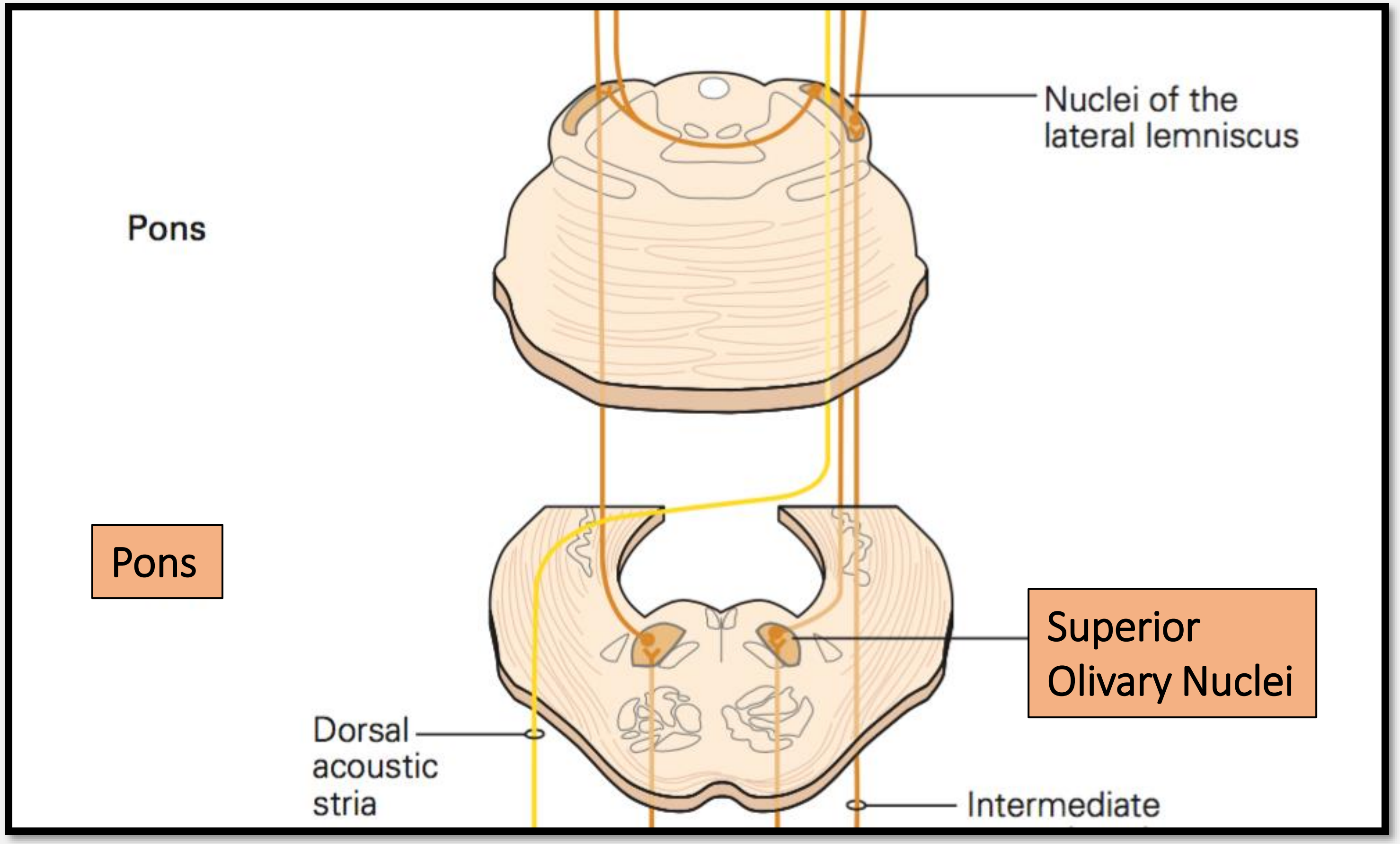


Kandel Fig 31-2

Auditory pathways

Superior olivary nuclei**

- Localizing Sound
- **Medial superior olive**
  - Interaural timing differences
- **Lateral superior olive**
  - Interaural amplitude differences



Kandel Fig 31-2

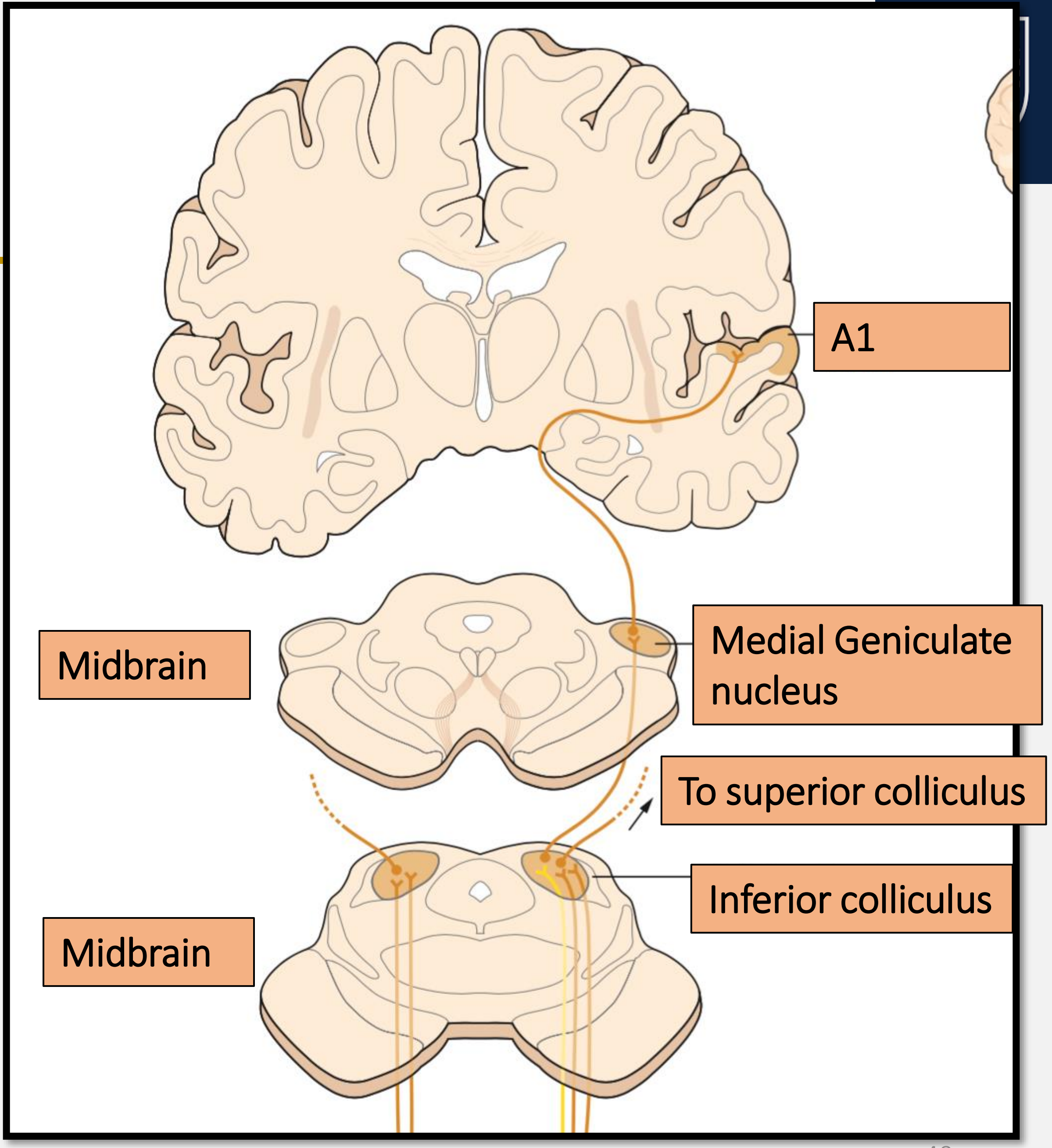
Auditory pathways

Inferior Colliculus

- Tonotopic map
- Convergence of all ascending pathways
- subcortical projection to superior colliculus – fast automatic behaviours
- Projection to medial geniculate nucleus (thalamus) then to A1 (primary auditory cortex)

Superior Colliculus

- Integrates LSO, MSO, cochlear nucleus to localize and orient to sounds in 3D space
- Visual inputs too for reflexive orienting



Kandel Fig 31-2

Primary auditory cortex

Tonotopic organization

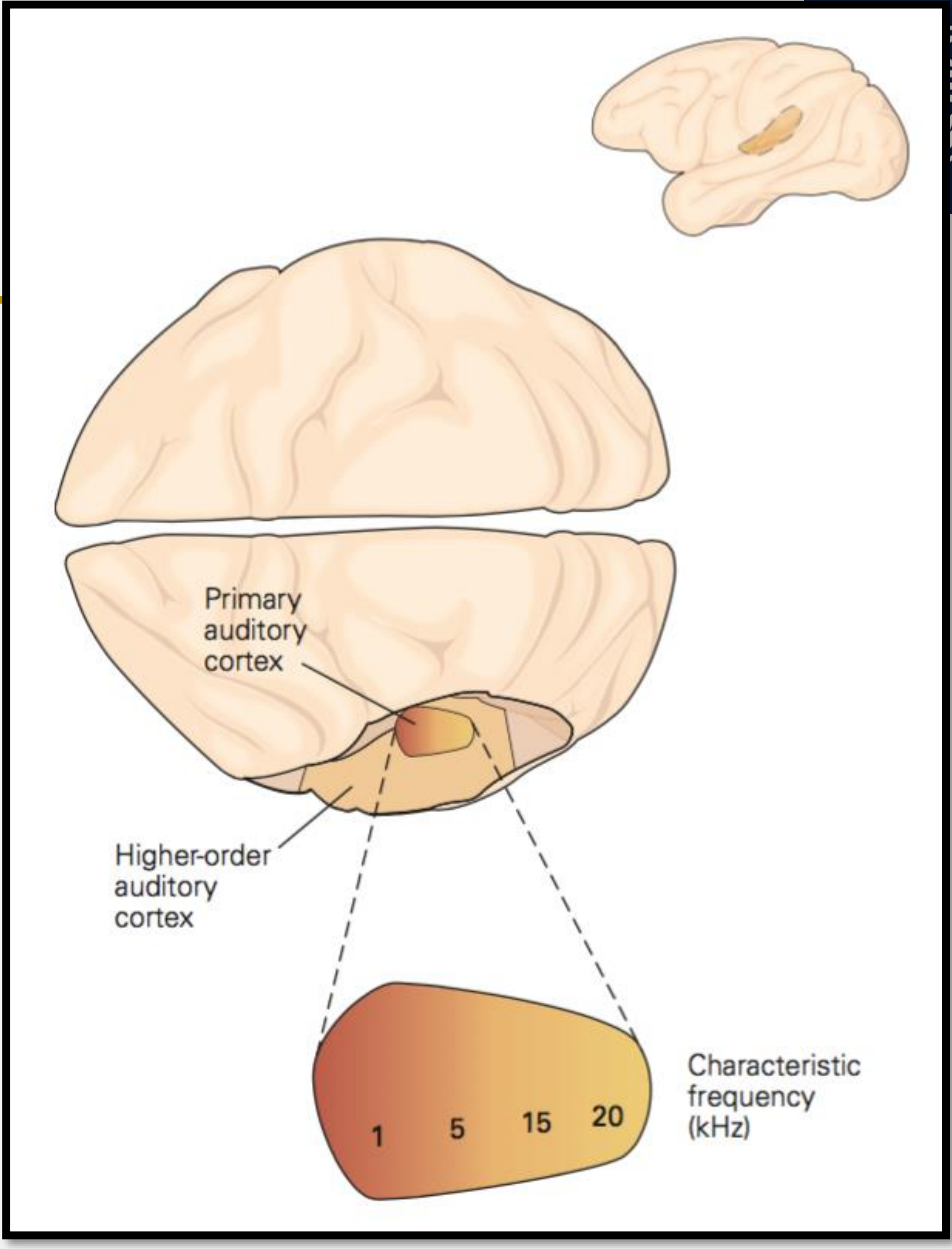
- Relevant sounds occupy greater proportion of A1
- Plastic – changes with experience

Columnar organization

- Individual columns respond to specific frequencies
- Some columns respond to both ears, some have ear dominance

Higher Auditory regions

- Respond to more complex sounds



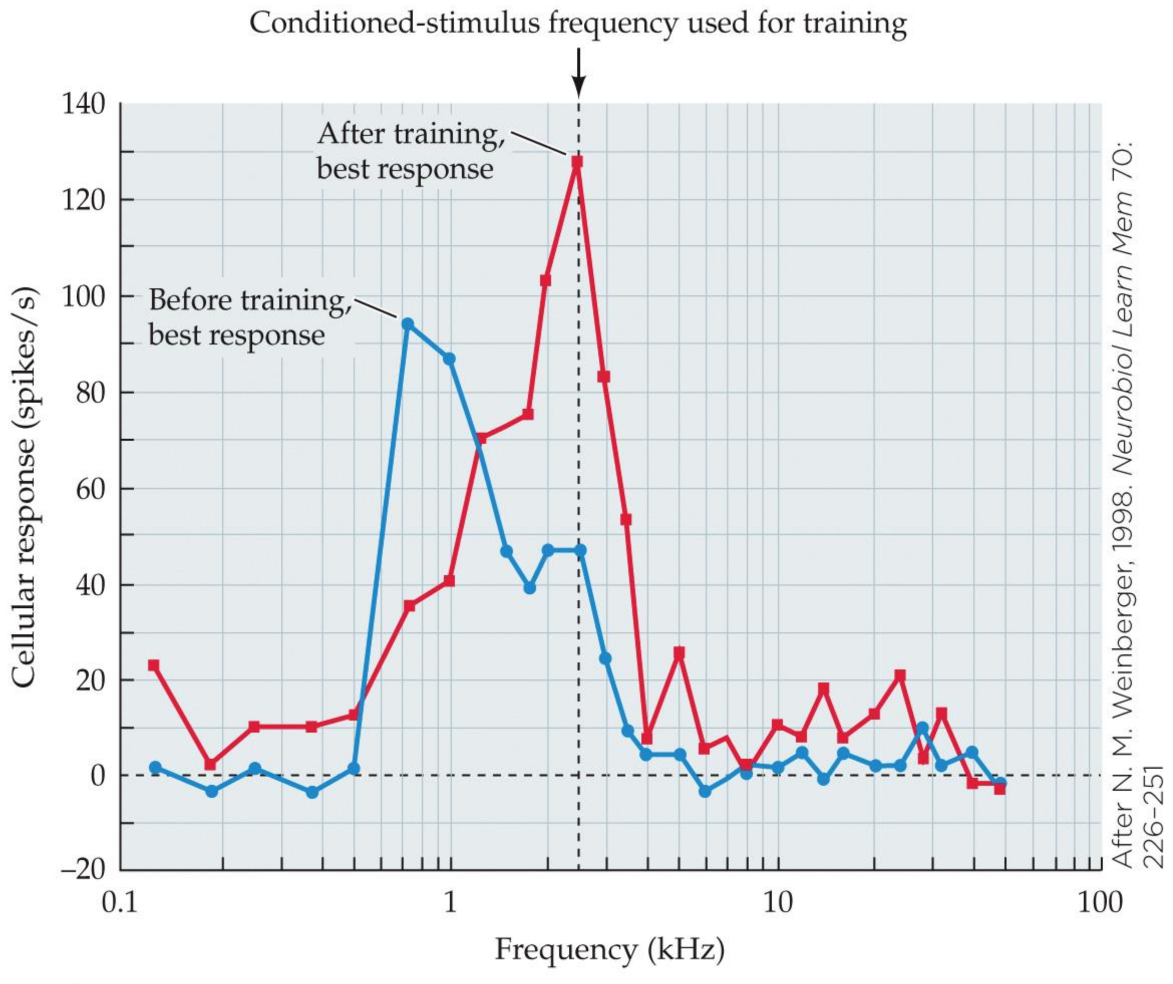
Kandel Fig 31-11

Experience and A1

- Experience affects auditory perception and pathways.
- Auditory experience contributes to development of sound localization in human infants.

Studies with lab animals

- confirm that experience with sounds of a particular frequency can cause a rapid retuning of auditory neurons.
    - (Schiavo 2020 – maternalistic behaviour)
    - (NM Weinberger 1998 – as shown in figure)



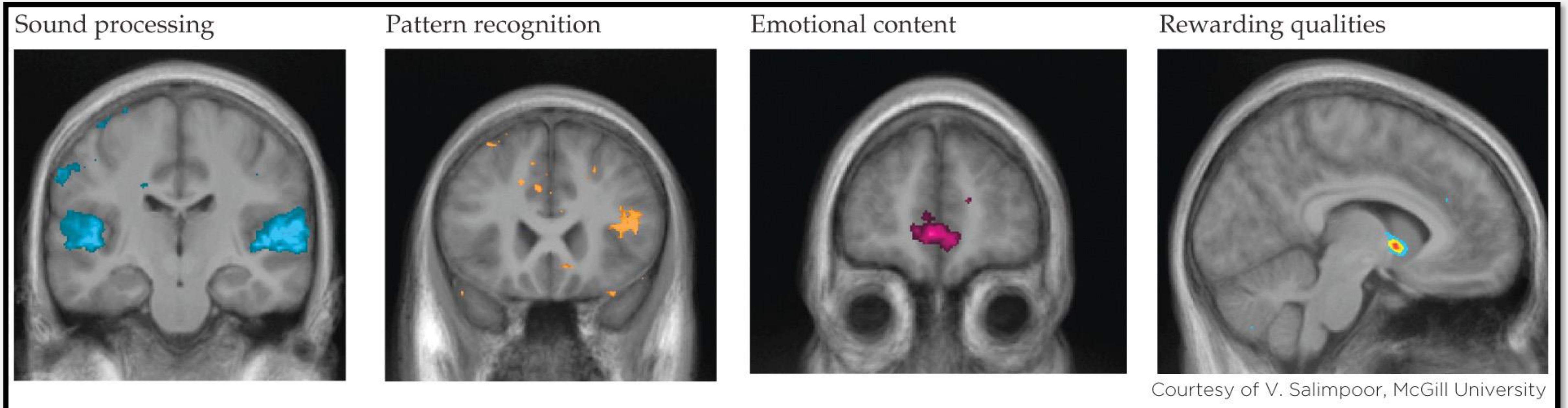
BEHAVIORAL NEUROSCIENCE 10e, Figure 9.14

Musical training in humans

Heschl's gyrus

- portion of auditory cortex that first processes music, is larger (2x) in musicians and more strongly activated (2x) by music.
- Extent of which a musician's brain is extra sensitive to music correlated with the age at which serious musical training began, and duration
  - More training = larger differences in auditory cortex as adults (Habibi et al. 2020)
- Children with extensive musical training = improved perception and discrimination of basic speech sounds later in life (Intartaglia et al. 2017)
  - Early experience alters the structure and functioning of the auditory cortex in an enduring manner
- Piano training in adulthood – increase cortical thickness in A1 and Heschl's gyrus (Worschech et al. 2022).

Music processing

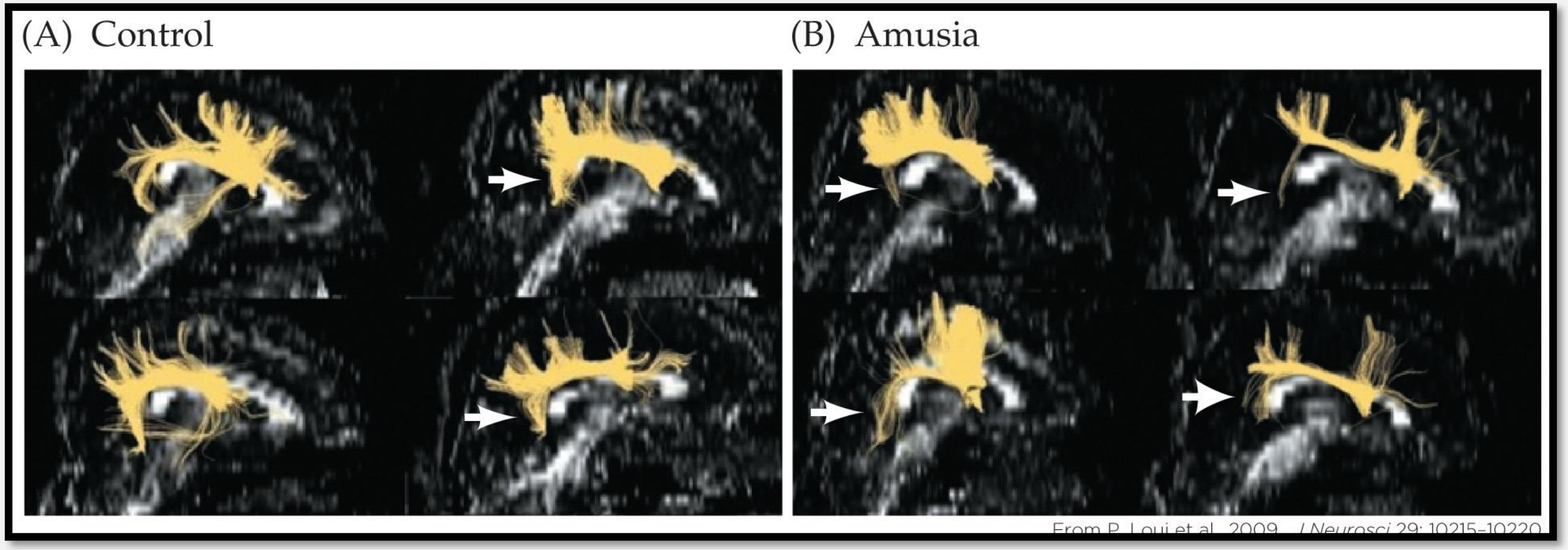


BEHAVIORAL NEUROSCIENCE 10e, Figure 9.15

Ability limited by individual genetics

Amusia

- an inability to discern tunes
- Amusia seems to be a problem in recognizing pitch, not the timing aspects of music (*rhythm*).
- **Diffusion tensor imaging** (**DTI**), using MRI, shows fewer connections between frontal cortex and temporal lobe in tone-deaf people.



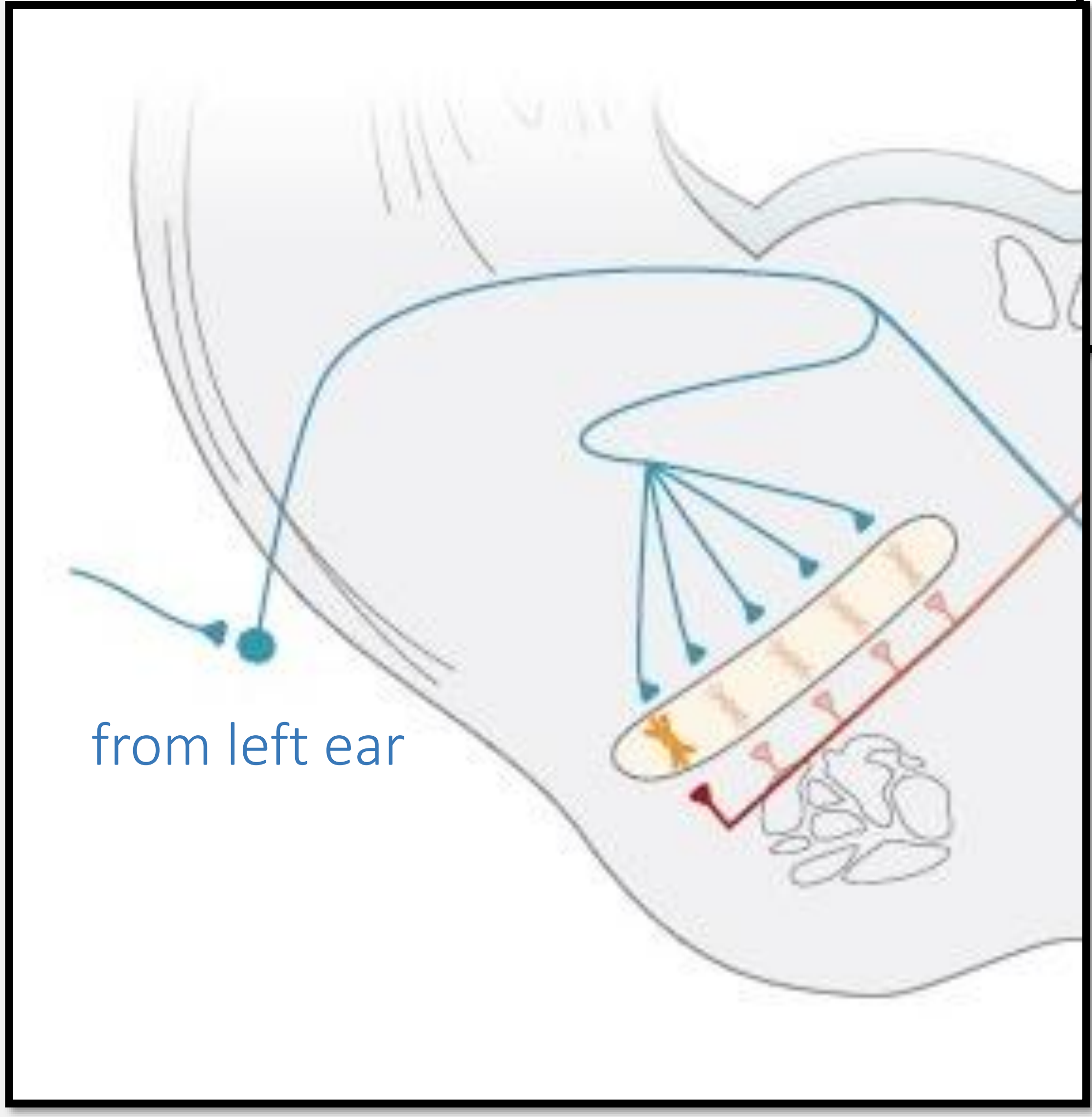
From P. Loui et al., 2009. *J Neurosci* 29: 10215–10220

Sound localization

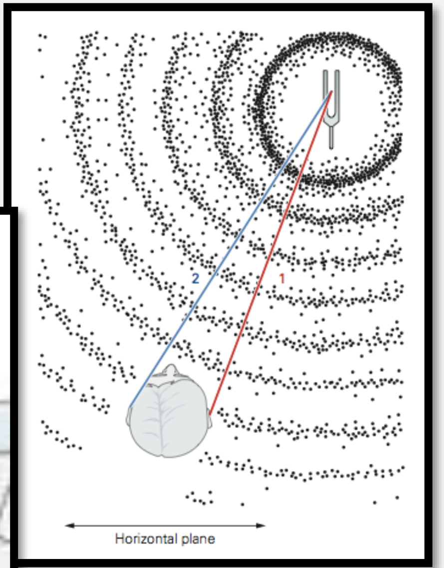
Sound localization in the horizontal plane

Medial superior olive coincidence detectors

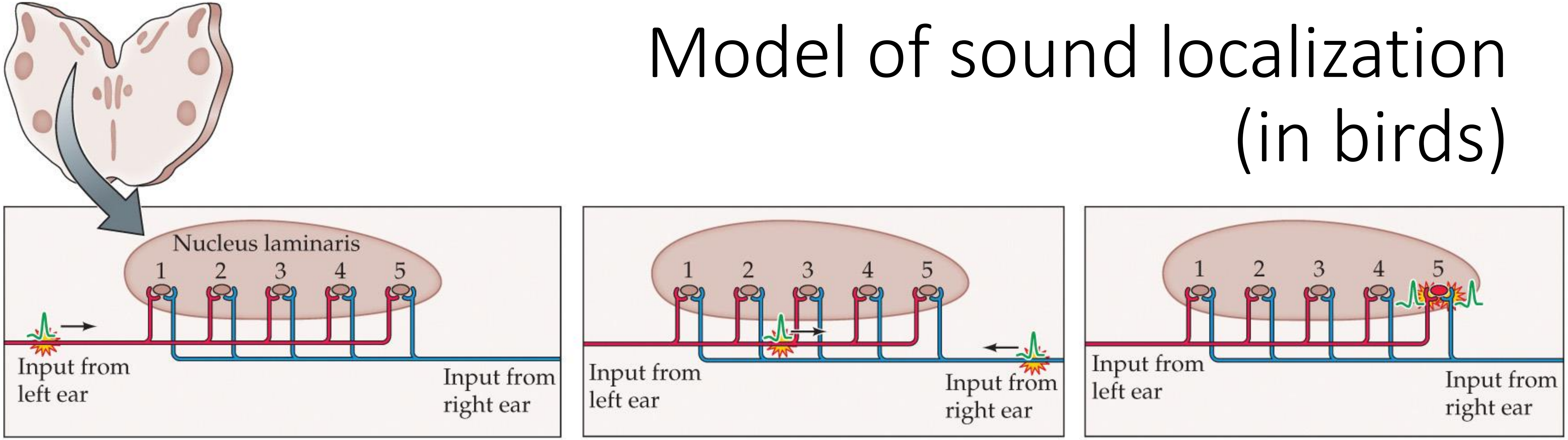
- Can detect 1 degree difference in sound localization (~10μs difference between ears)
- Maps the contralateral hemifield
- Uses latency differences – interaural timing differences
- **Medial superior olive**



from right ear



Model of sound localization (in birds)



1 Sound to the left of midline causes input action potentials from the left cochlea/cochlear nucleus to arrive at the nucleus laminaris.

2 Moments later, the same sound reaches the right ear, causing action potentials from the right ear/right cochlear nucleus to arrive at the nucleus laminaris slightly later than the action potentials from the left ear.

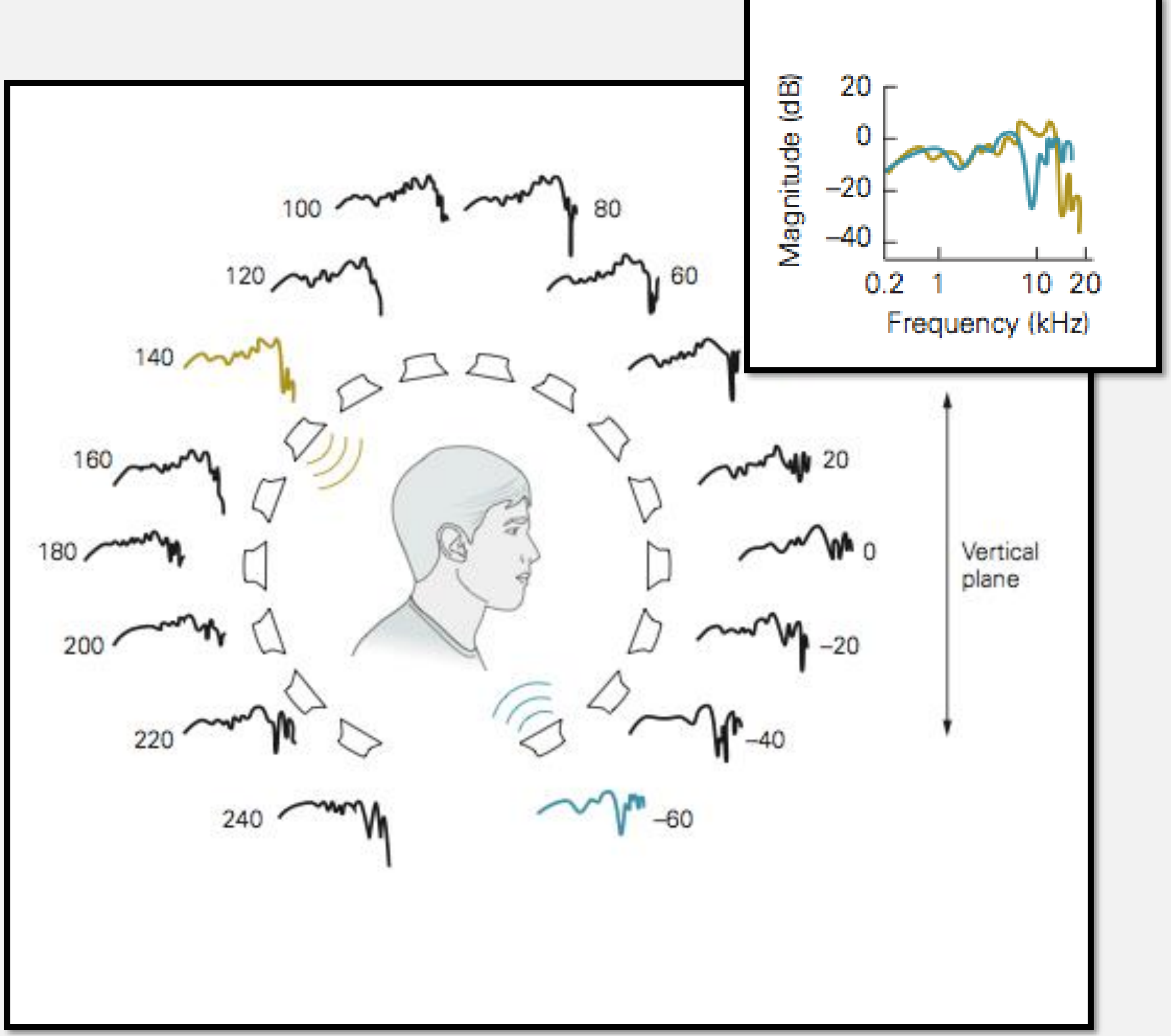
3 In this example, the result of the difference in timing of the left- and right-ear signals is that they converge at neuron 5 in the nucleus laminaris. Neuron 5 is thus a coincidence detector that localizes sounds originating from a specific point to the left of midline. In this simple example only 5 neurons are modeled; in reality, the operation of thousands of such coincidence-detecting neurons provides a detailed spatial map of sound sources.

BEHAVIORAL NEUROSCIENCE 10e, Figure 9.12

Sound localization in the vertical plane

Spectral filtering

- Ears (pinnae), head, shoulders filter some frequencies, enhance others
- The auditory system can use this information to help location sound in the vertical plane



Kandel Fig 31-1

Question?

A patient comes in who has had a stroke. Acute damage to their temporal and occipital lobes has rendered them deaf and blind. However, you notice that as they walk in, they actively step around objects on the ground, and as a child cried in the waiting room, they turned there head towards to the child.

How is this possible?

Vestibular System

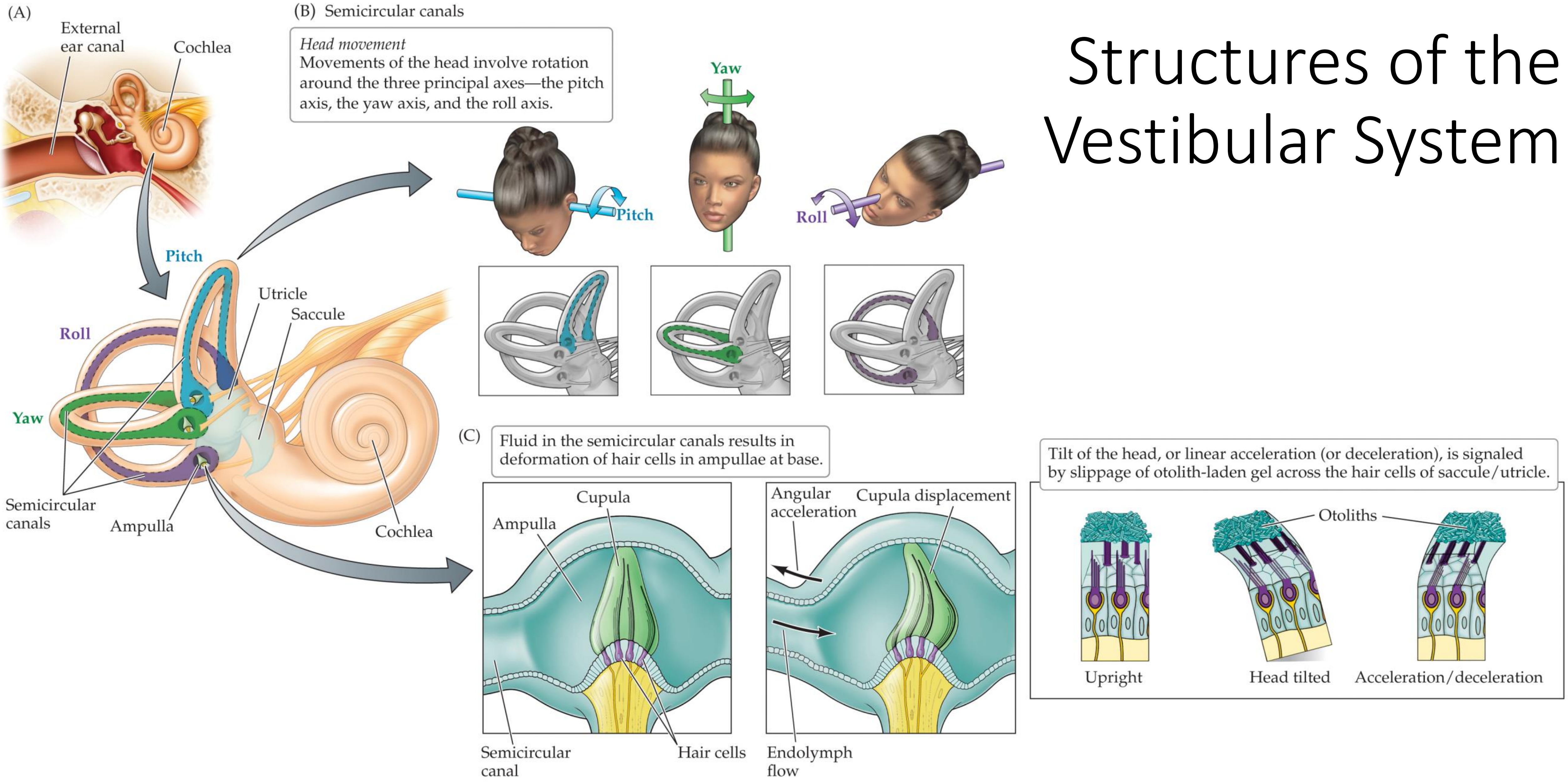
Detection of the position and movement of the head

An Inner Ear System Senses Gravity and Acceleration

The vestibular system detects position and movement of the head:

- **Semicircular canals**—three fluid-filled tubes in different planes
  - **Ampulla**: Enlarged region of hair cells in each semicircular canal. Stereocilia are embedded in a gelatinous mass, the **cupula**.
- **Utricle**—fluid-filled sac that responds to static head positions
- **Saccule**—fluid-filled sac that responds to static head positions

Structures of the Vestibular System



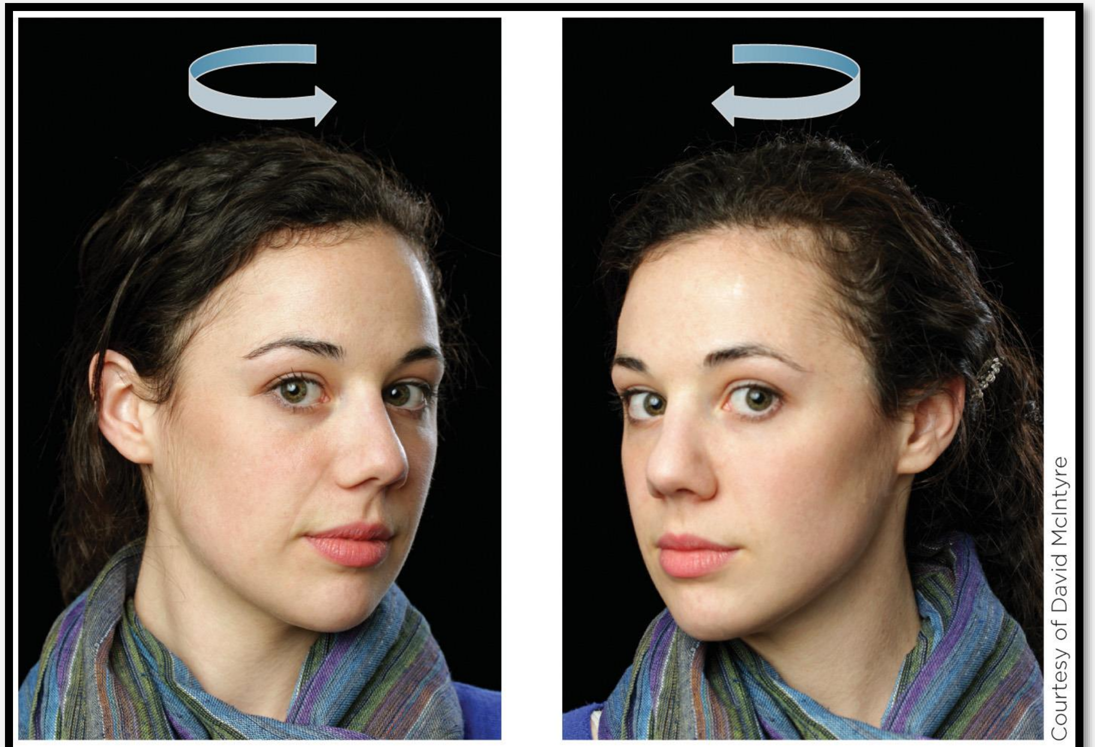
BEHAVIORAL NEUROSCIENCE 10e, **Figure 9.21**

Vestibular system

- Nerve fibers from vestibular receptors synapse in the **vestibular nuclei** in the brainstem; some go directly to the cerebellum.
- Outputs of the vestibular nuclei go to motor nuclei of the eye muscles, the thalamus, cerebral cortex, and others.

Vestibulo-ocular reflex (VOR):

- allows maintenance of gaze at a fixed point while the head moves.



BEHAVIORAL NEUROSCIENCE 10e, Figure 9.22