Human Phys PCB 4701

Sensory Physiology
Fox Chapter 10 part 2
Vestibular & Audition

Anatomy of Inner Ear

Hair Cells
Receptor cells for audition and vestibular system.

Vestibular Apparatus
Utricle & Saccule detect linear acceleration
Semicircular Canals detect rotational acceleration

Audition
Cochlea detects **sound** waves

Inner ear connected by ducts filled with **endolymph**, a high [K^+] fluid

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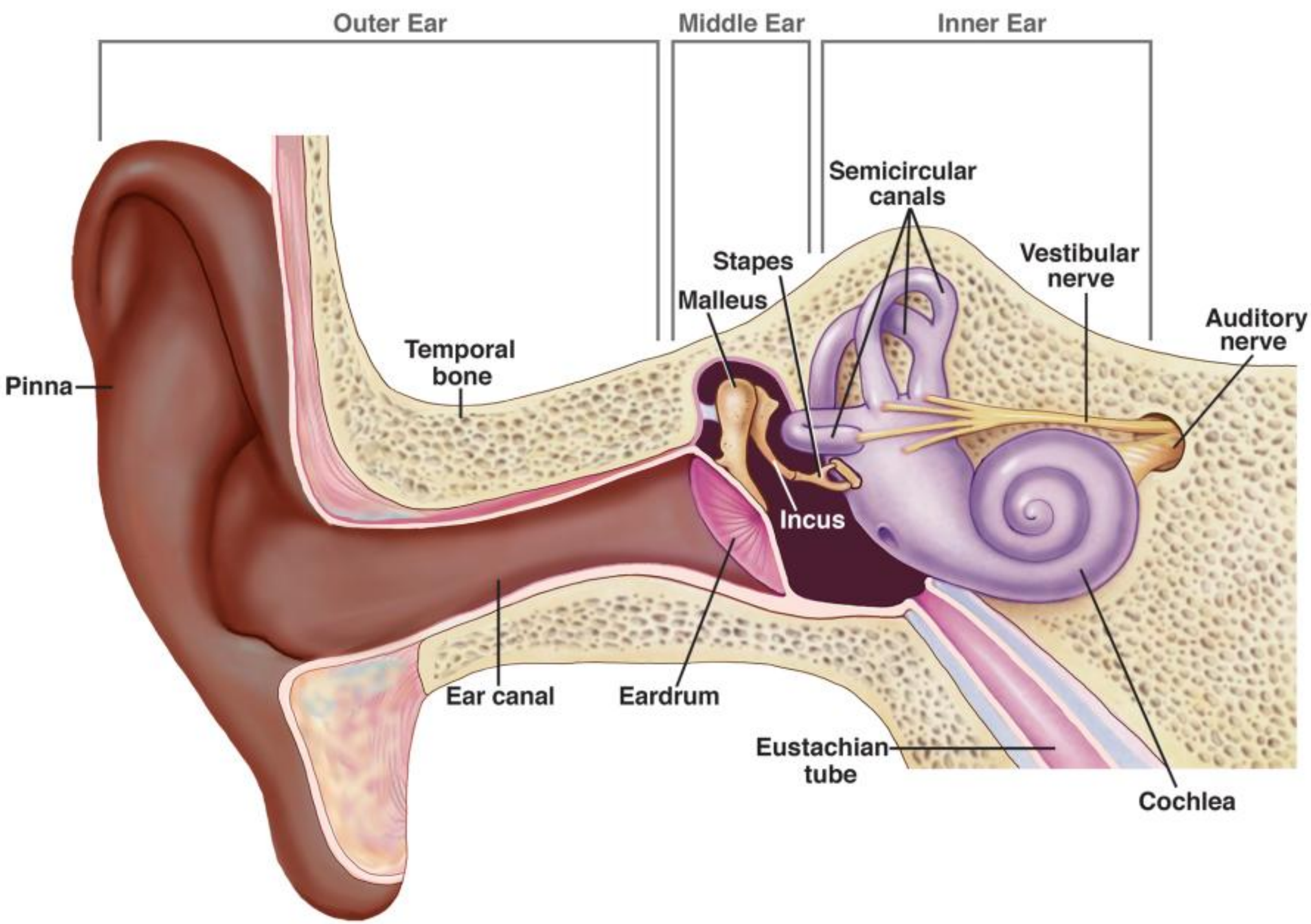
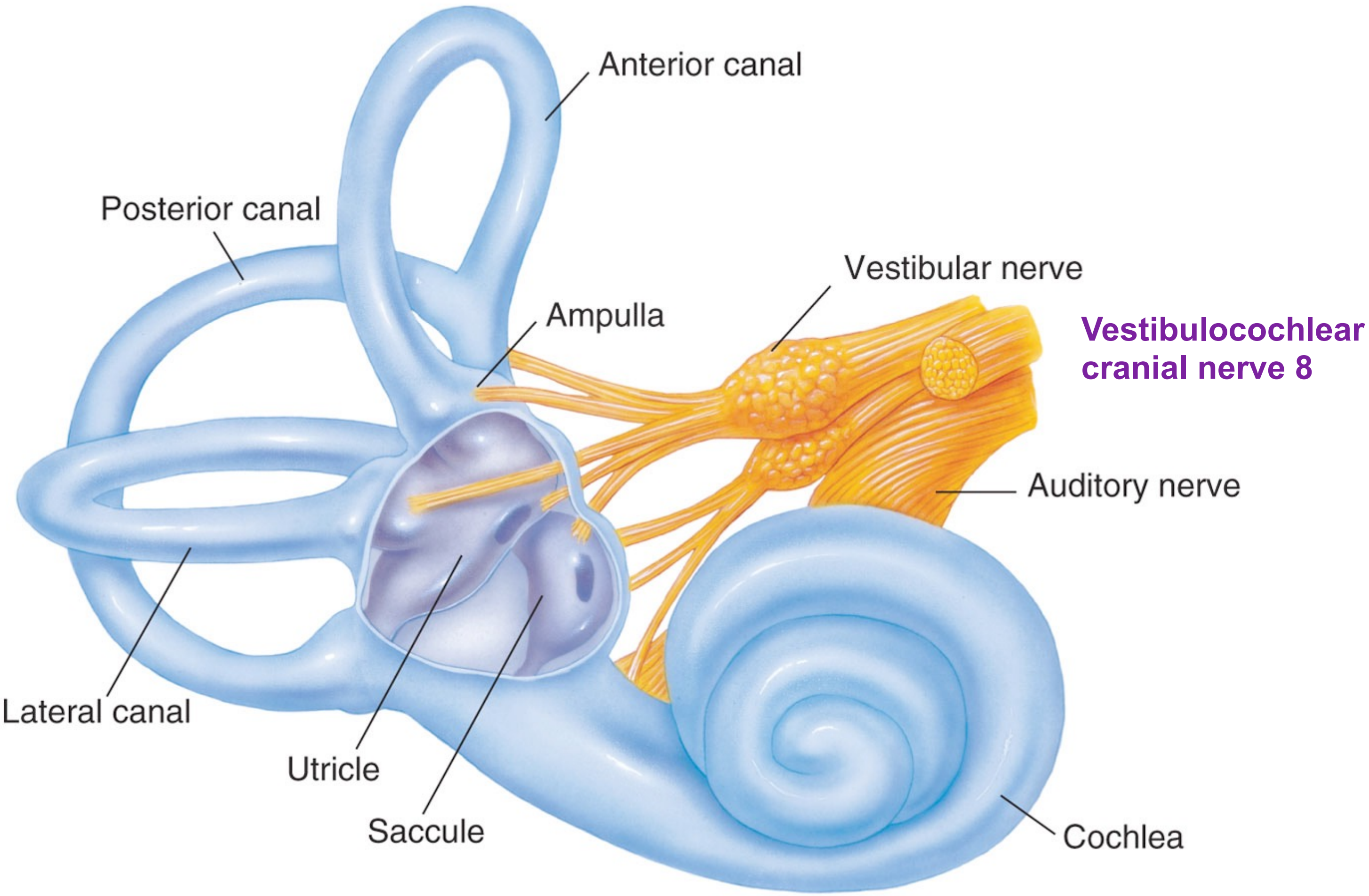

Outer Ear
Middle Ear
Inner Ear
Semicircular canals
Stapes
Vestibular nerve
Malleus
Auditory nerve
Temporal bone
Pinna
Incus
Ear canal
Eardrum
Eustachian tube
Cochlea

NIDCD

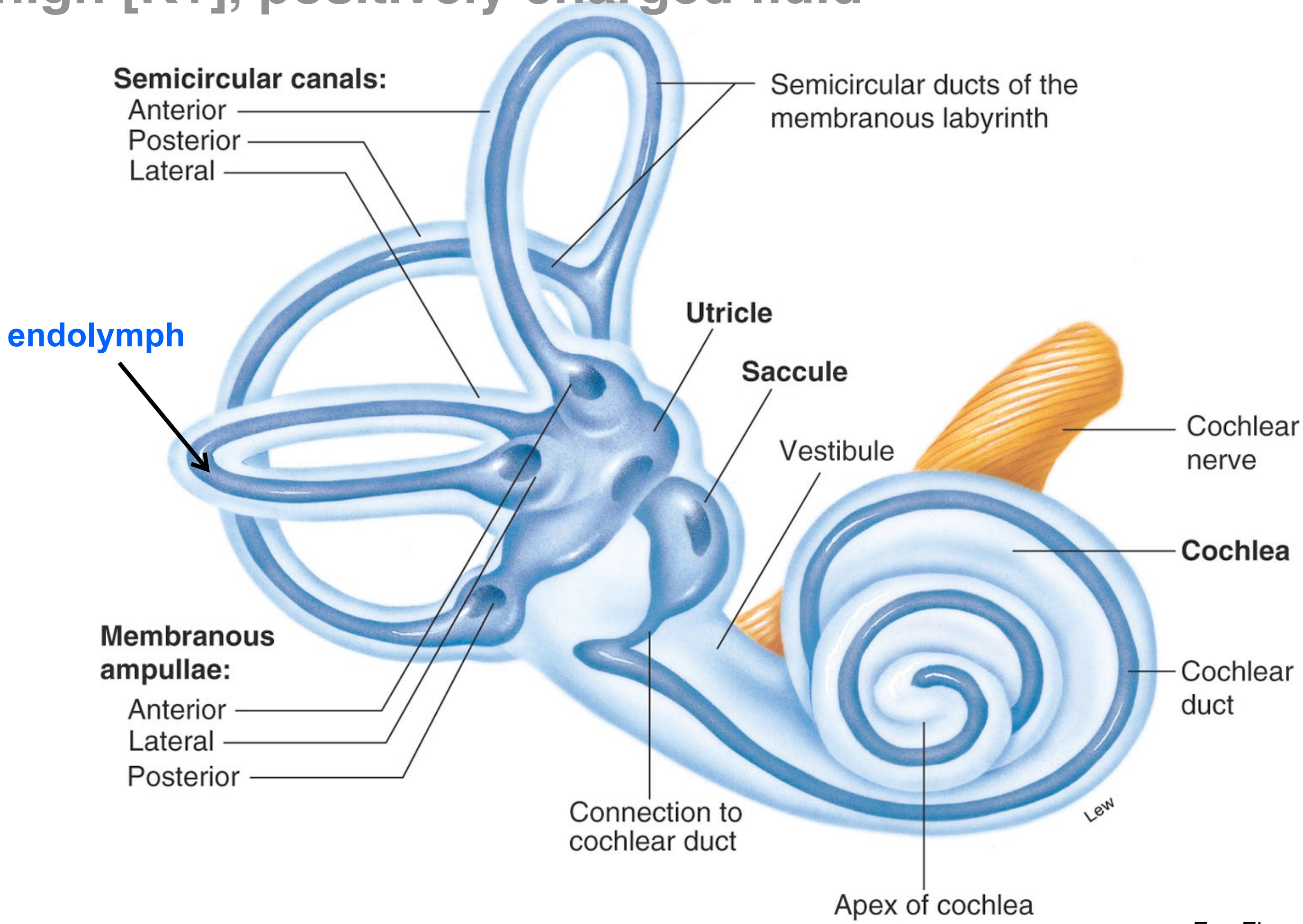
Figure 10.12



Anterior canal
Posterior canal
Vestibular nerve
Ampulla
Vestibulocochlear
cranial nerve 8
Auditory nerve
Lateral canal
Utricle
Saccule
Cochlea

Endolymph of inner ear

high [K+], positively charged fluid



Fox Figure 10.13

Hair Cells of inner ear

Mechanoreceptors that detect vibration (audition), head acceleration (vestibular)

Stereocilia -- tufted projections that stick into endolymph and gelatinous tectoral membrane and bend with vibration.

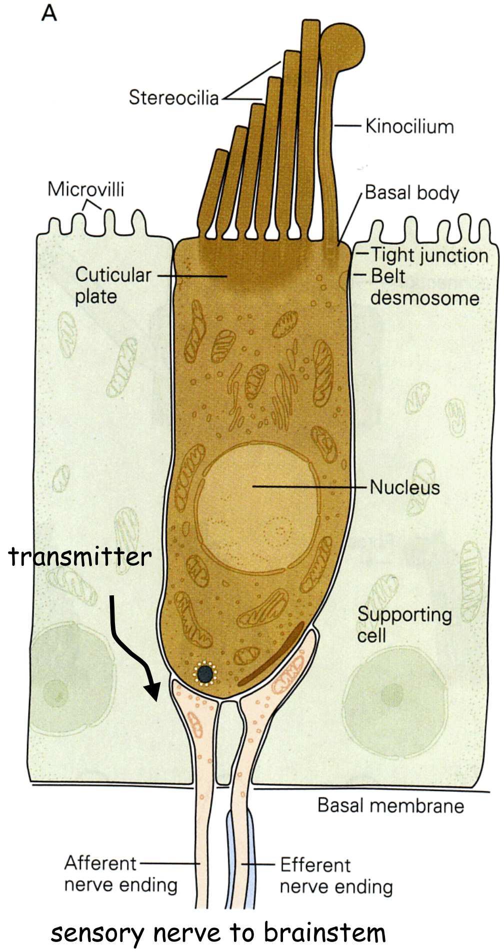
Bending of stereocilia causes change in membrane potential, and regulates release of neurotransmitter onto afferent nerve

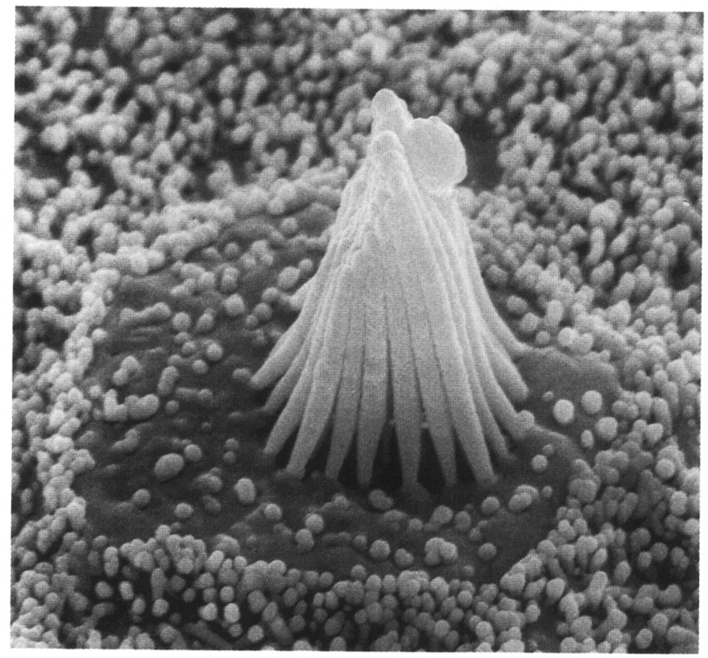
- depolarization -> more transmitter release -> more Action Potentials
- hyperpolarization -> less transmitter release -> fewer Action Potentials

Bending of stereocilia opens **K+ channels**.

Because endolymph is high in K+, K+ rushes into hair cell to cause depolarization.

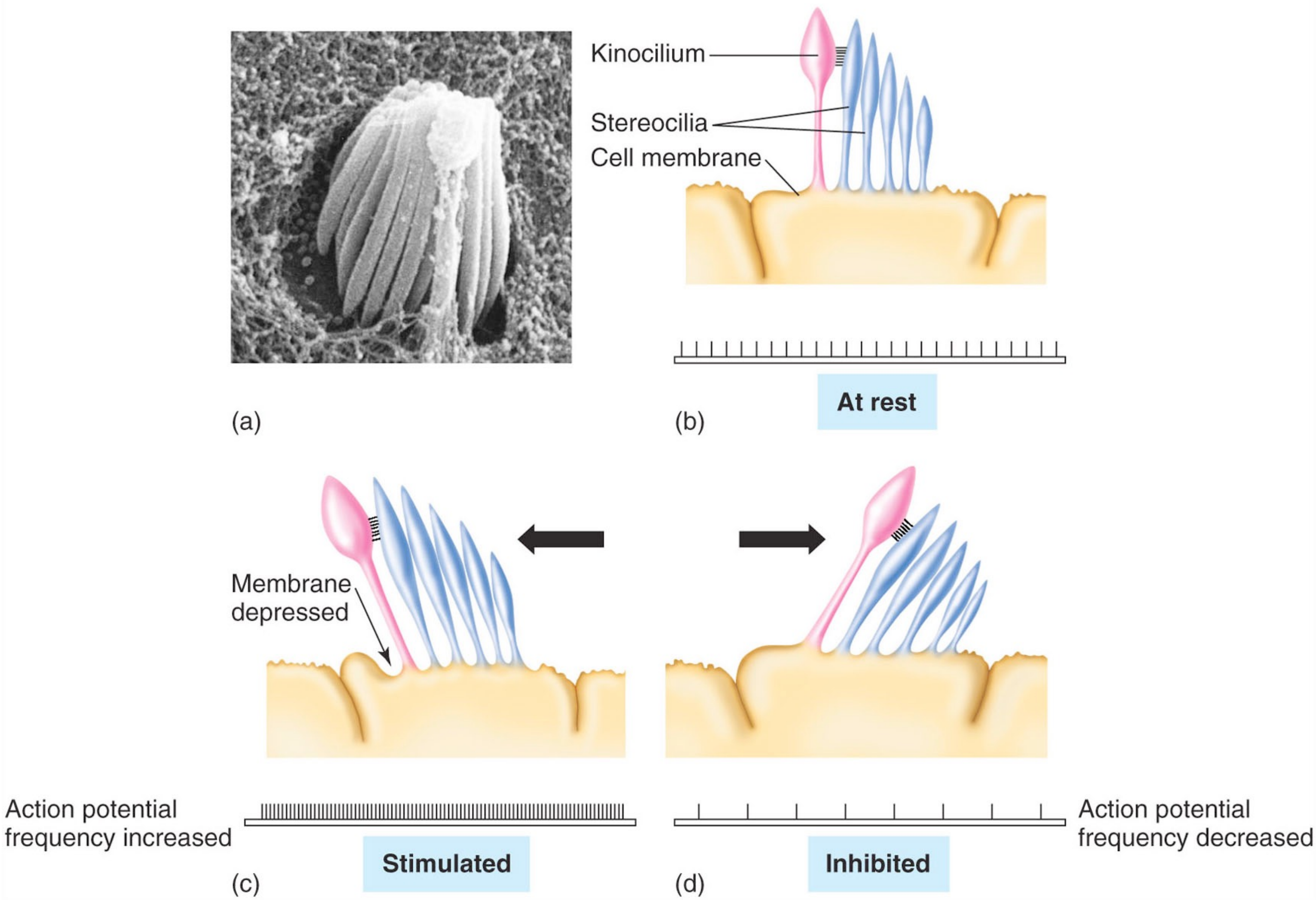
Hair cell





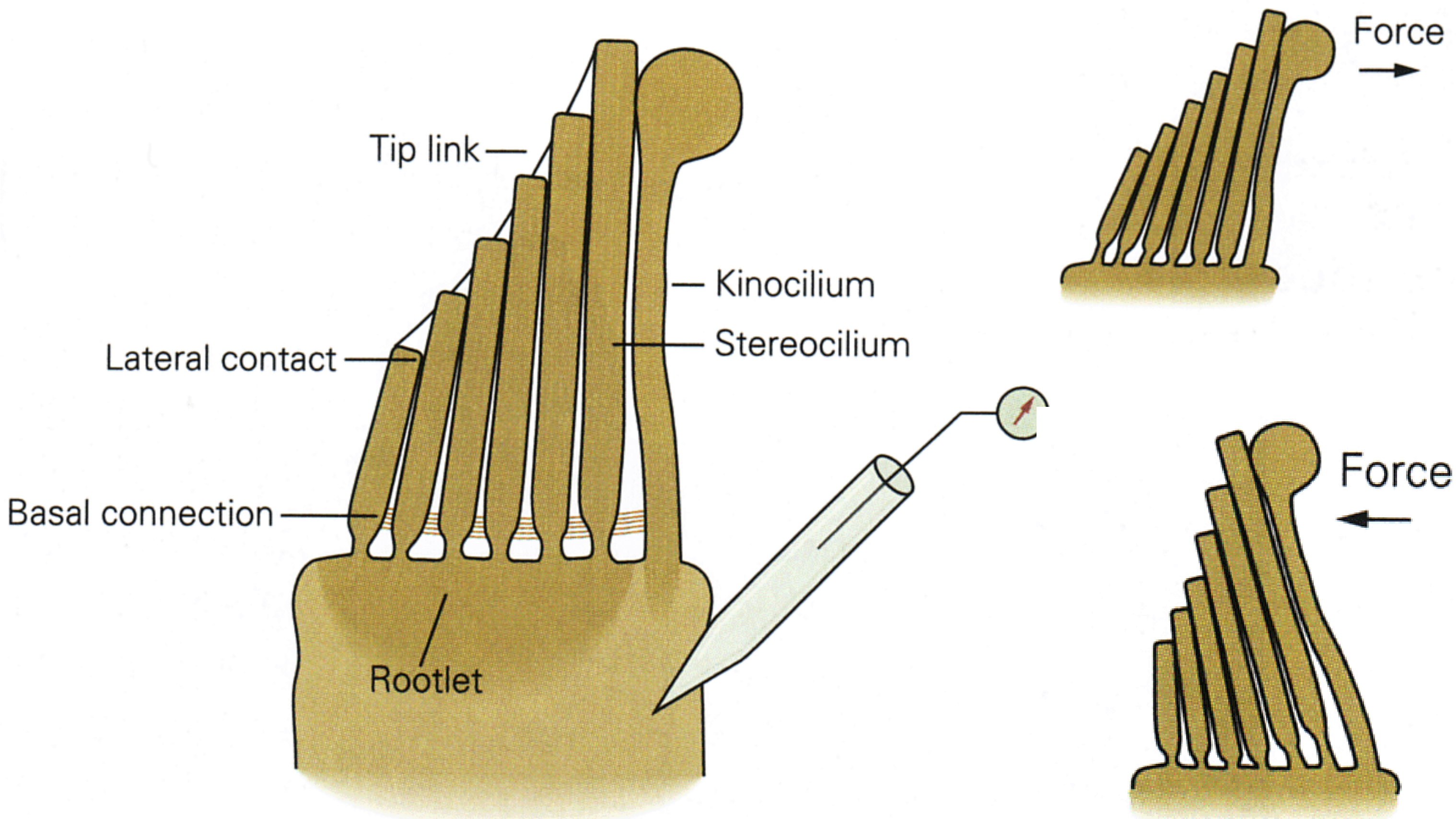
Stereocilia -- tufted projections that stick into gelatinous tectoral membrane and bend with vibration

Figure 10.14



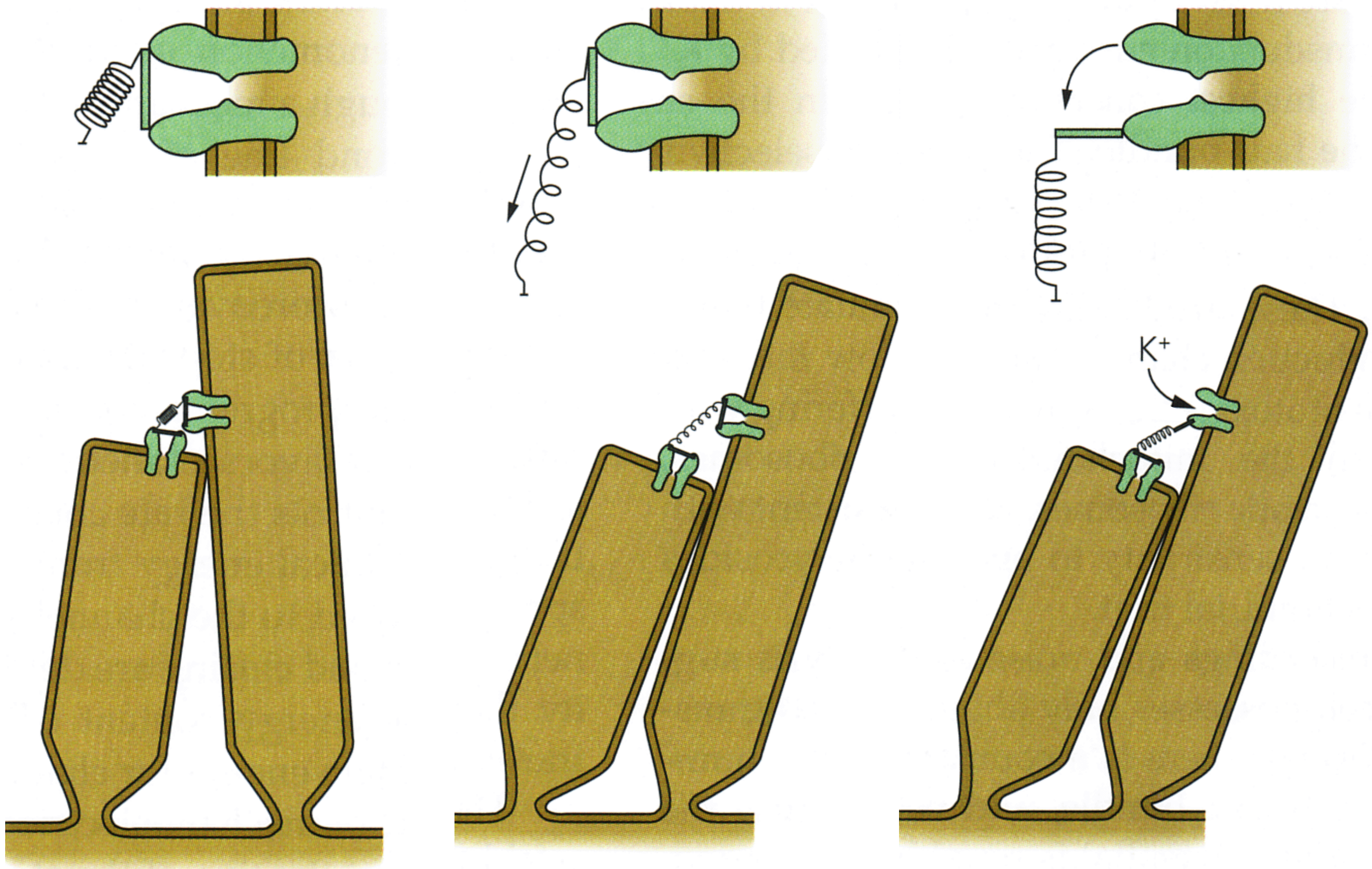
Kinocilium
Stereocilia
Cell membrane
At rest
(a)
(b)
Membrane depressed
Action potential frequency increased
Stimulated
(c)
Inhibited
(d)
Action potential frequency decreased

Vibration bends hair cells



Deflection of stereocilia opens K+ channels

K+ rushes into hair cell, causing depolarization

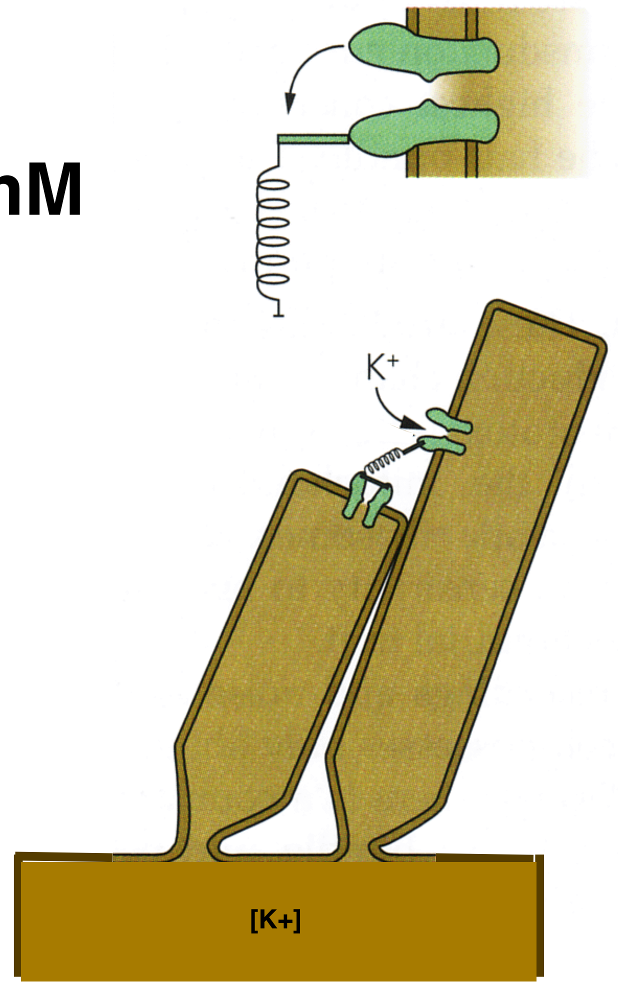


Endolymph of inner ear has high [K+]

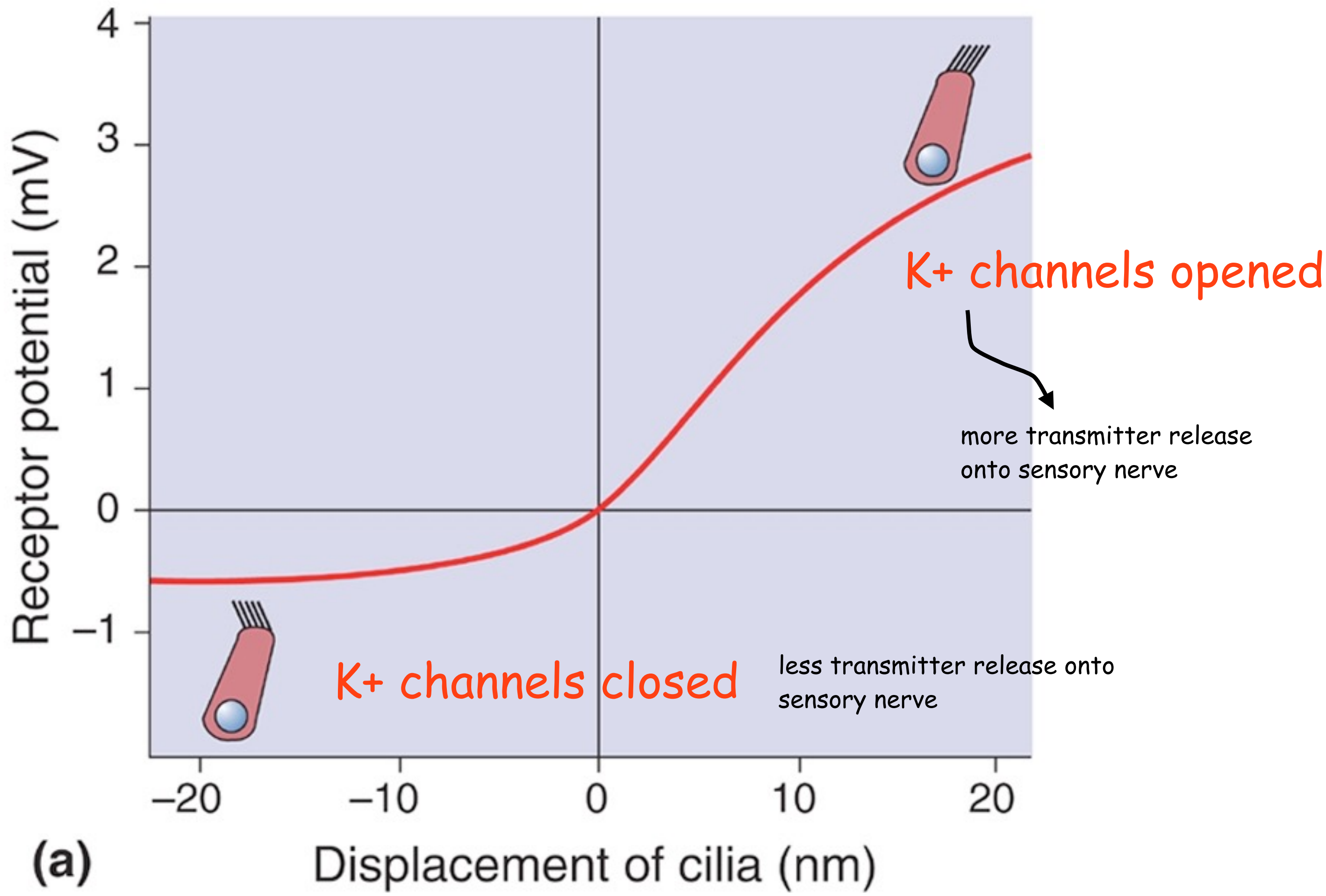
K+ in hair cells works like Na+ in neurons

[K+] = 157 mM

[Na+] = 1.3 mM



Bending of stereocilia causes change in membrane potential



Vestibular System

To maintain balance and maintenance of gaze (eye position) and posture (skeletal position).

Requires 2 out of 3 components: inner ear, vision, and/or **proprioception** (position of joints, limbs)

Utricle detects linear acceleration, using **otoliths** ("ear stones", calcium carbonate crystals) as inertial mass to detect gravity and starting/stopping during linear motion.

Semicircular Canals detect rotational acceleration in each of 3 planes. Sloshing of endolymph around the canal; deforms **cupula** which bends hair cells.

Loss of inner ears -> inability to detect gravity, rotation.

Conflict Hypothesis of Motion Sickness

When inputs to vestibular system don't agree with each other, causes dizzyness and nausea

e.g. reading book in bumpy car: visual field is steady, but inner ear reports accelerations

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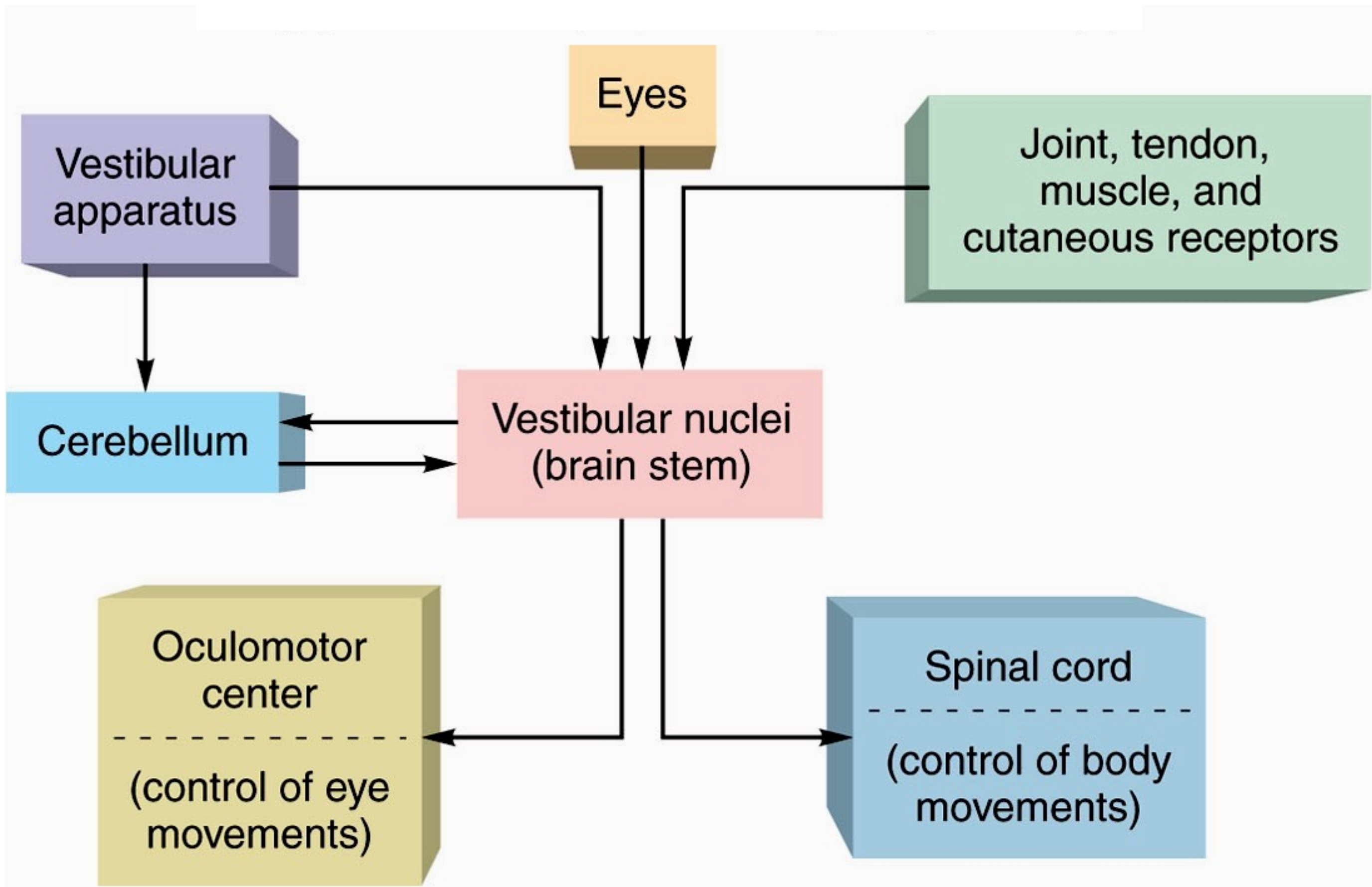
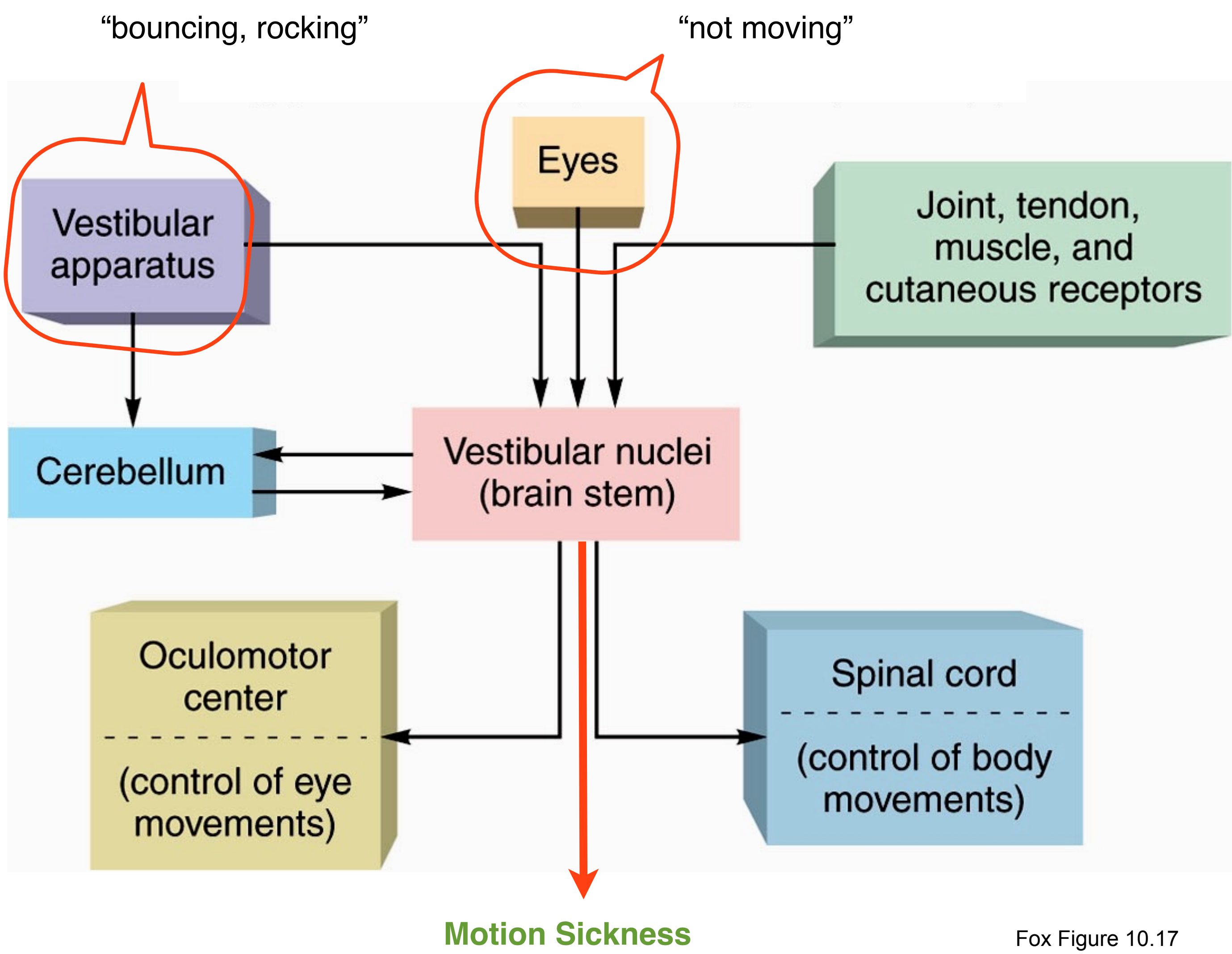
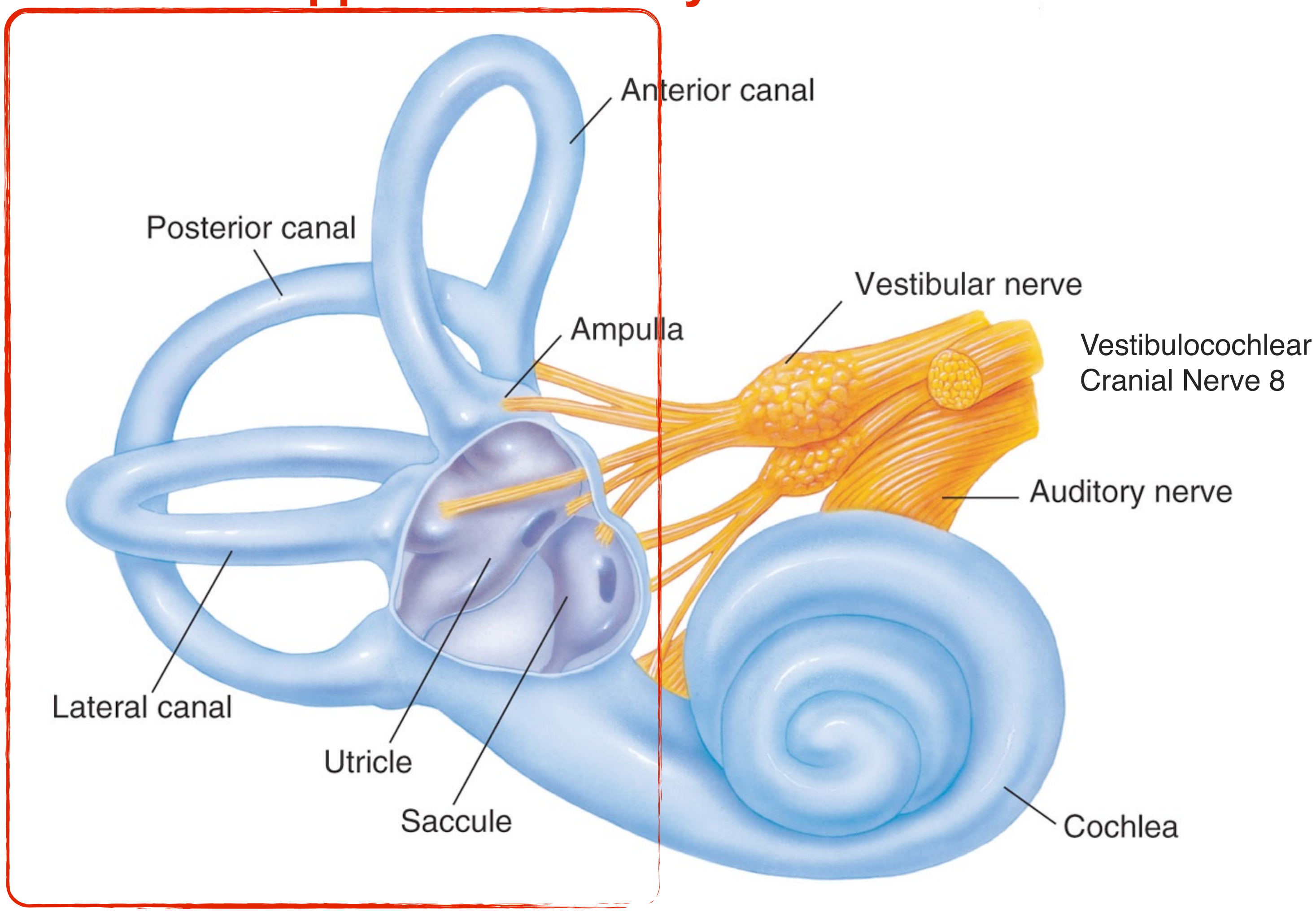


Fox Figure 10.17



Fox Figure 10.17

Vestibular Apparatus = “Labyrinth”

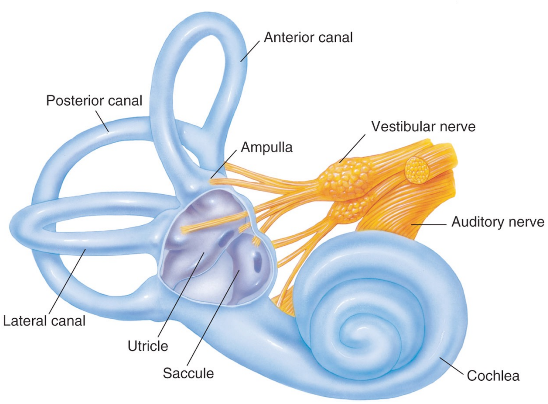


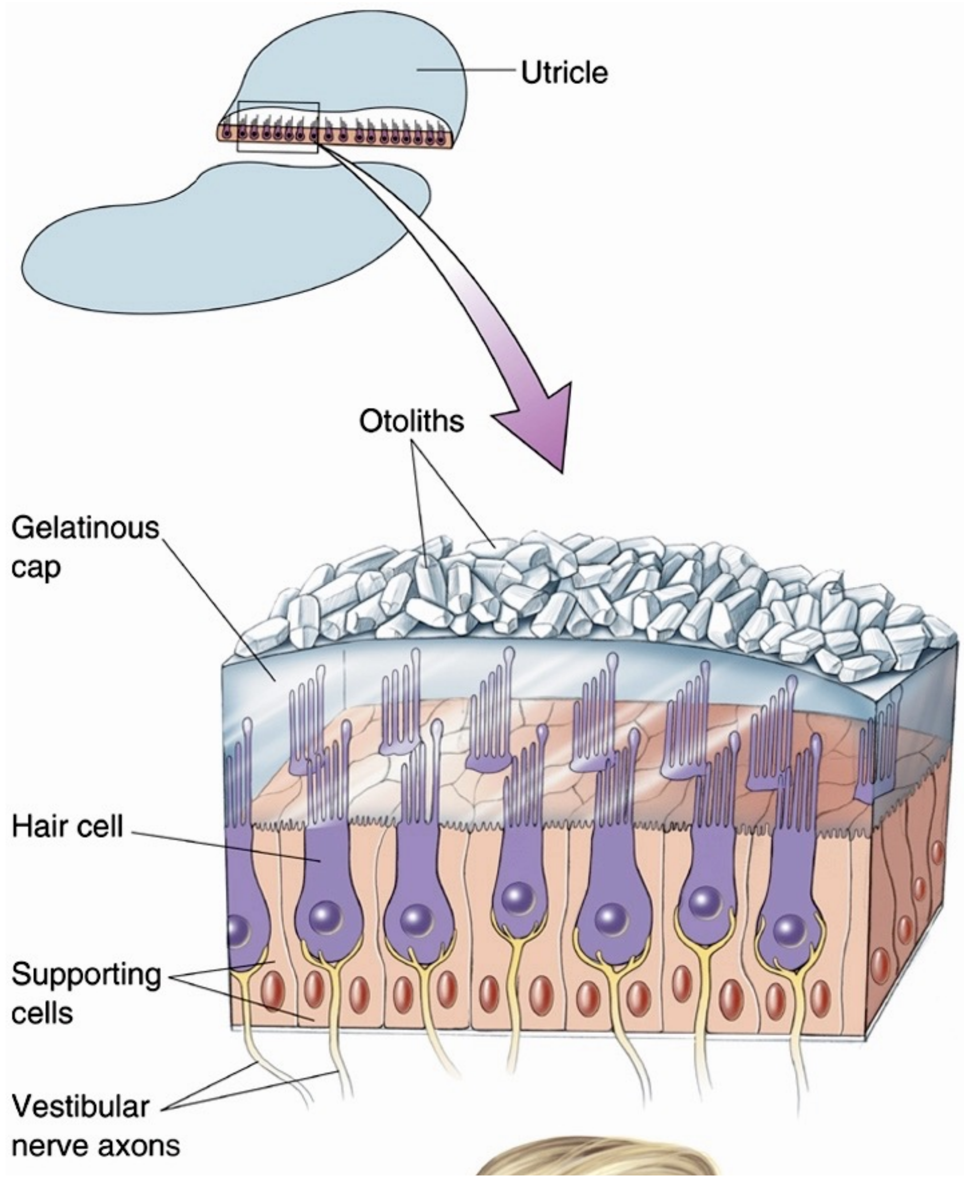
Fox Figure 10.12

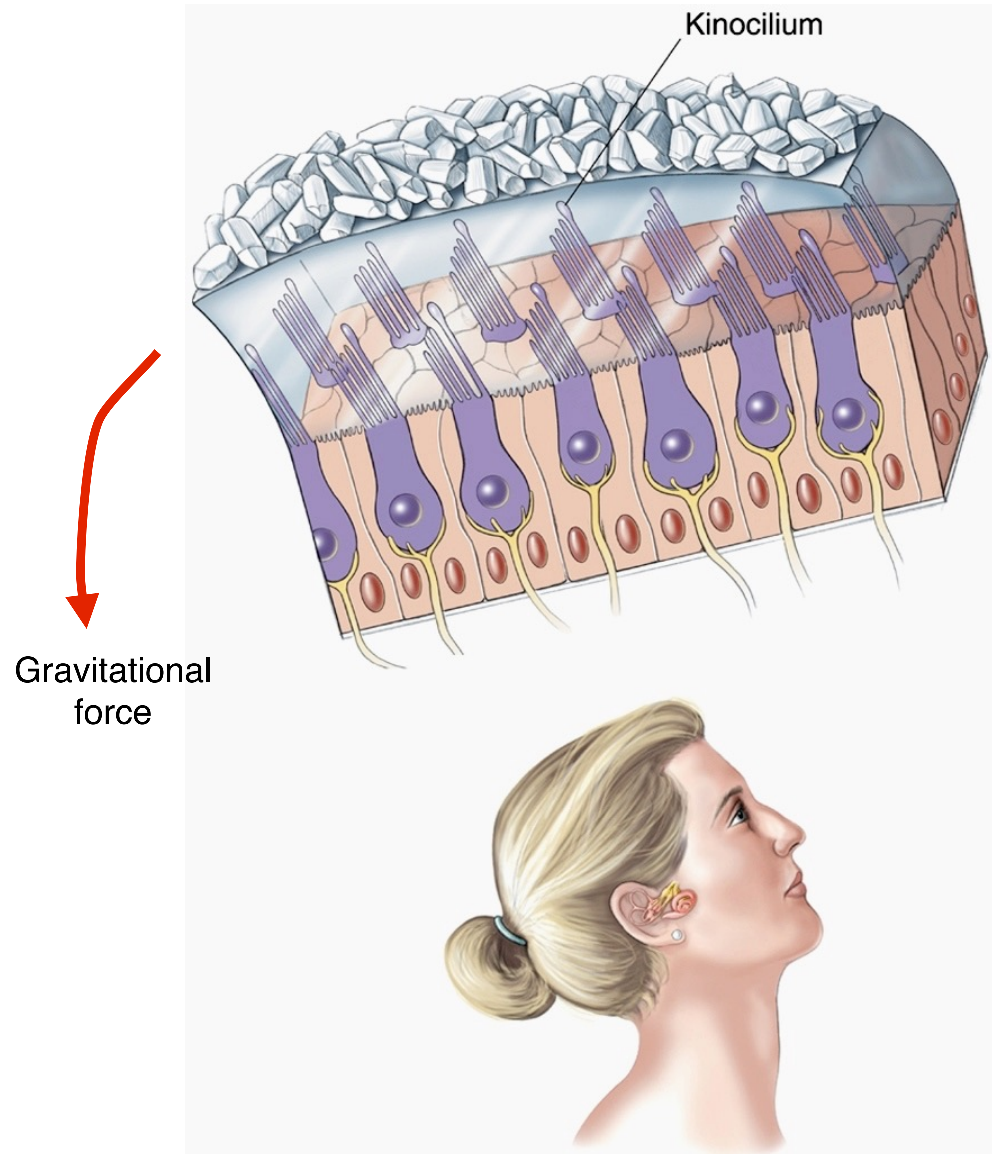
Utricle

detection of

linear acceleration

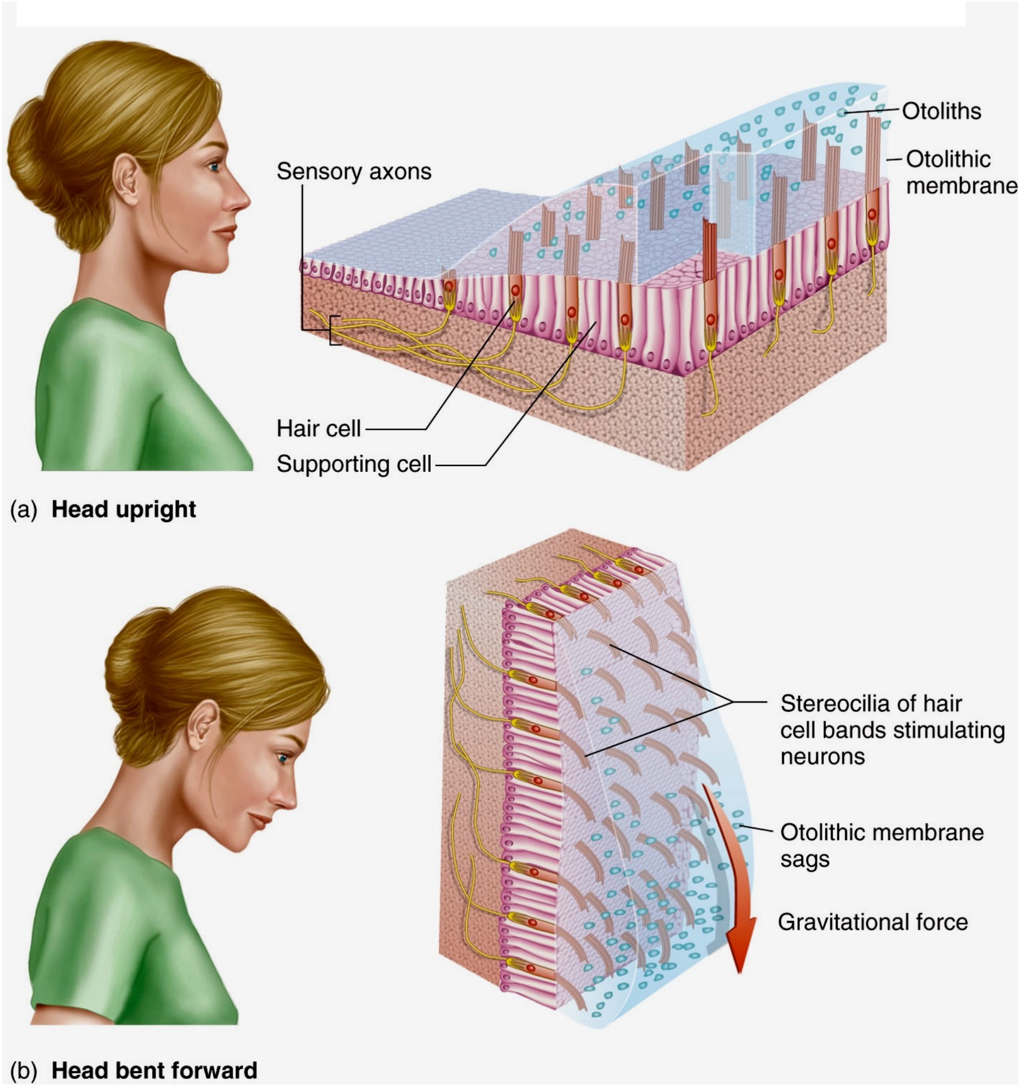




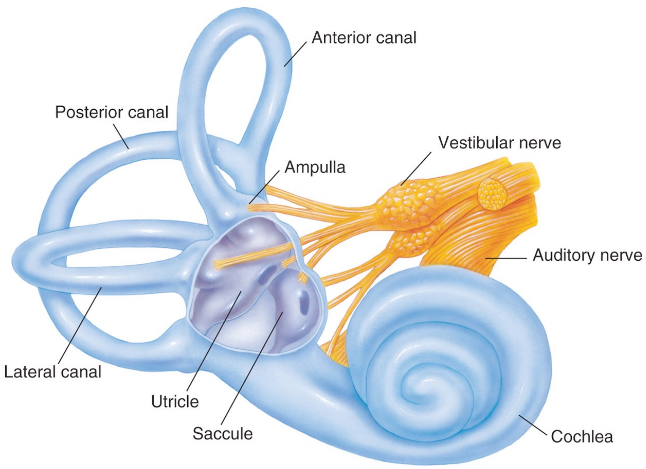


see Fox Figure 10.15

Figure 10.15


Otoliths
Otolithic membrane
Sensory axons
Hair cell
Supporting cell
(a) Head upright
Stereocilia of hair cell bands stimulating neurons
Otolithic membrane sags
Gravitational force
(b) Head bent forward

Semicircular Canals
detection of
rotational acceleration



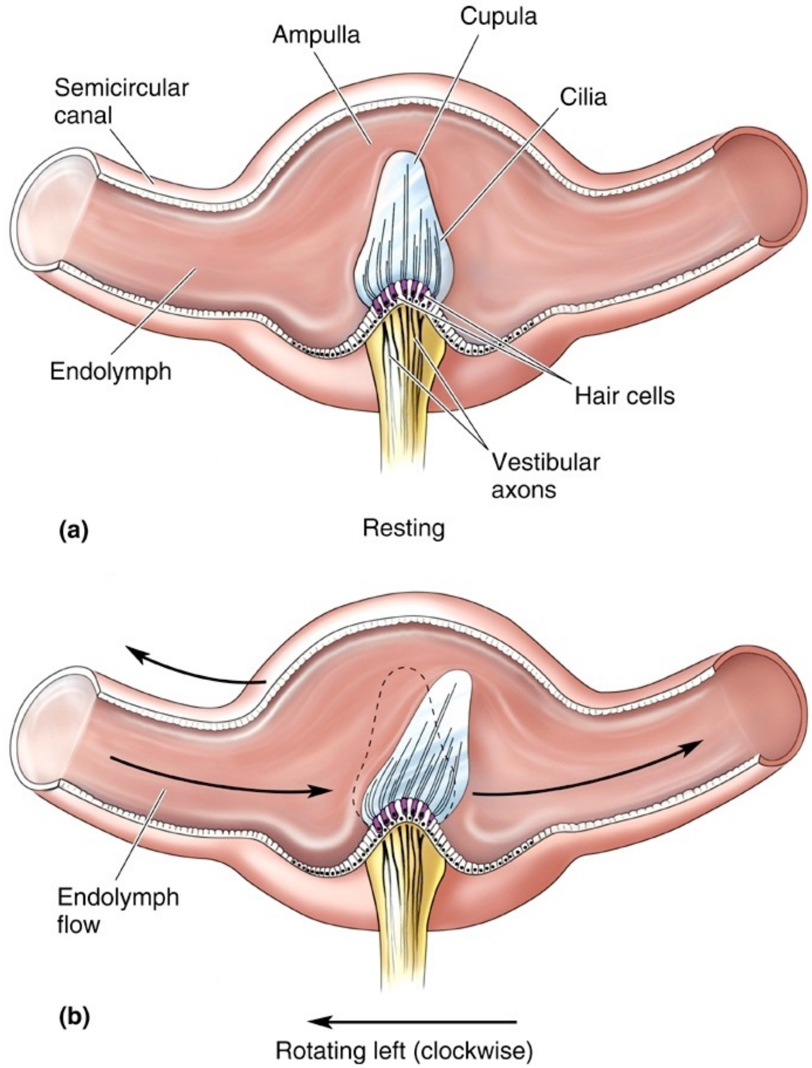
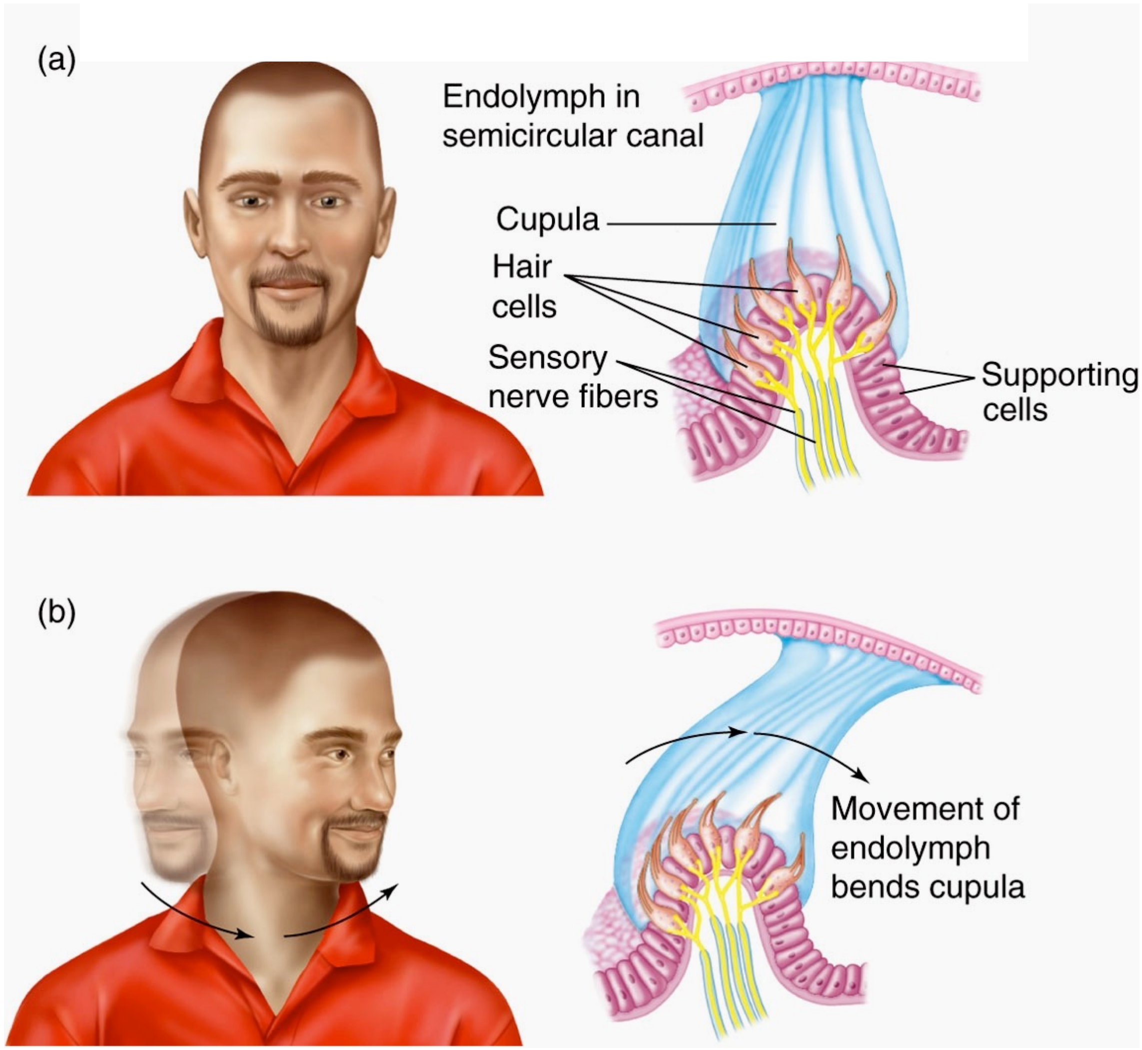
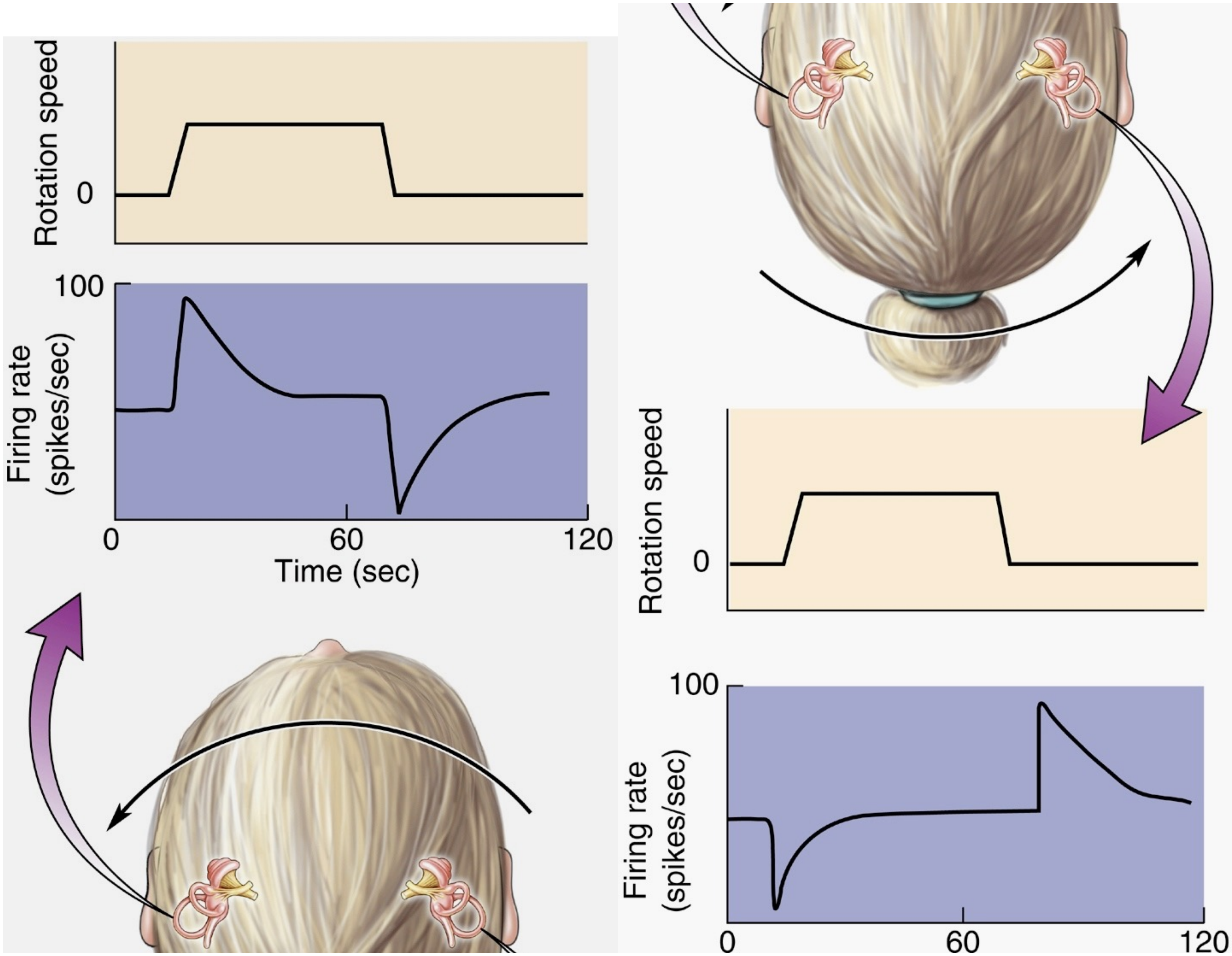


Figure 10.16


(a)
Endolymph in semicircular canal
Cupula
Hair cells
Sensory nerve fibers
Supporting cells
(b)
Movement of endolymph bends cupula



Rotation speed
0
100
Firing rate (spikes/sec)
0
60
120
Time (sec)
Rotation speed
0
100
Firing rate (spikes/sec)
0
60
120

Properties of Auditory System

1. Capture sound using outer ear (auricle, external auditory meatus) to the middle ear via **tympanic membrane** and **middle ear bones** (malleus, incus,stapes): transfer & amplify vibration to the **oval window**

2. Transmit to receptors: vibration of **basilar membrane** that runs length of cochlea. Response of basilar membrane varies across its length.

   Low frequency sound vibrates **apex** of cochlea.

   High frequency sound vibrates **base** of cochlea.

3. Transduction of sound frequency into spatial location (**tonotopy**) to stimulate auditory nerve fibers (Cranial Nerve 8: vestibulocochlear nerve).

4. Receptive Field of Auditory Neuron: tuned to **characteristic frequency**. Neuron's response (rate of action potentials) reflects intensity of sound at characteristic frequency.

5. Cranial Nerve 8 projects to cochlear nucleus in the brainstem.

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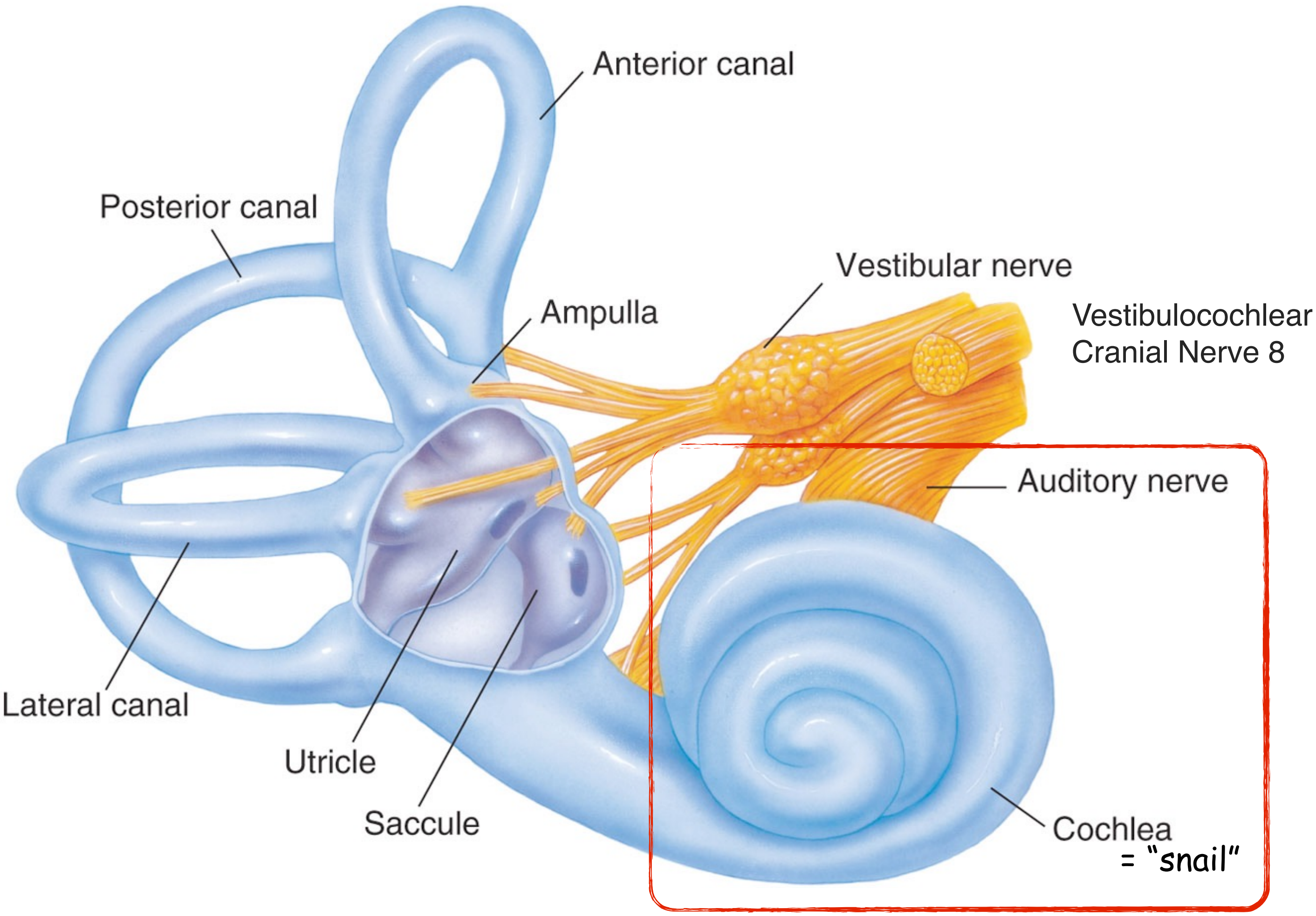
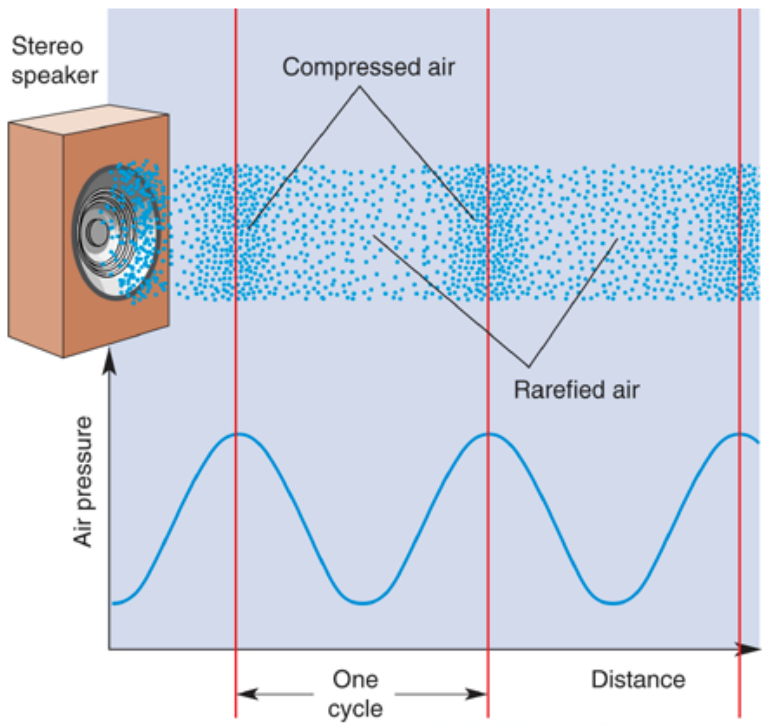
Cochlea & Sound Detection



Fox Figure 10.12

The Nature of Sound

- **Audible variations in air pressure**
  - Sound frequency: Number of cycles per second expressed in units called hertz (Hz)
  - Cycle: Distance between successive compressed patches



The Nature of Sound

- Range: 20 Hz to 20,000 Hz
- Pitch: High pitch = high frequency; low frequency = low pitch
- Intensity: High intensity louder than low intensity

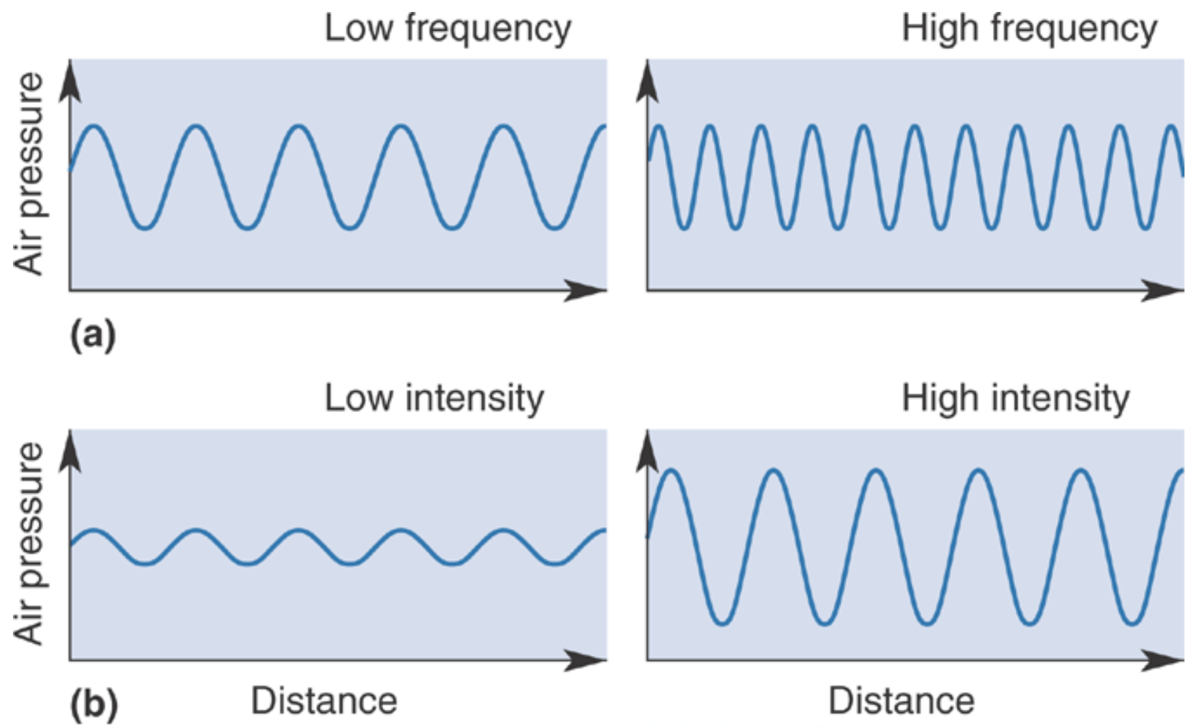
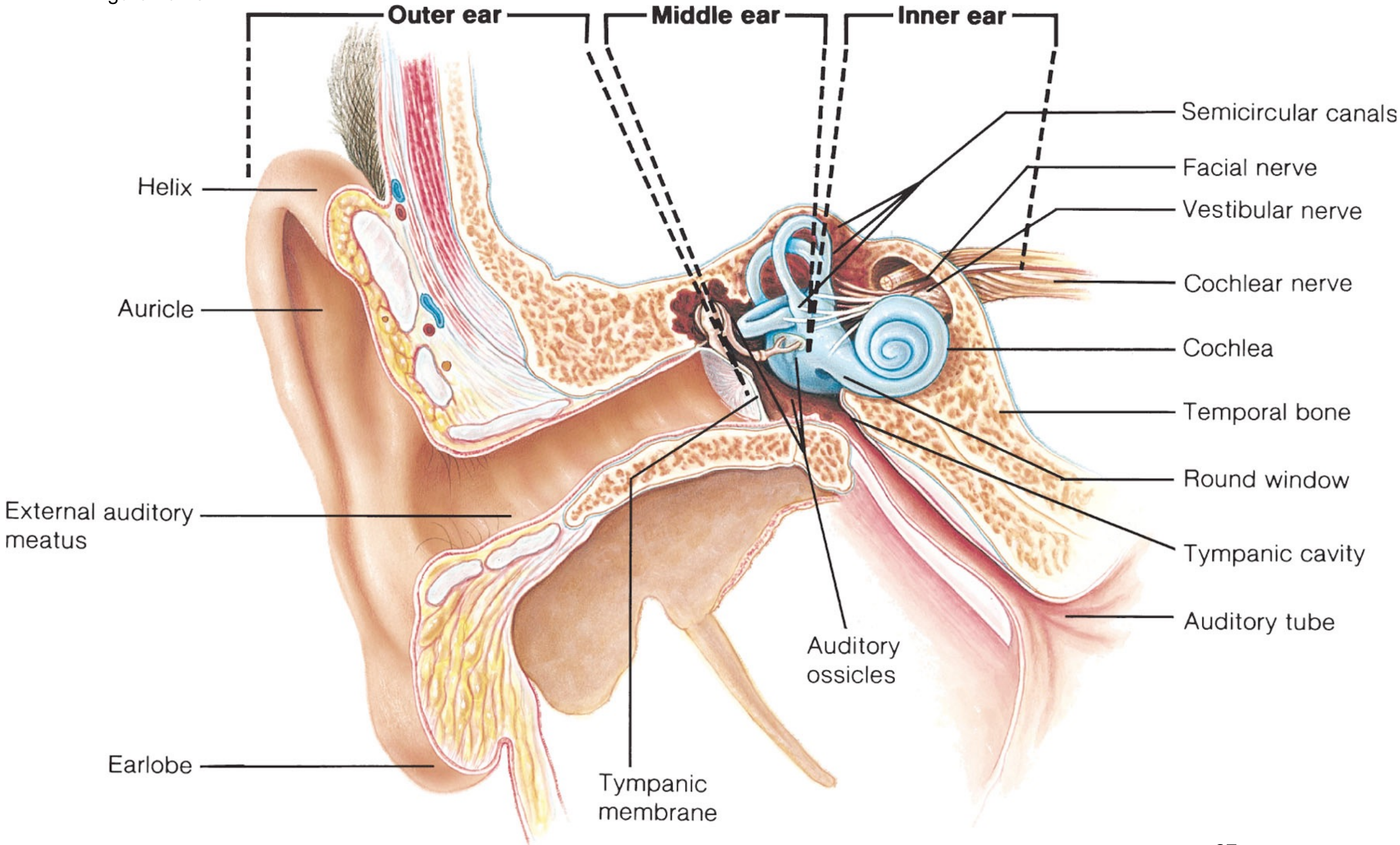
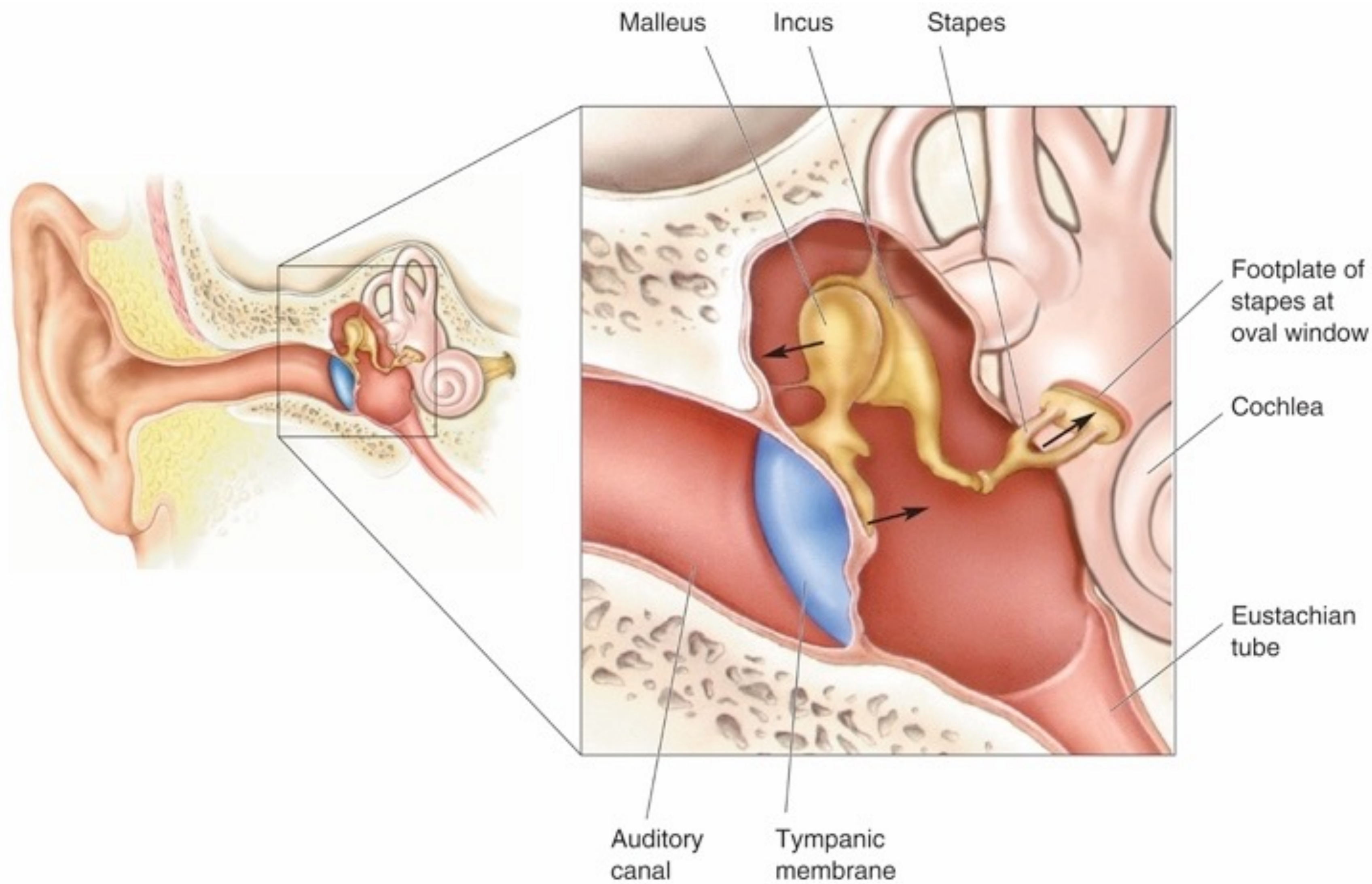


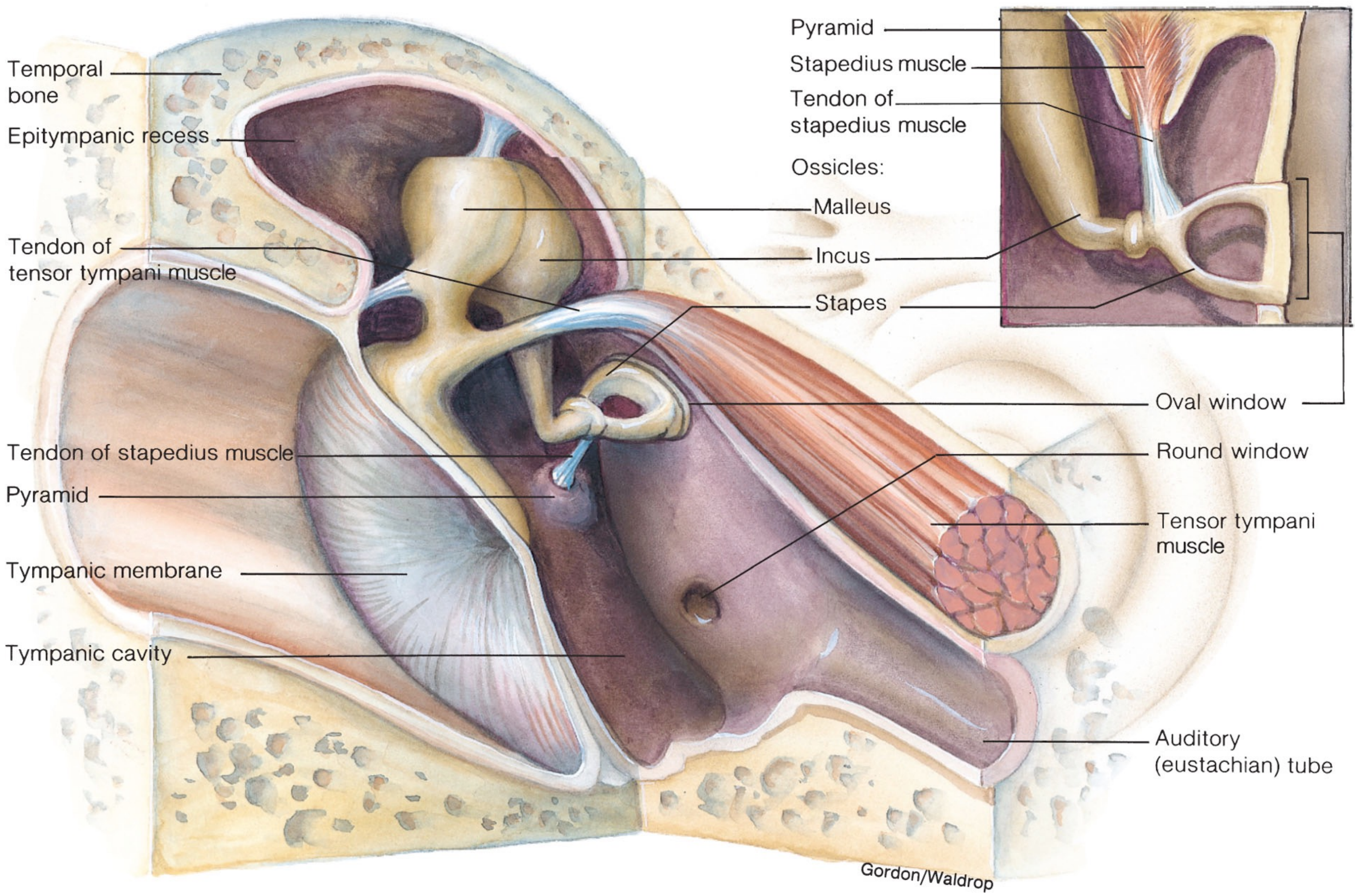
Figure 10.18


Outer ear
Middle ear
Inner ear
Helix
Auricle
External auditory meatus
Earlobe
Tympanic membrane
Auditory ossicles
Semicircular canals
Facial nerve
Vestibular nerve
Cochlear nerve
Cochlea
Temporal bone
Round window
Tympanic cavity
Auditory tube



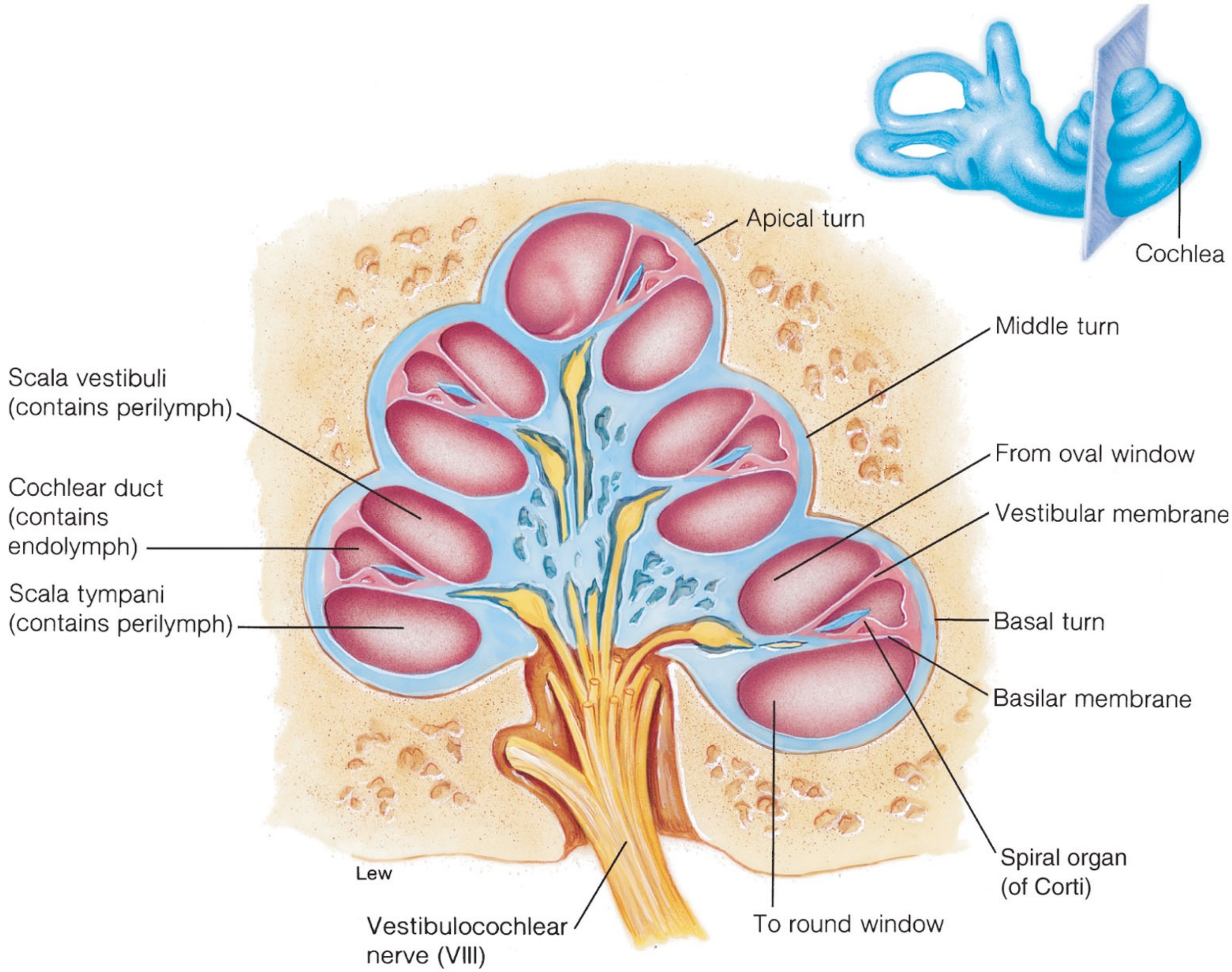
Malleus
Incus
Stapes
Footplate of stapes at oval window
Cochlea
Eustachian tube
Auditory canal
Tympanic membrane

Figure 10.19



Temporal bone
Epitympanic recess
Tendon of tensor tympani muscle
Tendon of stapedius muscle
Pyramid
Tympanic membrane
Tympanic cavity
Pyramid
Stapedius muscle
Tendon of stapedius muscle
Ossicles:
Malleus
Incus
Stapes
Oval window
Round window
Tensor tympani muscle
Auditory (eustachian) tube
Gordon/Waldrop

Figure


Apical turn
Cochlea
Middle turn
Scala vestibuli
(contains perilymph)
From oval window
Vestibular membrane
Cochlear duct
(contains
endolymph)
Scala tympani
(contains perilymph)
Basal turn
Basilar membrane
Spiral organ
(of Corti)
Lew
Vestibulocochlear
nerve (VIII)
To round window

Vibration of Basilar Membrane

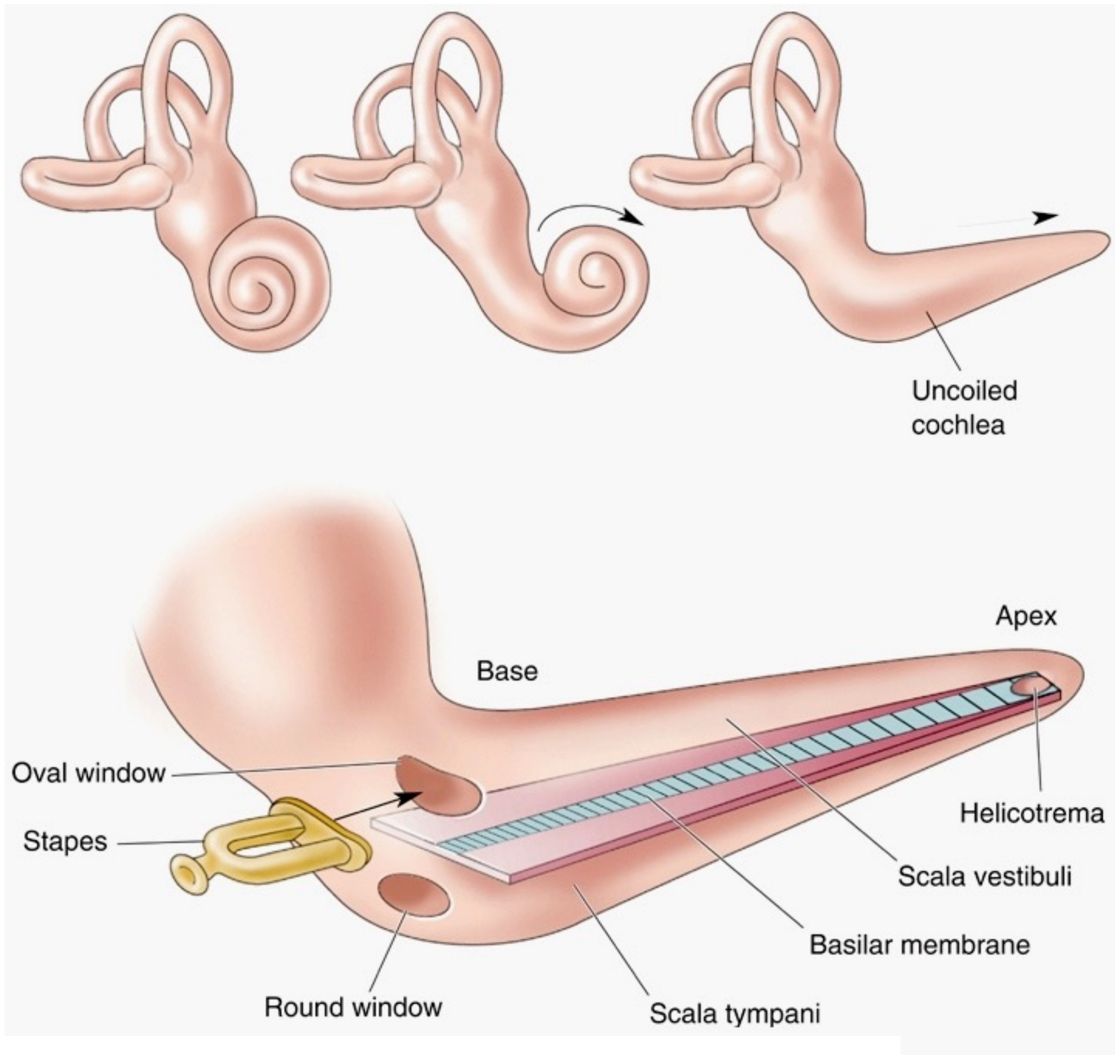
Vibrations of oval window -> vibrations in endolymph -> vibration of basilar membrane.

Response of basilar membrane varies across its length.

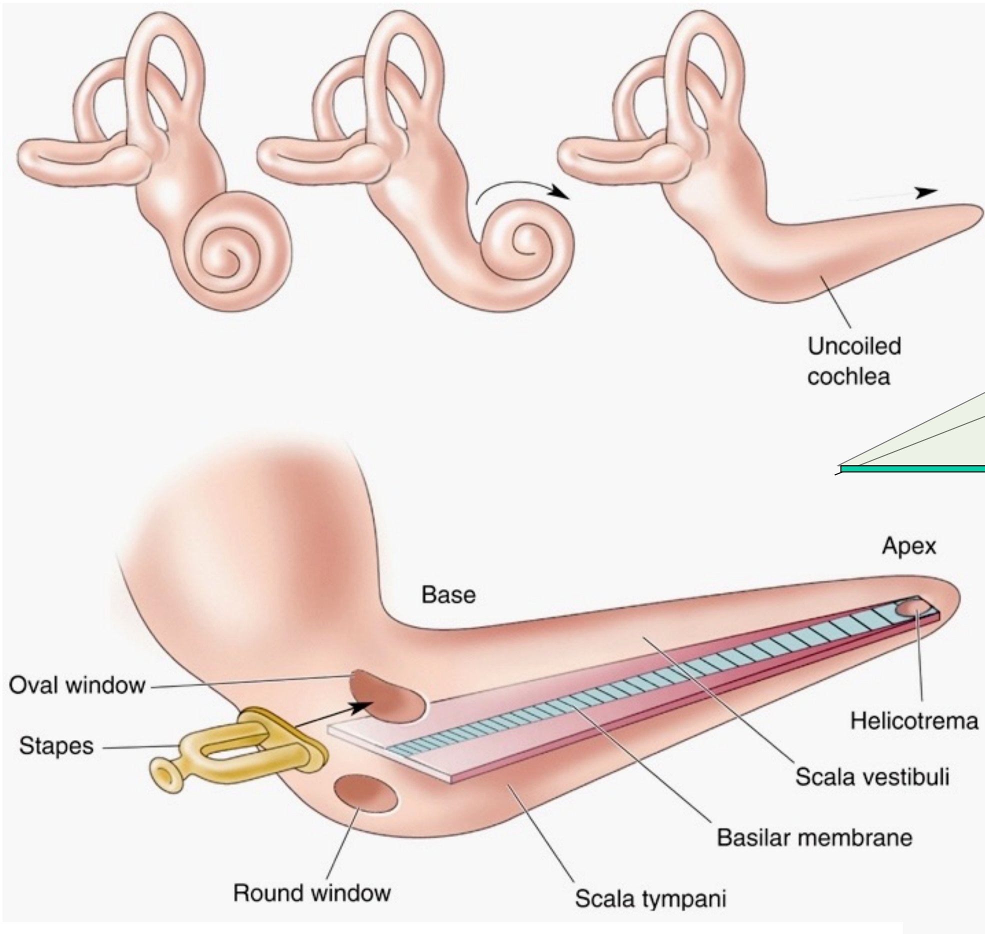
Low frequency sound vibrates **apex** of cochlea (basilar membrane **thicker**).

High frequency sound vibrates **base** of cochlea (basilar membrane **thinner**).

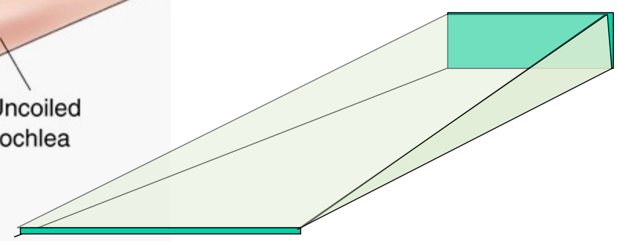
Transduce sound frequency into spatial location.



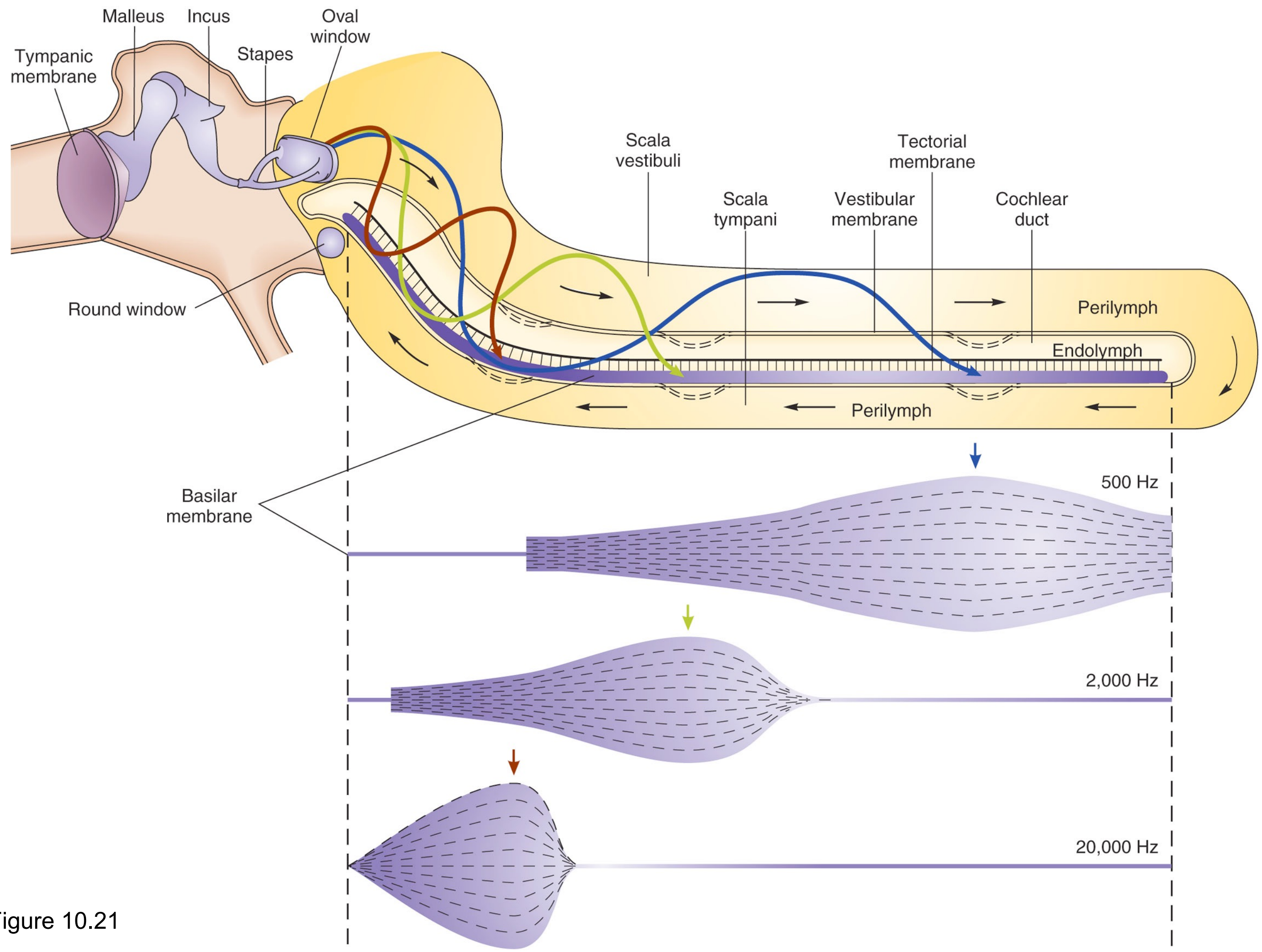
Uncoiled cochlea
Apex
Base
Oval window
Stapes
Helicotrema
Scala vestibuli
Basilar membrane
Round window
Scala tympani



apex: thick, vibrates at low frequency



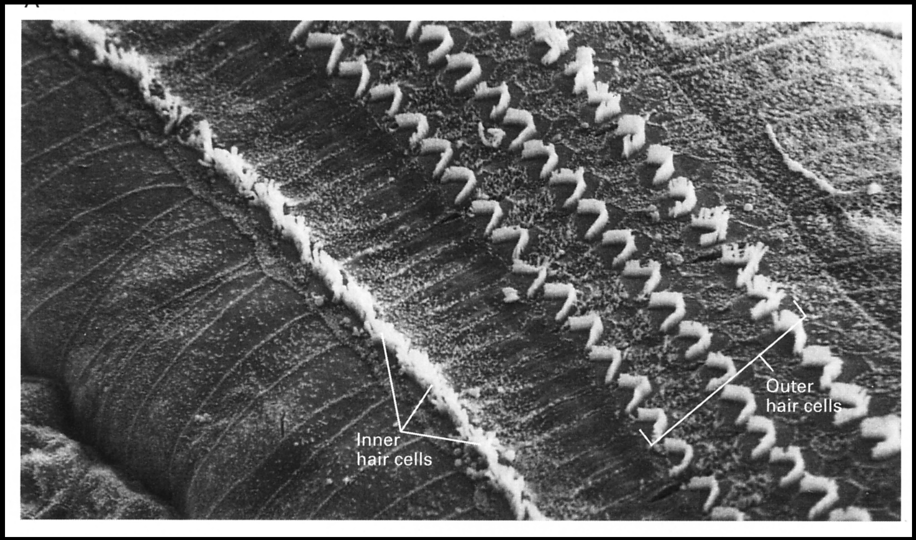
base: thin, vibrates at high frequency

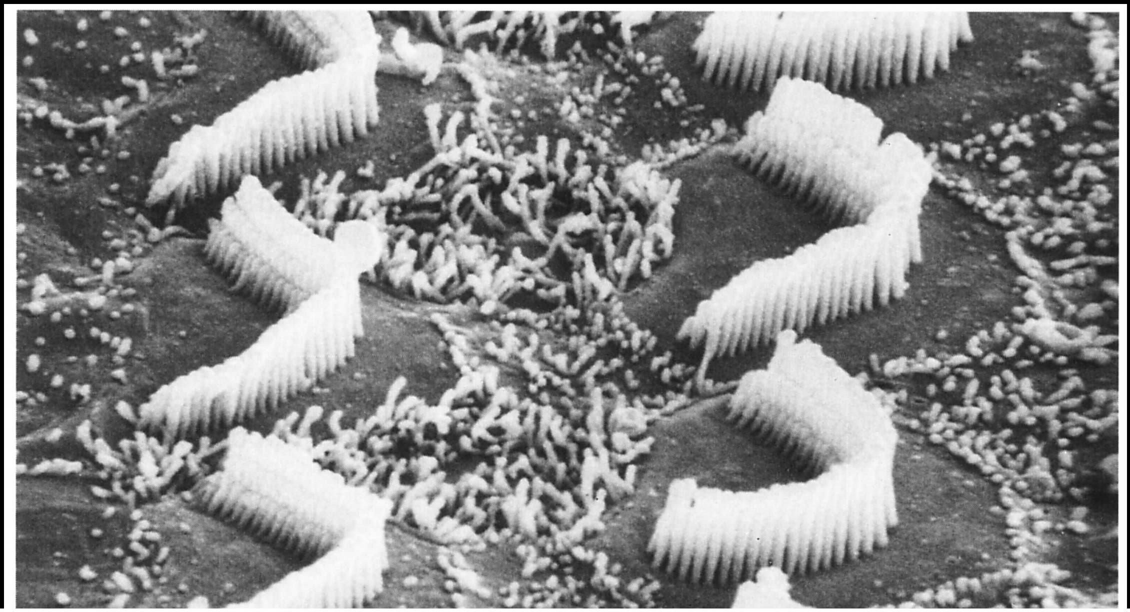


Malleus
Incus
Oval window
Tympanic membrane
Stapes
Scala vestibuli
Tectorial membrane
Scala tympani
Vestibular membrane
Cochlear duct
Perilymph
Endolymph
Round window
Perilymph
Basilar membrane
500 Hz
2,000 Hz
20,000 Hz

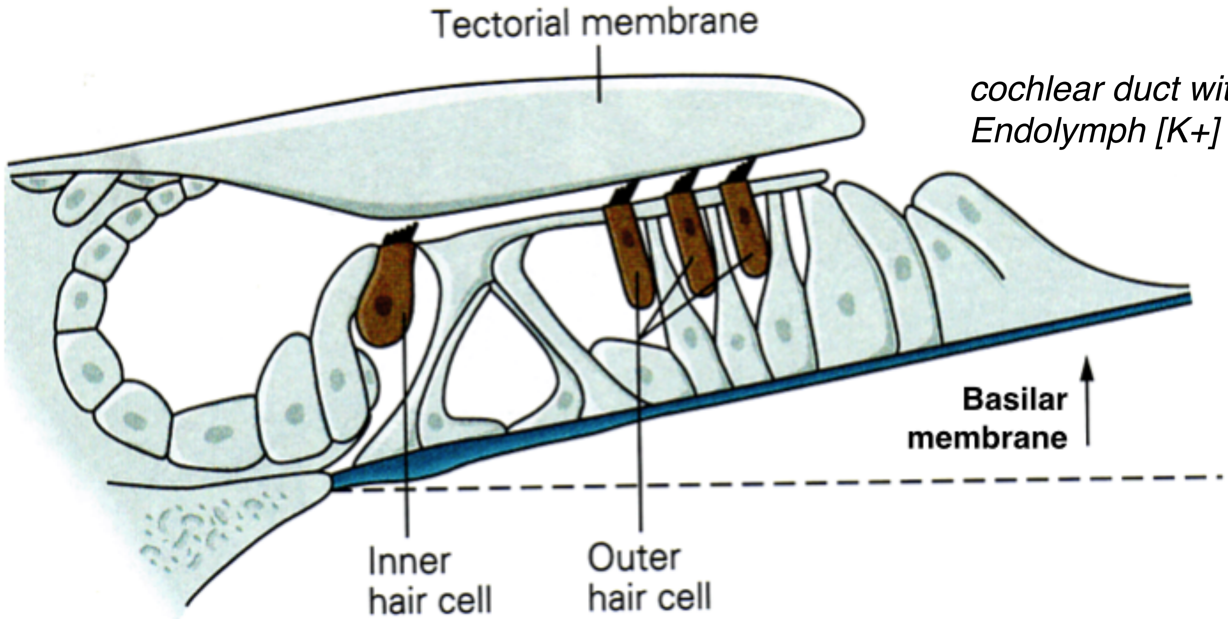
Figure 10.21

Hair cells





Basilar membrane vibration bends hair cells

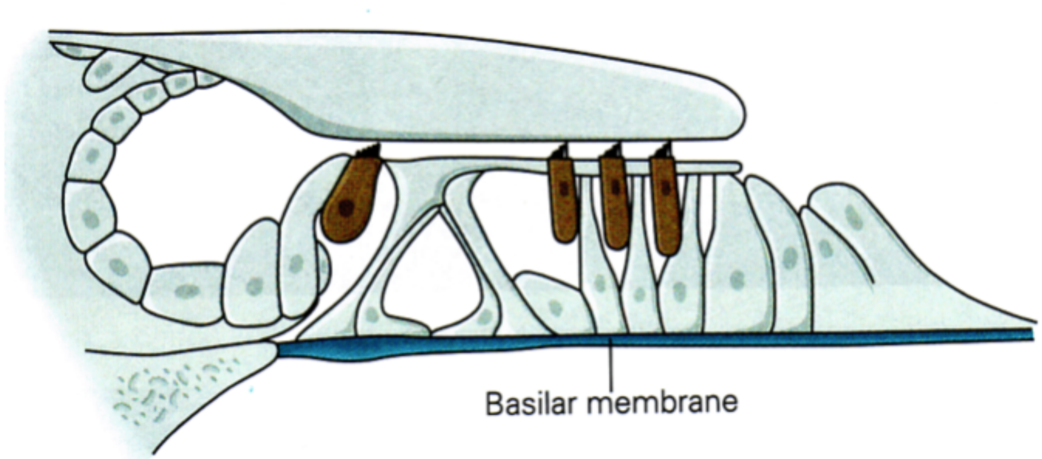


cochlear duct with Endolymph [K+]

Perilymph Vibrates

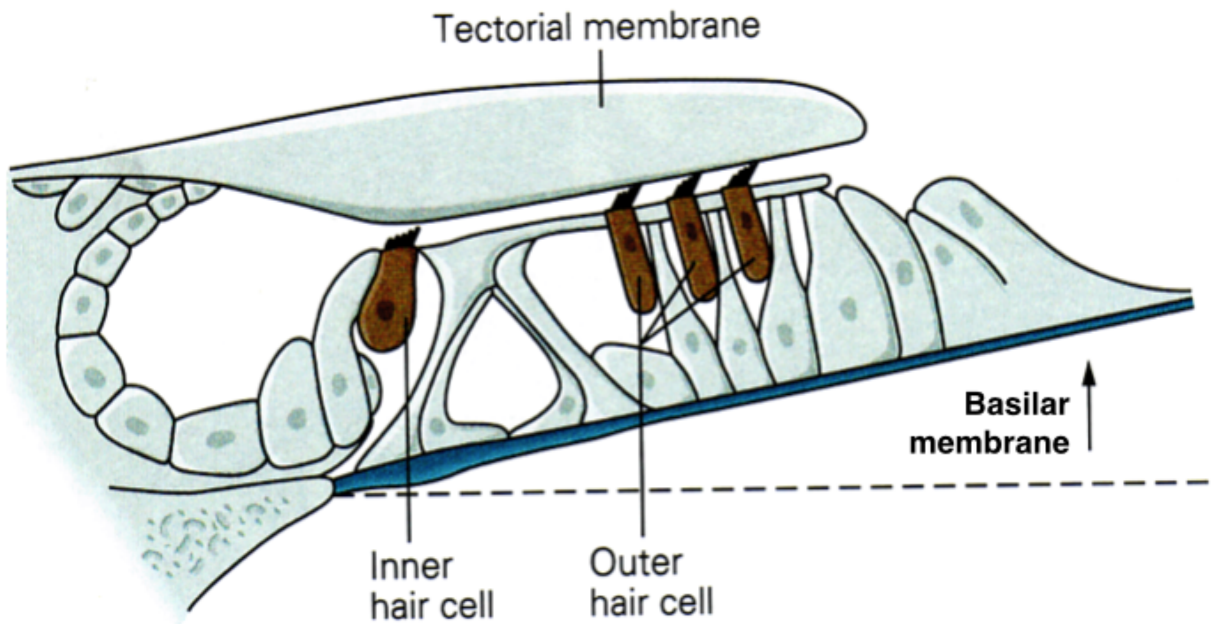
see Fox Figure 10.22

Basilar membrane vibration bends hair cells



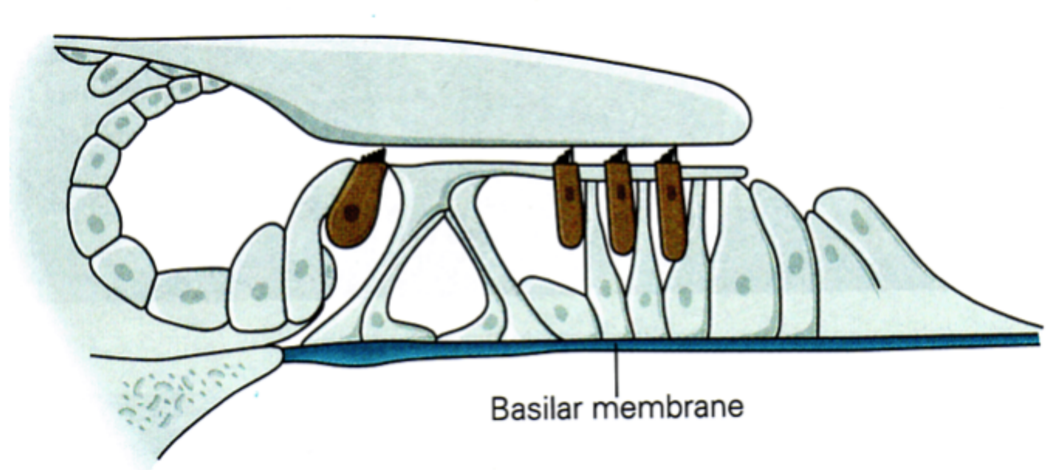
see Fox Figure 10.22

Basilar membrane vibration bends hair cells



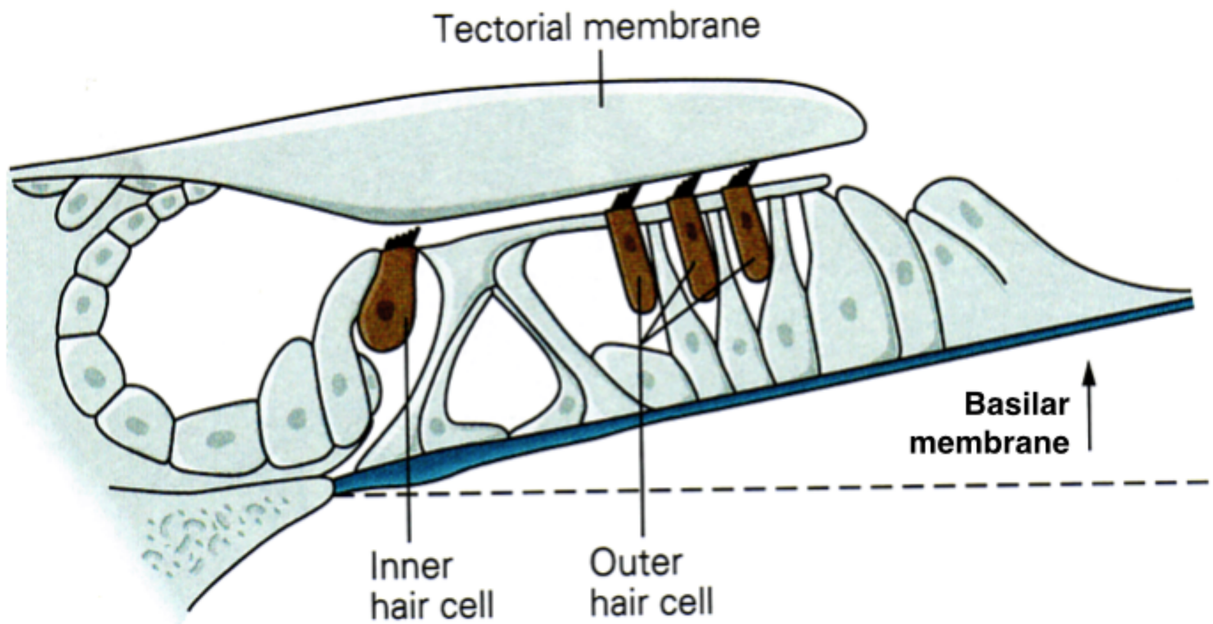
see Fox Figure 10.22

Basilar membrane vibration bends hair cells



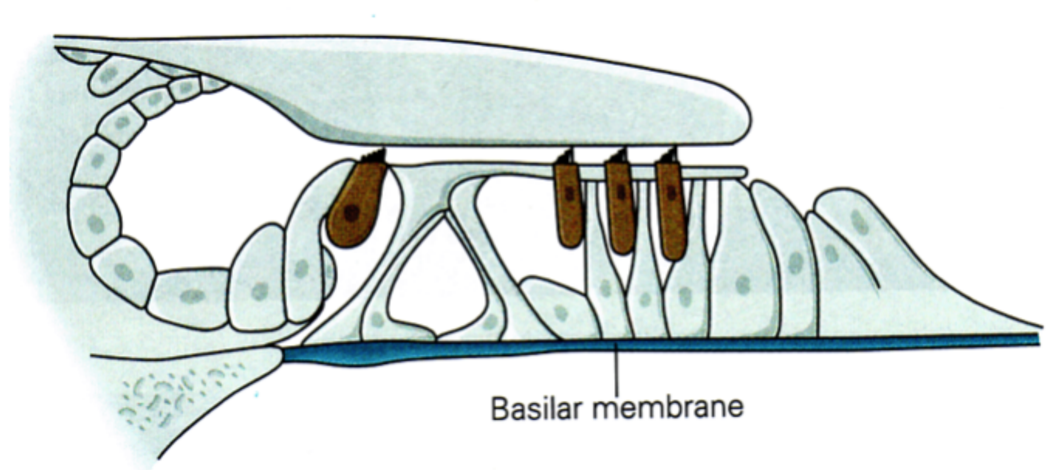
see Fox Figure 10.22

Basilar membrane vibration bends hair cells



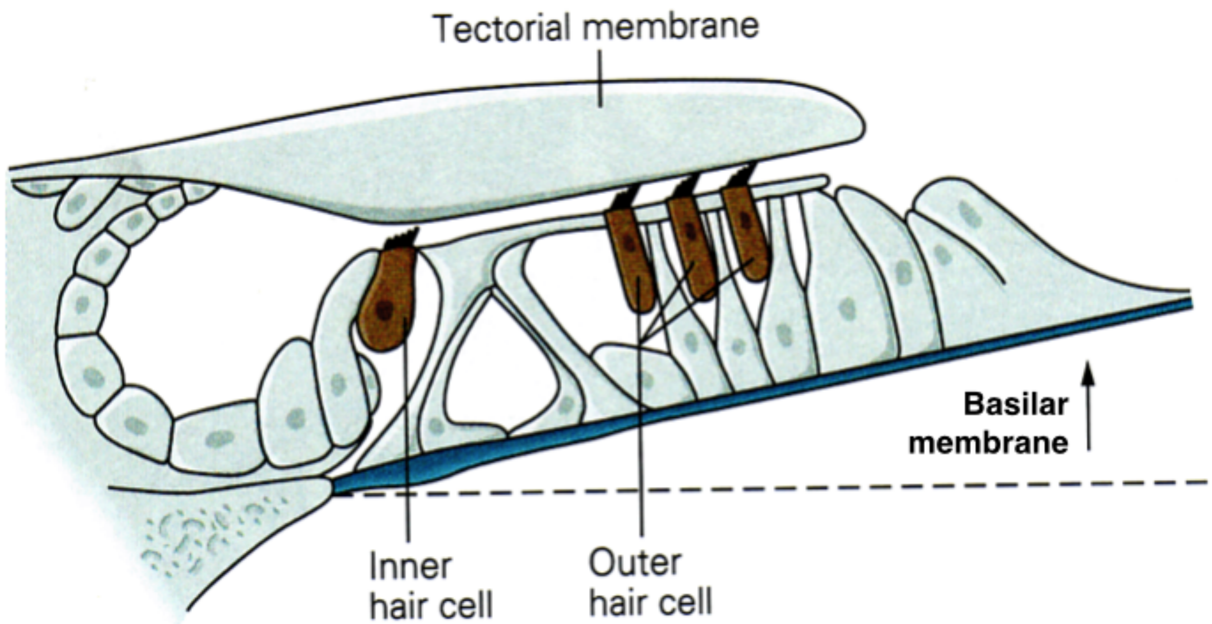
see Fox Figure 10.22

Basilar membrane vibration bends hair cells



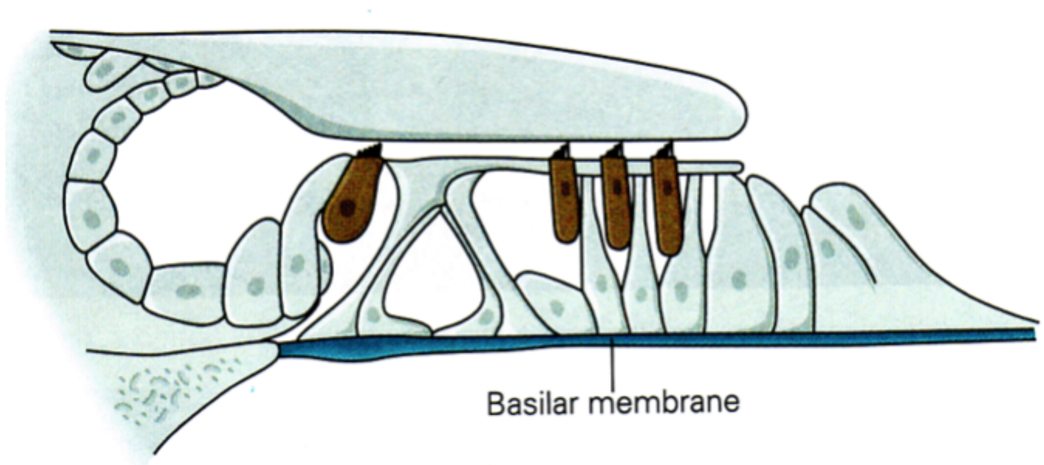
see Fox Figure 10.22

Basilar membrane vibration bends hair cells



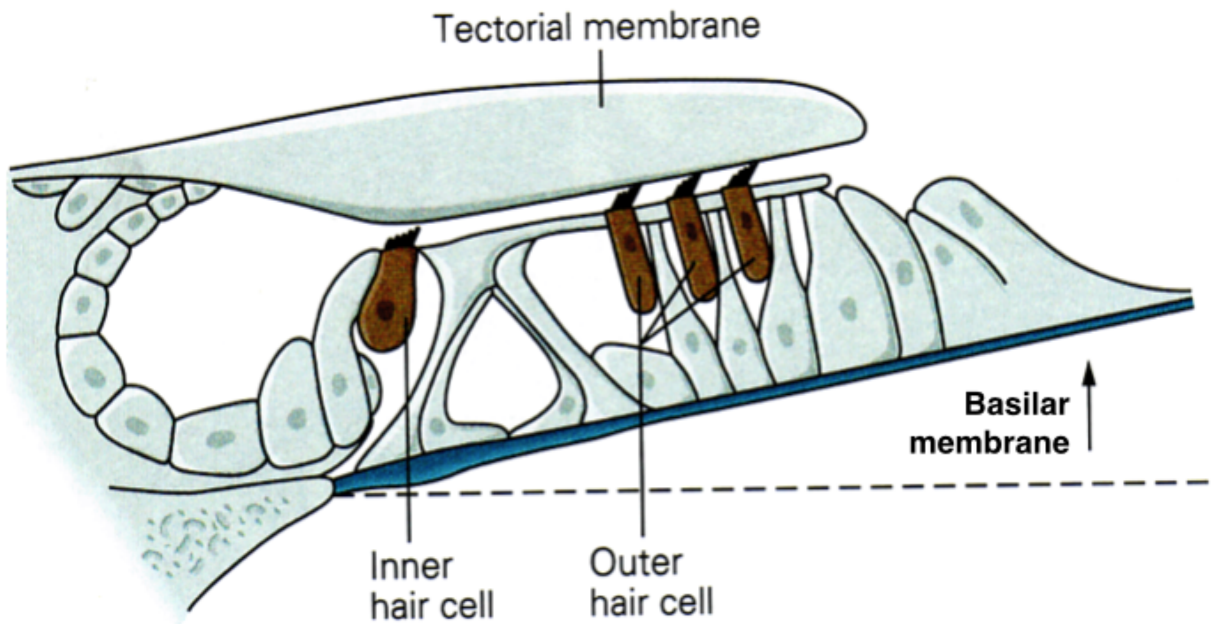
see Fox Figure 10.22

Basilar membrane vibration bends hair cells



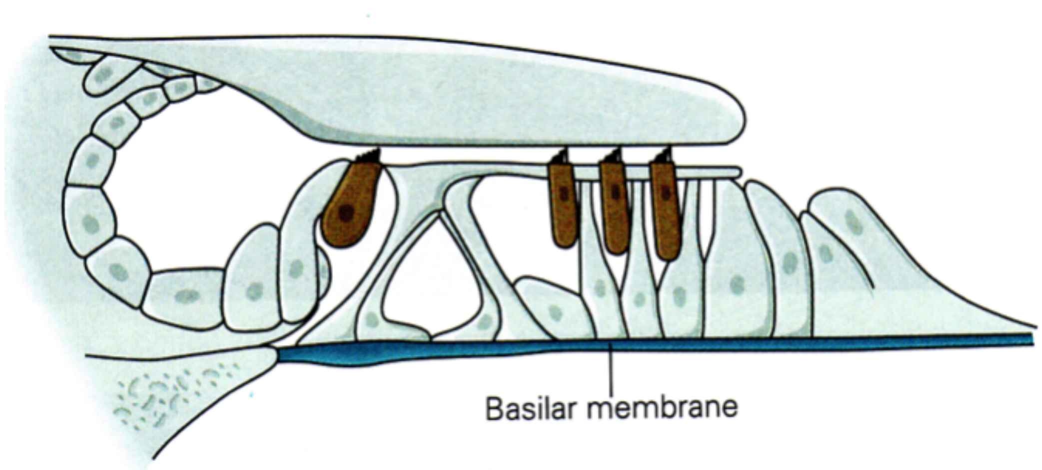
see Fox Figure 10.22

Basilar membrane vibration bends hair cells



see Fox Figure 10.22

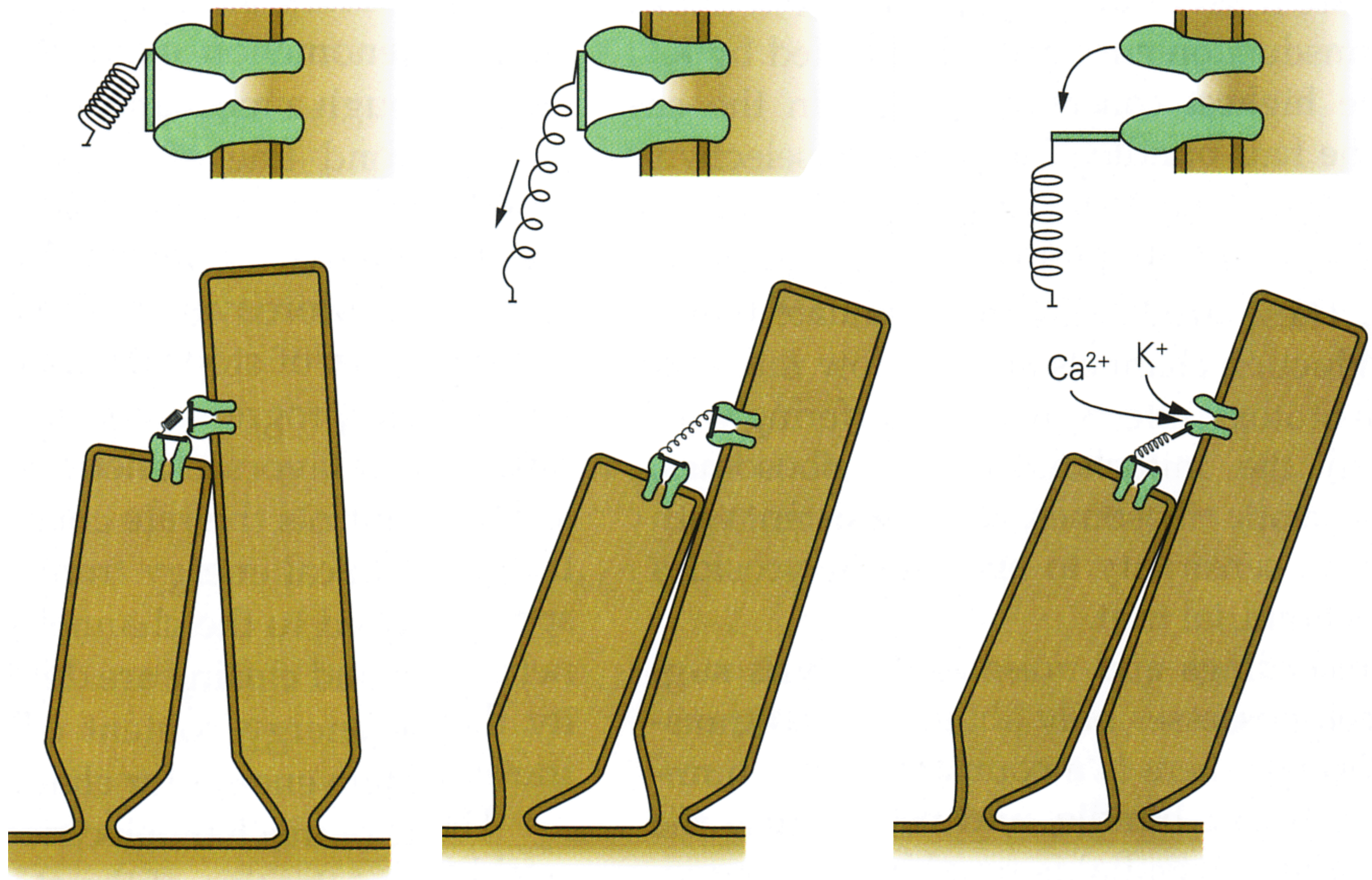
Basilar membrane vibration bends hair cells



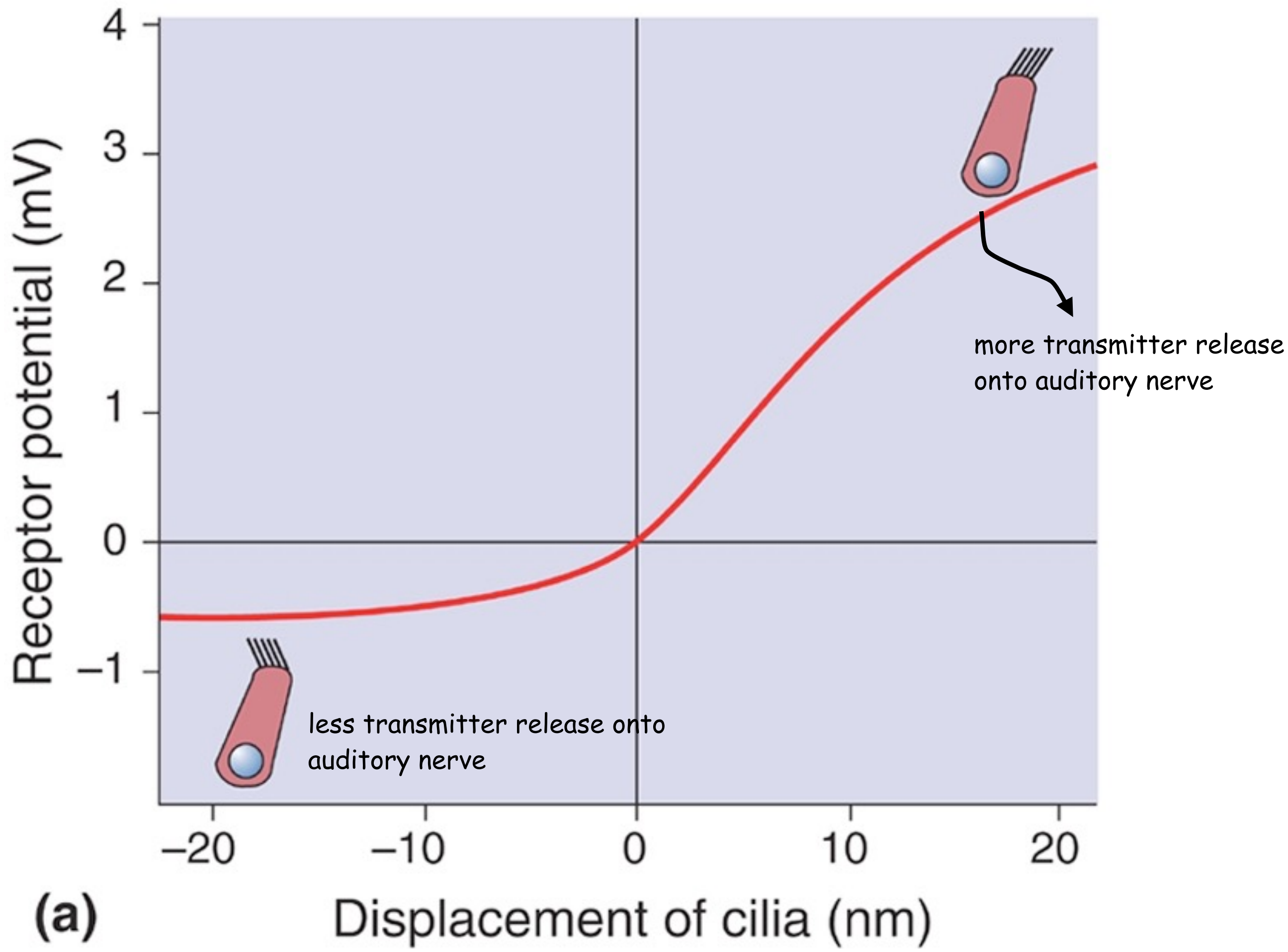
LAST FRAME

see Fox Figure 10.22

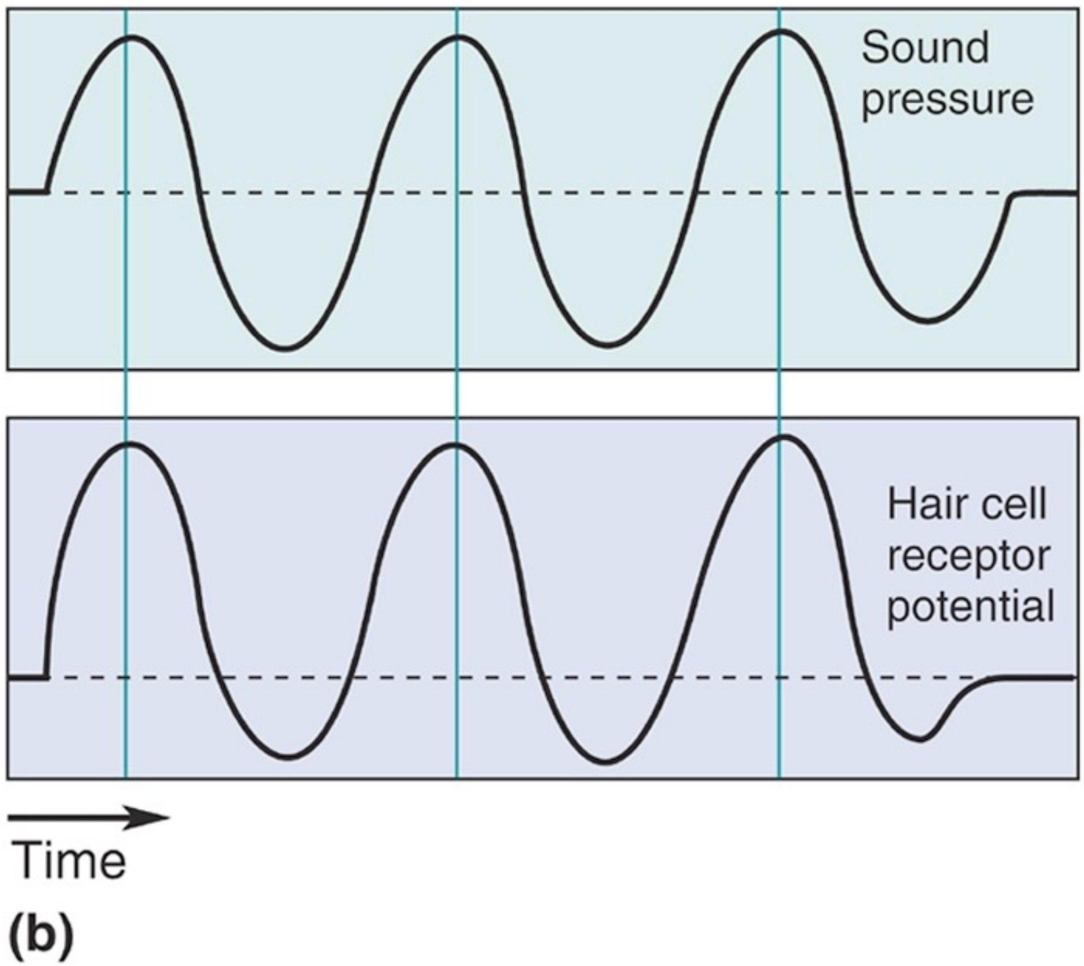
Deflection of stereocilia opens K+ channels



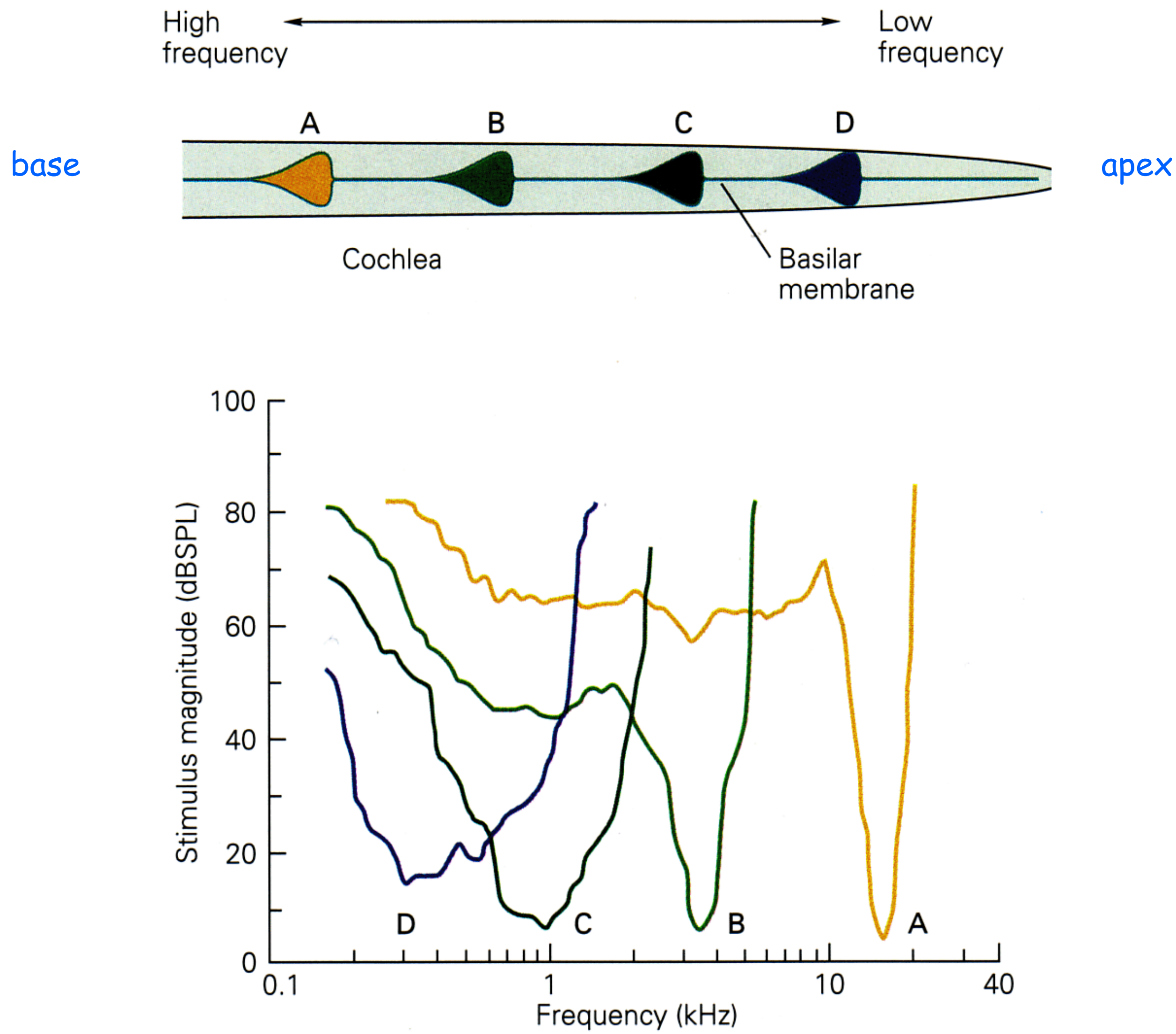
Bending of stereocilia causes change in membrane potential



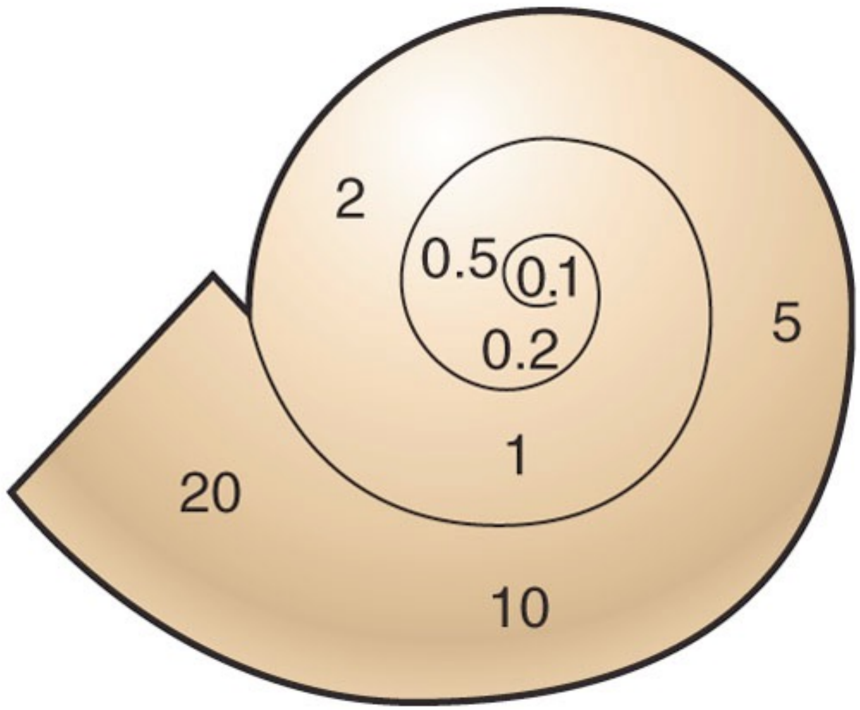
Bending of stereocilia causes change in membrane potential



Hair cells are tuned by position in cochlea

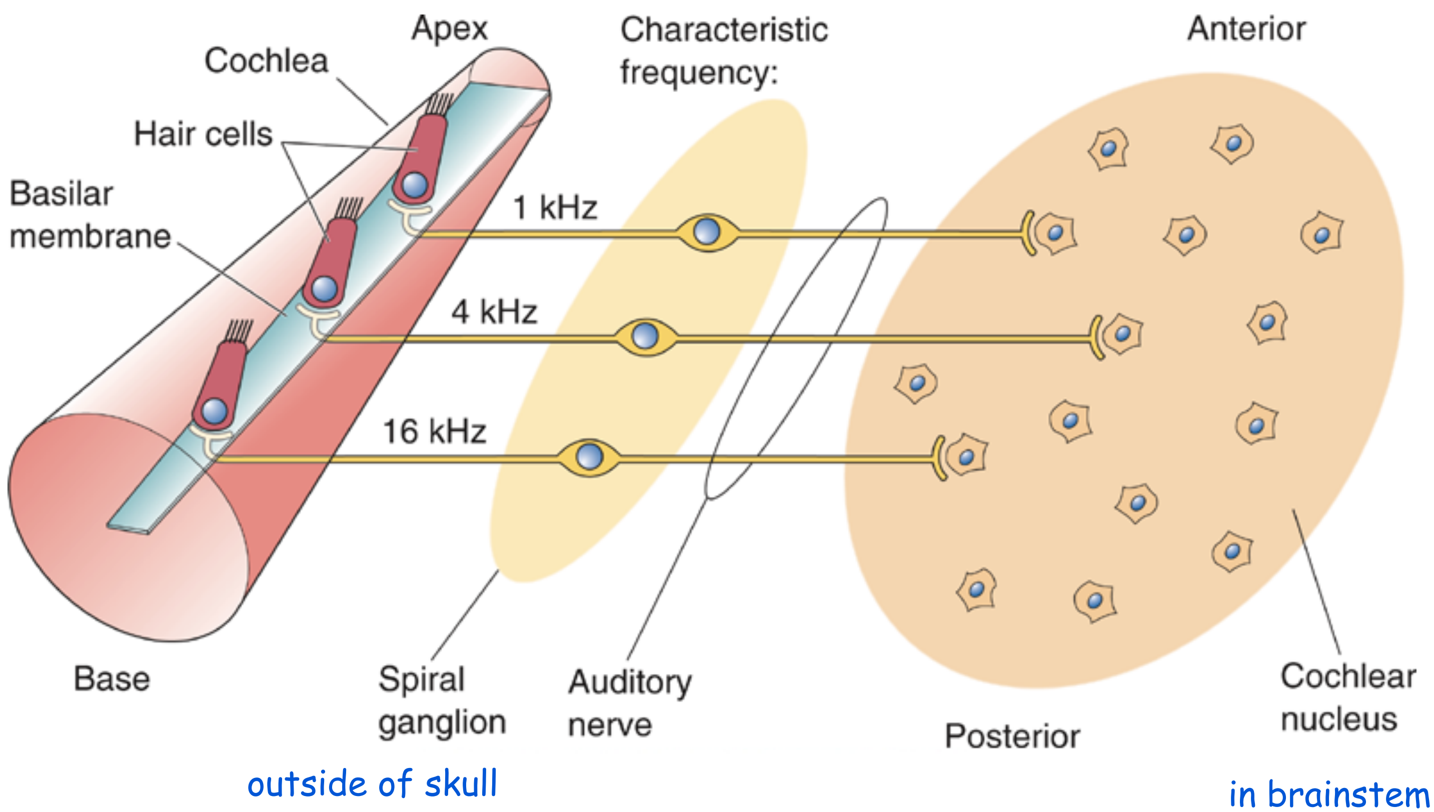


Frequencies Map on to Extent of Cochlea:
High frequencies at base, low frequencies at apex.

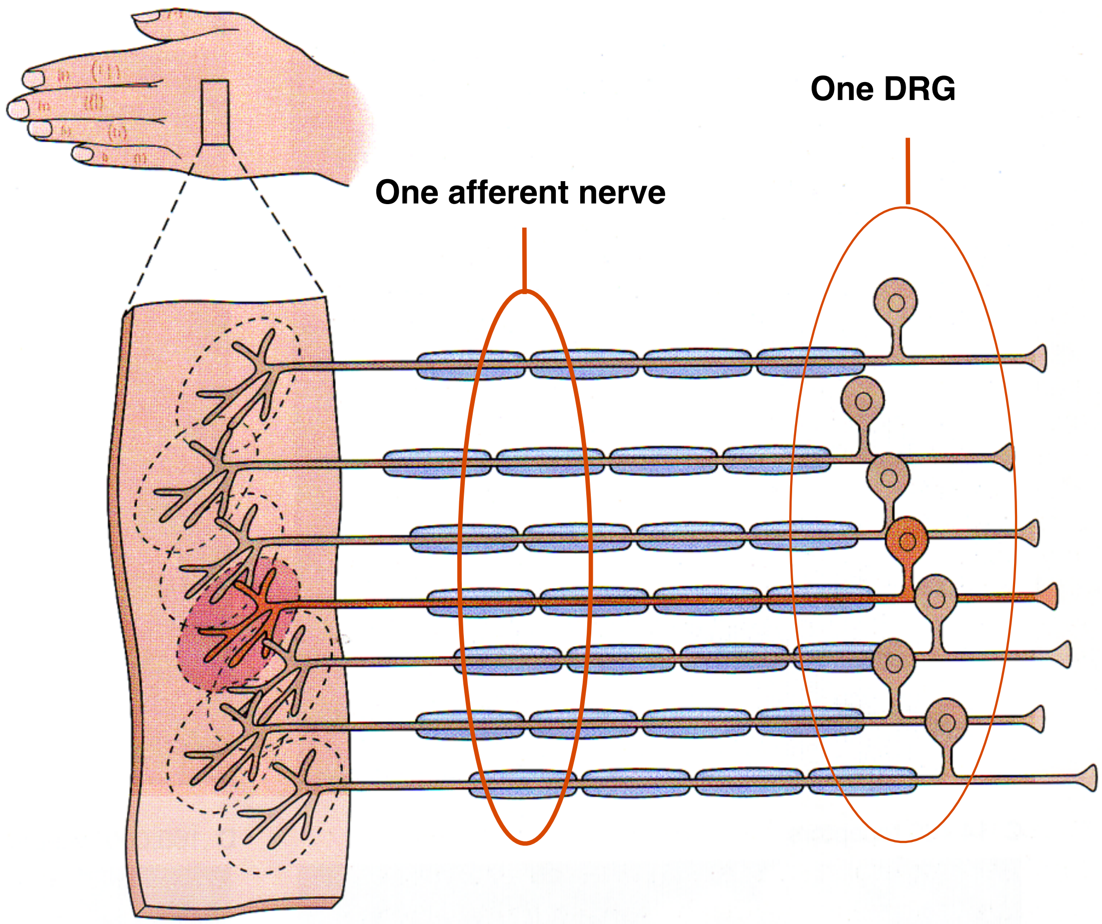


Fox Figure 10.23

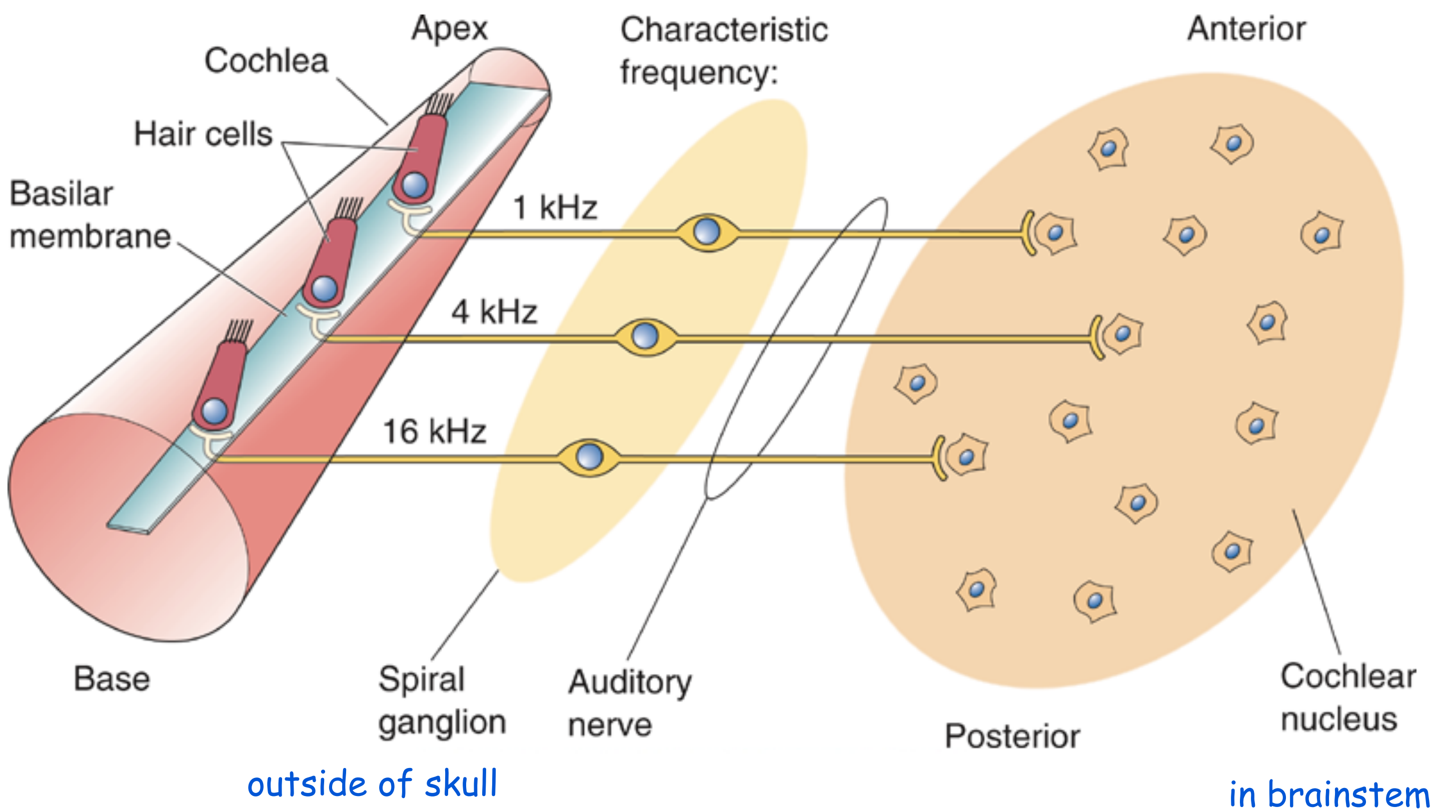
- Stimulus Frequency
  - Tonotopic maps on the basilar membrane
  - 20 - 20,000 Hz range, 0.3% discrimination



Somatosensory receptive fields of spinal sensory nerves

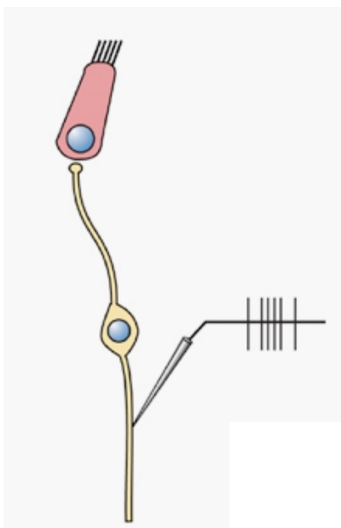


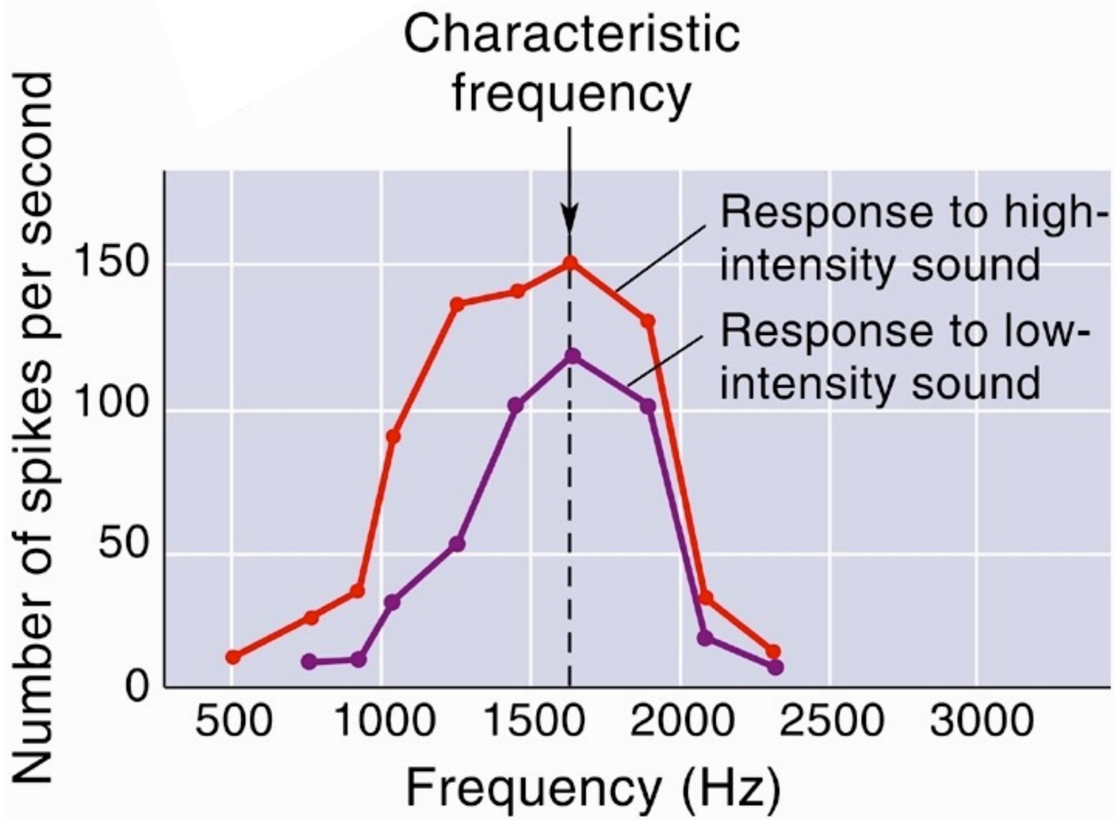
- Stimulus Frequency
  - Tonotopic maps on the basilar membrane
  - 20 - 20,000 Hz range, 0.3% discrimination



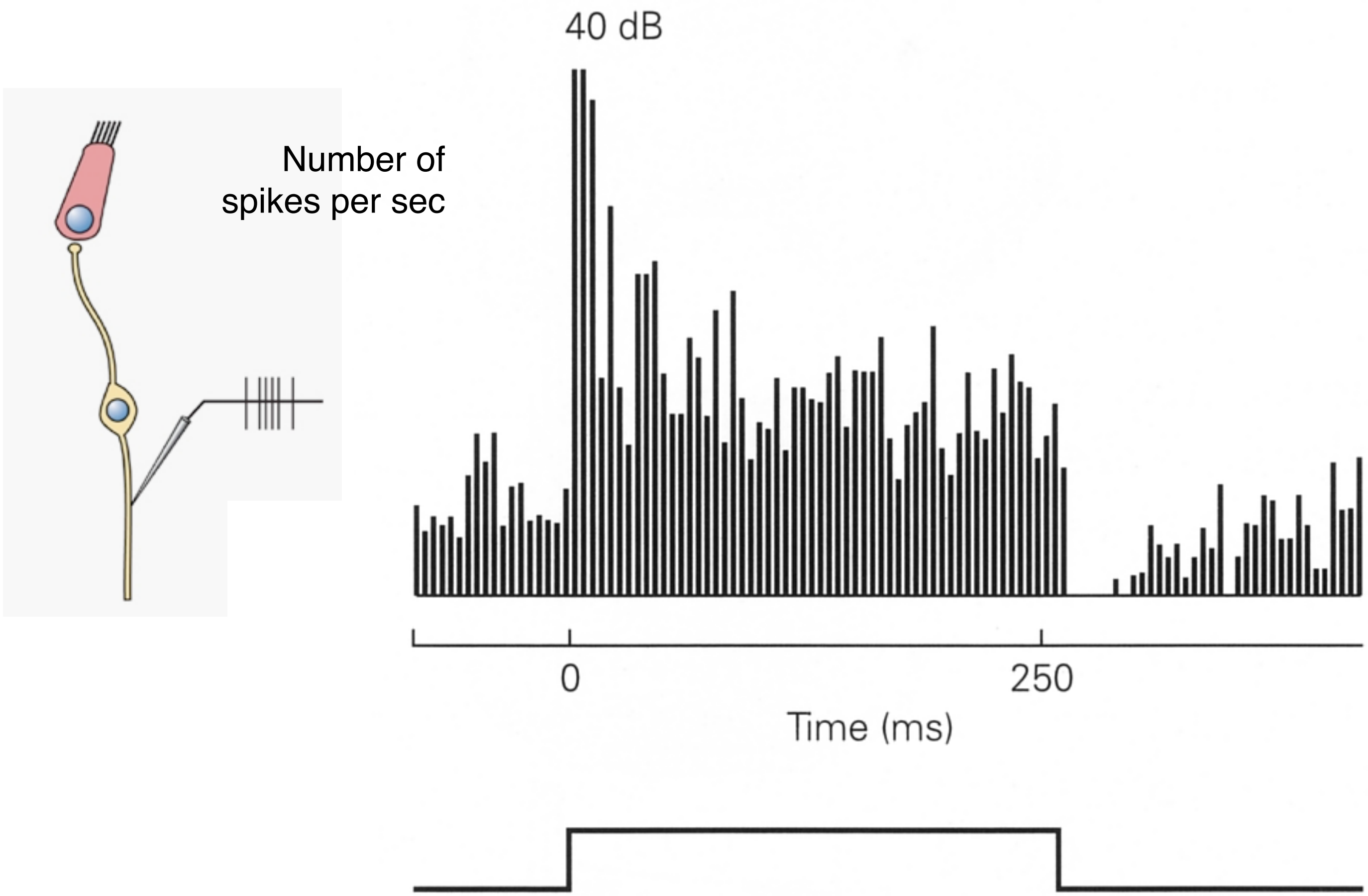
Each Auditory Neuron responds best to characteristic frequency

(position of hair cells in cochlea = receptive field of neuron)





Auditory Nerve encodes intensity of sound
(increased rate of action potentials = louder sound)



Damage to Inner Ear Hair Cells

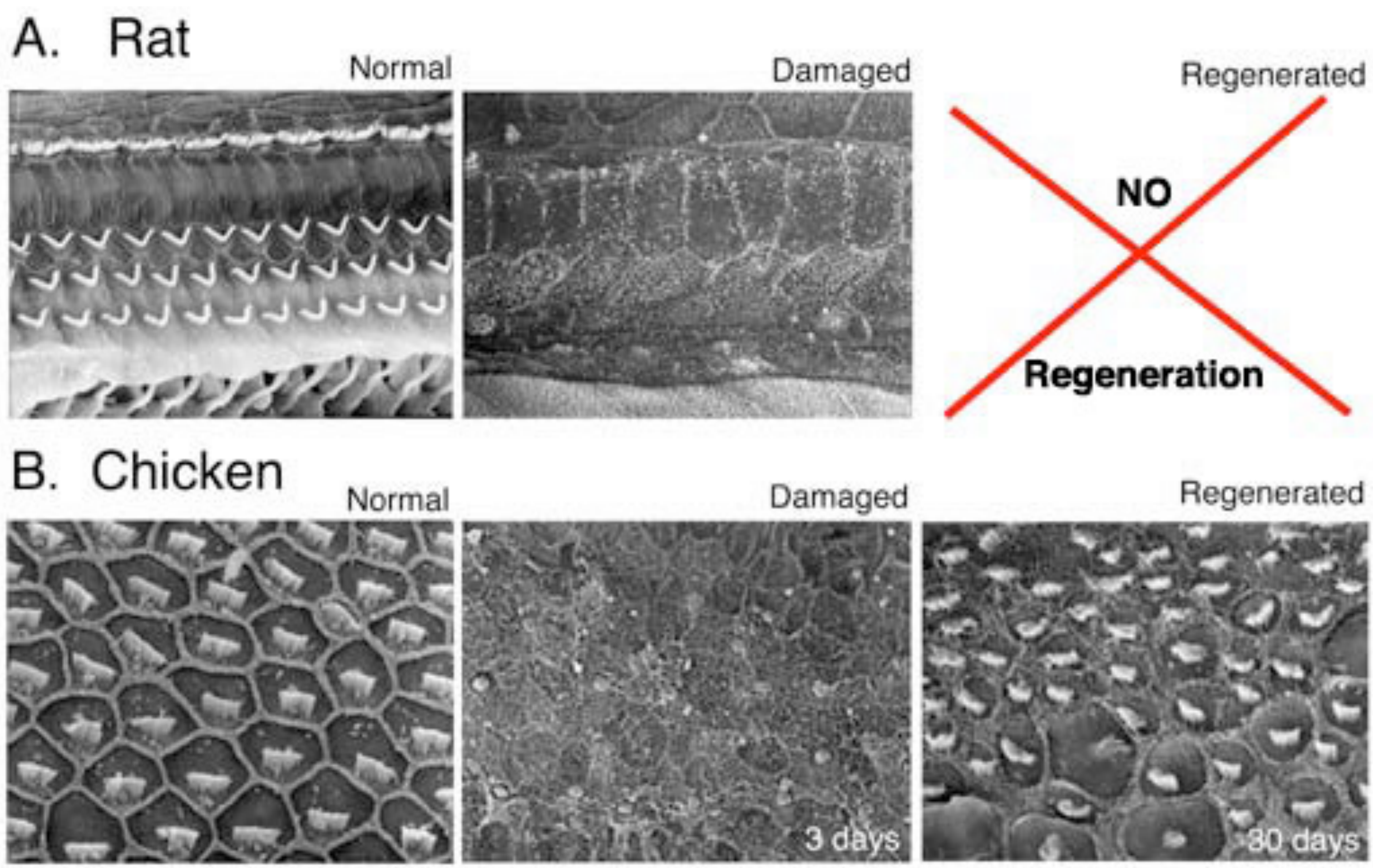
In mammals, hair cells die with old age (e.g. hi frequency hair cells) or after damage due to high intensity noise.

Hair cells do not regenerate (although they can regenerate in lower animals).

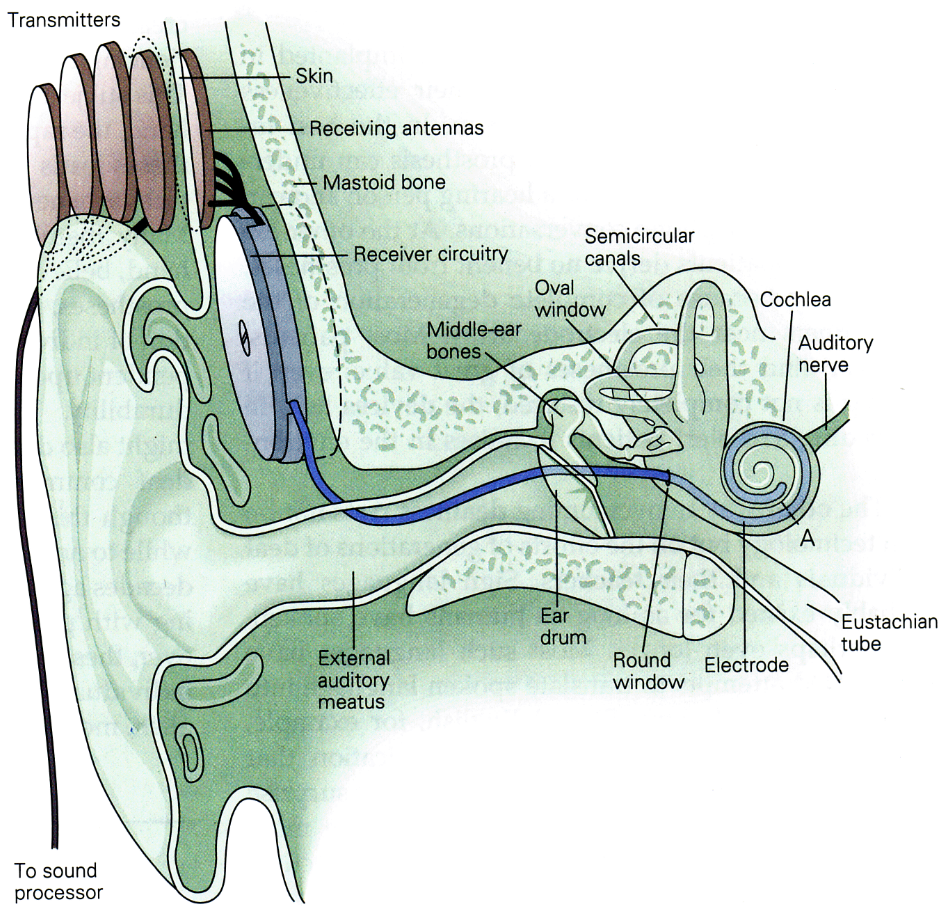
Cochlear Implants reproduce function of basilar membrane and hair cells: stimulate auditory nerve endings at appropriate point in cochlea to reproduce tonotopic mapping of missing hair cells.

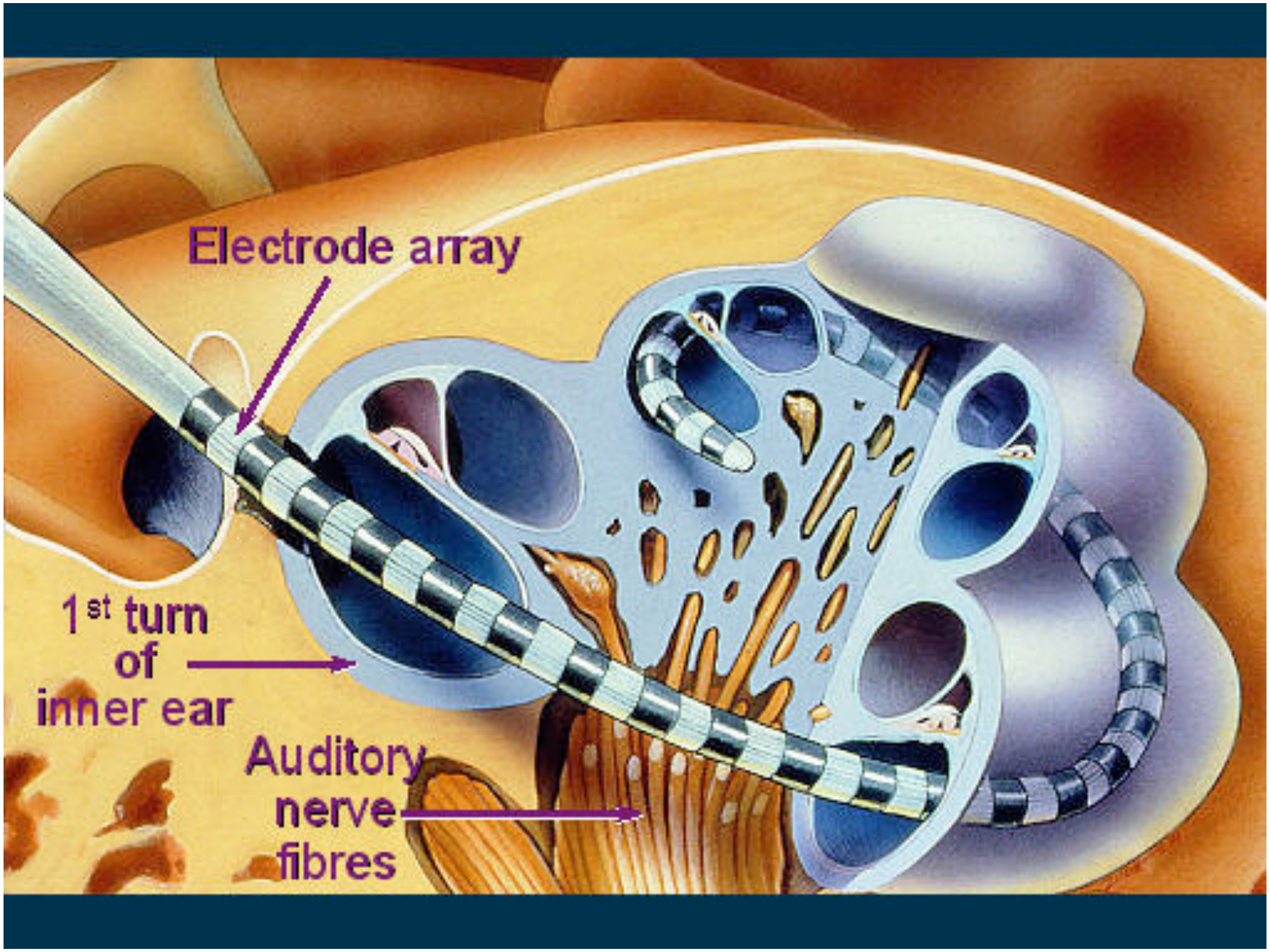
Example: sound of voice, music if only a small number of frequencies are restored.

T


A. Rat
Normal
Damaged
Regenerated
NO
Regeneration
B. Chicken
Normal
Damaged
Regenerated
3 days
30 days

Map frequencies to electrode location in cochlea

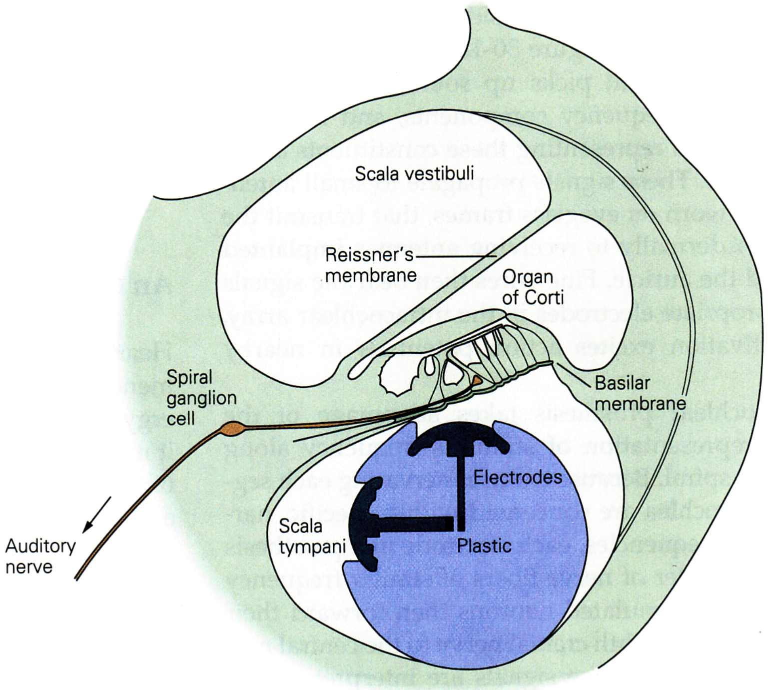


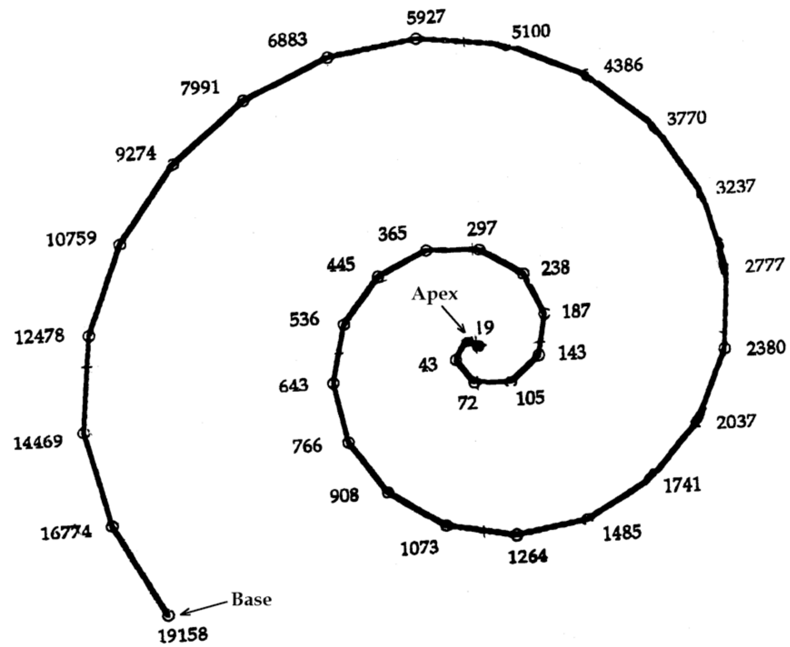


http://graemeclarkfoundation.org/bionic_ear/CI%20Function.htm

https://www.youtube.com/watch?v=bDx12M5u4uY

Cochlear implant to cure deafness by directly stimulating auditory nerves





cochlear implant -> 32 different frequencies
(normal inner ear -> 300+ different frequencies

http://graemeclarkfoundation.org/bionic_ear/CI%20Function.htm

On Next slide:

Speech: 1,2,4,8,16, 32 channels, then original

Speech: 1,2,4,8,16, 32 channels, then original

http://www.hei.org/research/aip/audiodemos.htm

On Next slide:

Music: 4, 8, 16, 32 channels, then original

(turn down volume)

Music: 4, 8, 16, 32 channels, then original

http://www.hei.org/research/aip/audiodemos.htm

Central Representation of Audition

Auditory input projects to mostly contralateral auditory cortex and some ipsilateral auditory cortex.

Tonotopy is preserved in auditory cortex: cortical neurons respond to characteristic frequencies, with mapping from low to high frequency across the auditory cortex.

Auditory cortex neurons send projections to higher levels of cortex that extract features from sound:

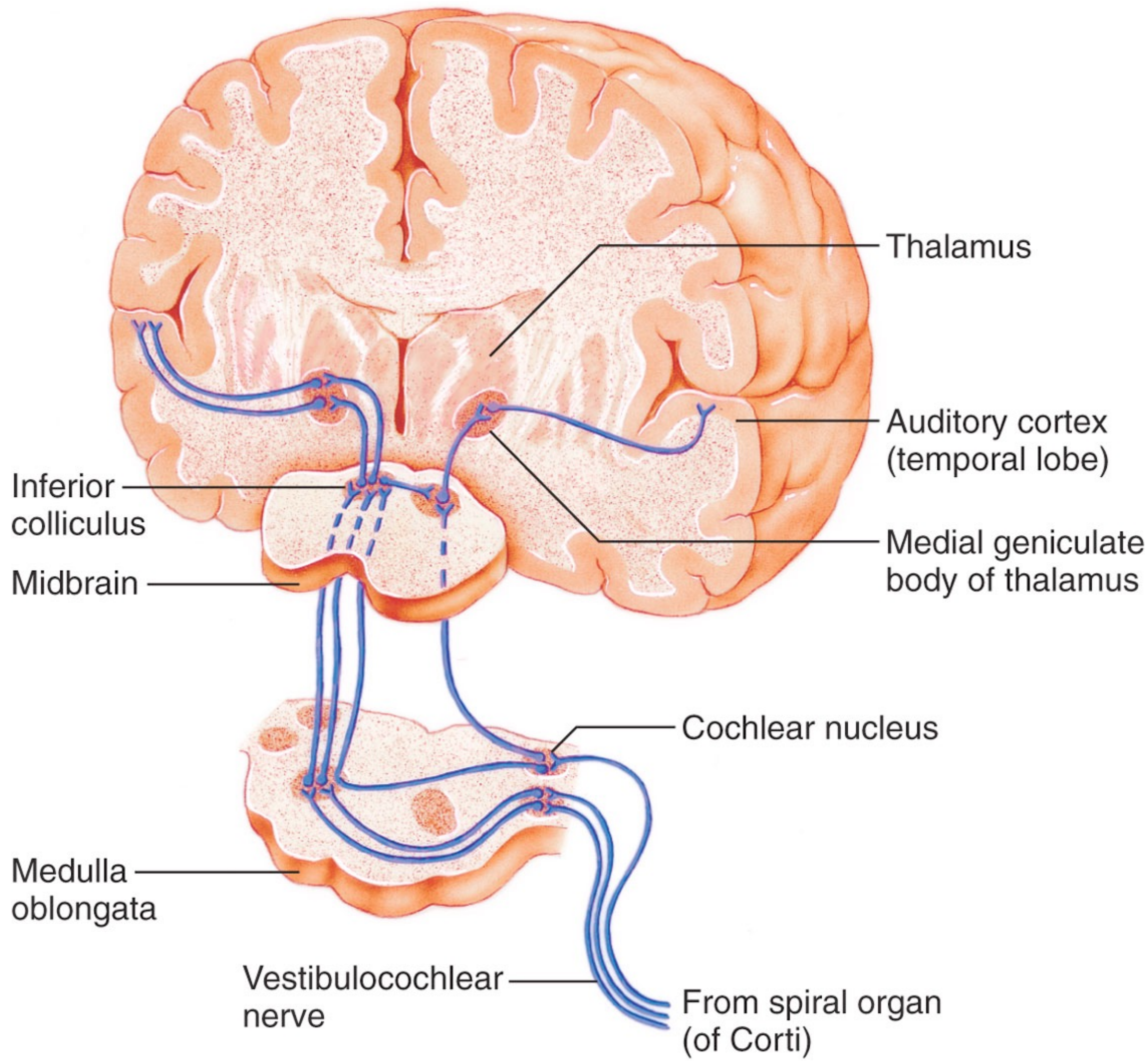
Wernicke's Area -- extracts meaning from words, integrate with vision

Broca's Area -- generates speech via projections to motor cortex (to move the tongue lips, & throat).

McGurk Effect: example of sound integration with visual information to change perception of syllable.

T

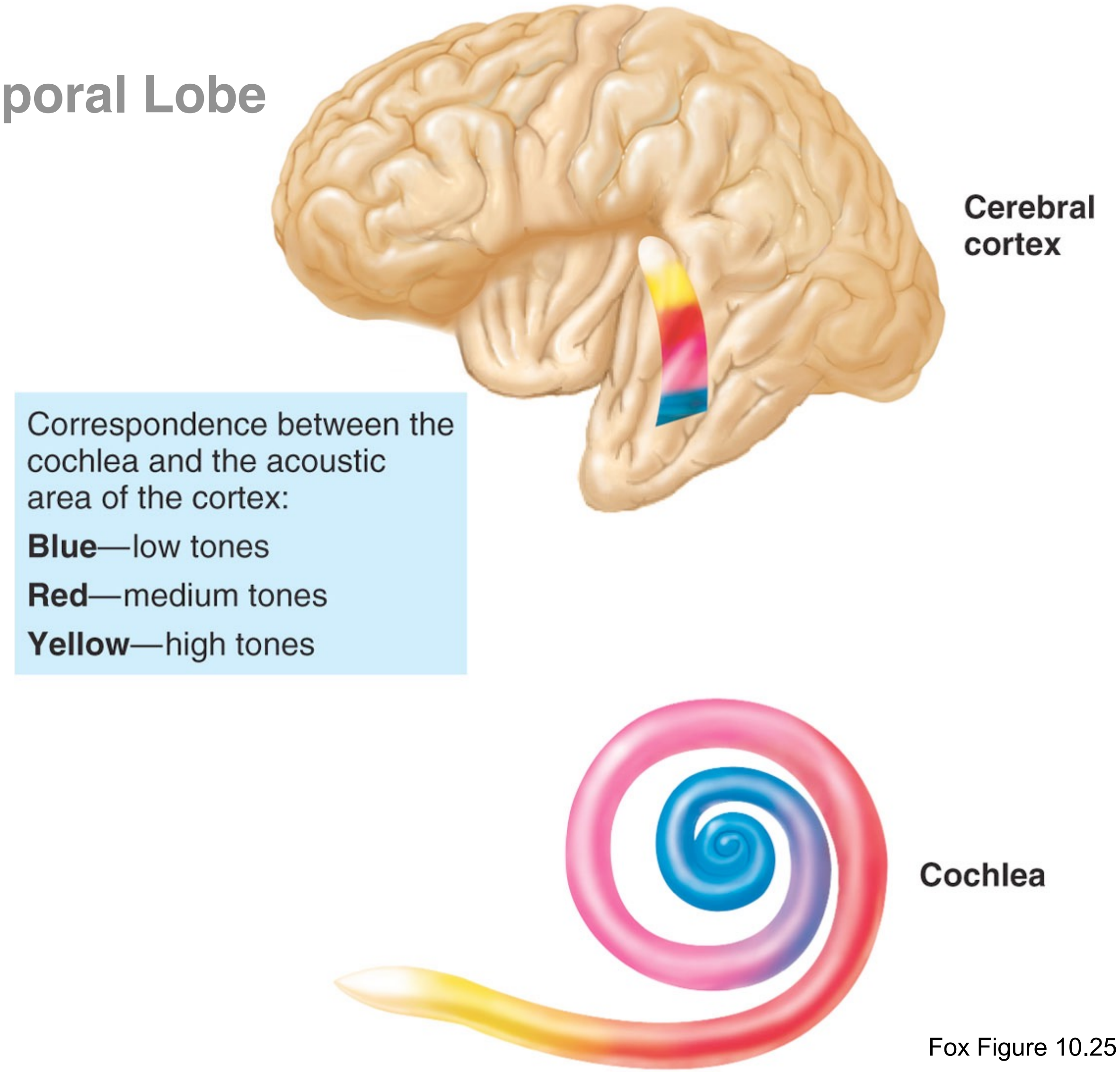
Figure 10.24



Thalamus
Auditory cortex (temporal lobe)
Inferior colliculus
Medial geniculate body of thalamus
Midbrain
Cochlear nucleus
Medulla oblongata
Vestibulocochlear nerve
From spiral organ (of Corti)

Auditory Cortex

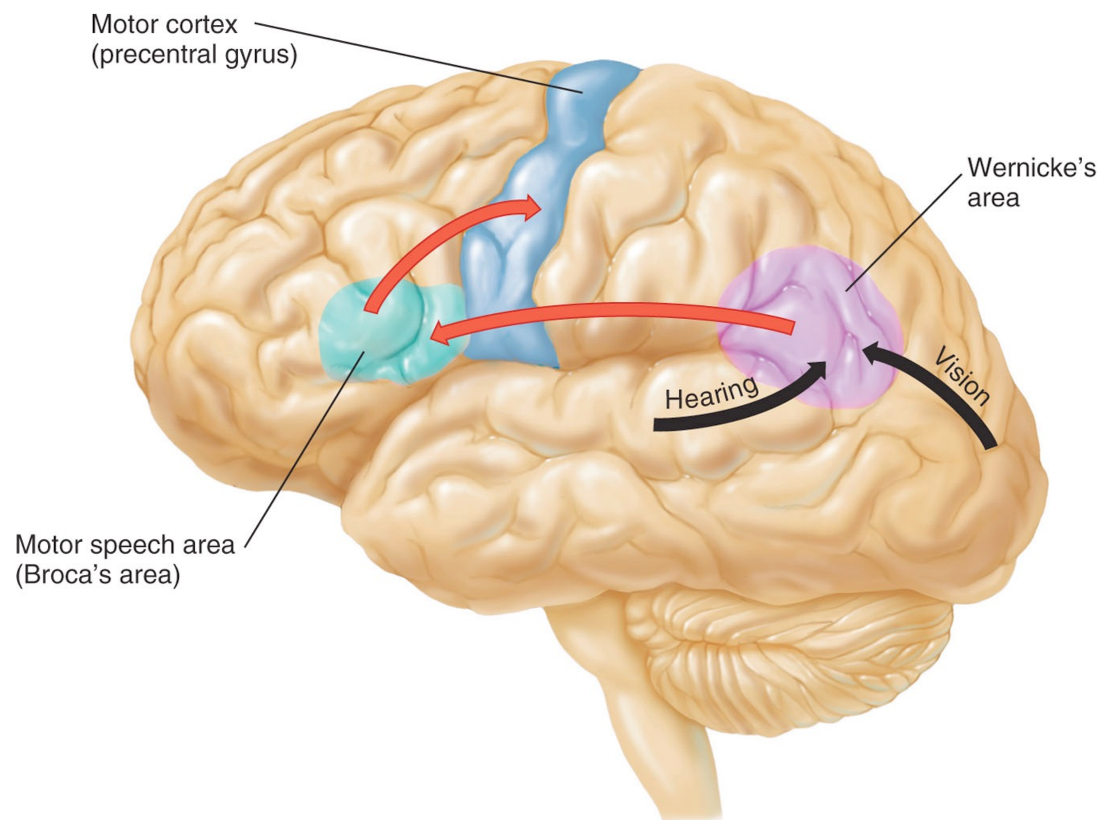
Inner surface of Temporal Lobe



Fox Figure 10.25

Feature Extraction and Integration of Auditory Input

Integration with vision, word extraction, speech generation



Fox Figure 8.14

Next 2 Slides: McGurk Effect

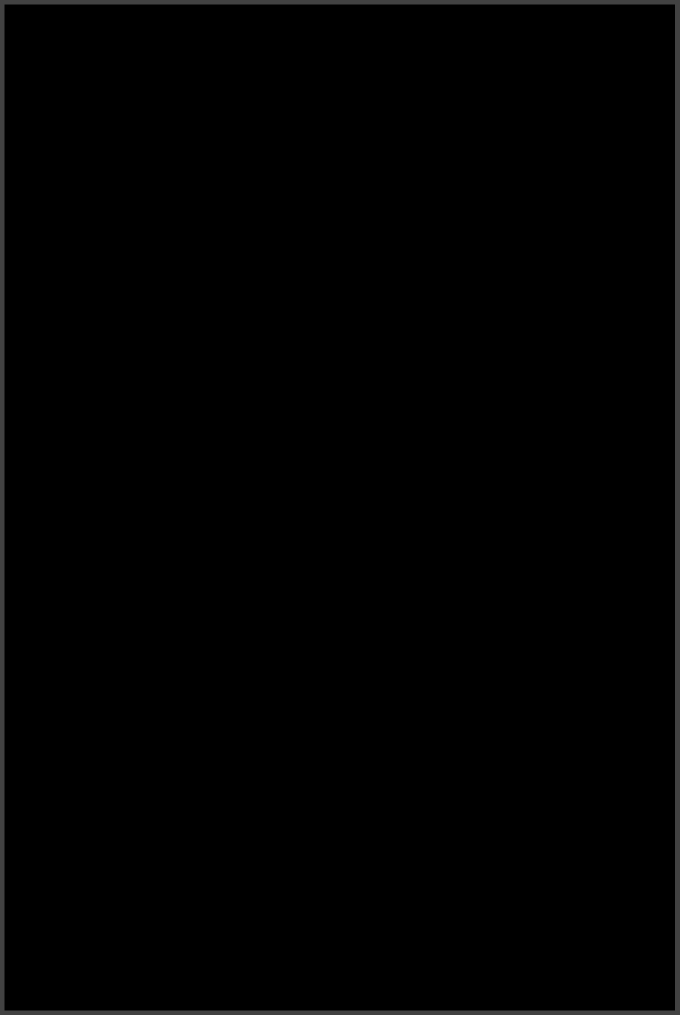
1. sound with mouth concealed
2. same sound, with mouth visible

McGurk Effect

1. video demonstrating McGurk Effect
2. animation & sound with mouth concealed
3. animation & same sound, with mouth visible

Integration of Vision and Audition: McGurk Effect

Integration of Vision and Audition: McGurk Effect



end recording