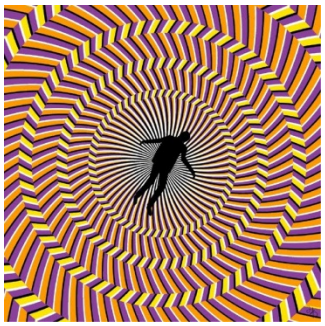
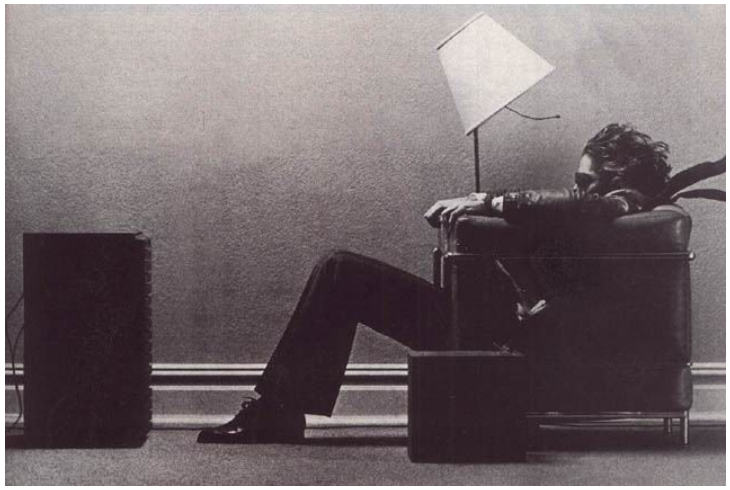
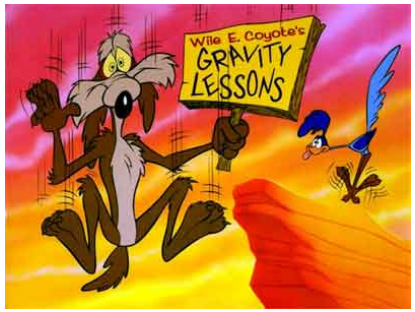


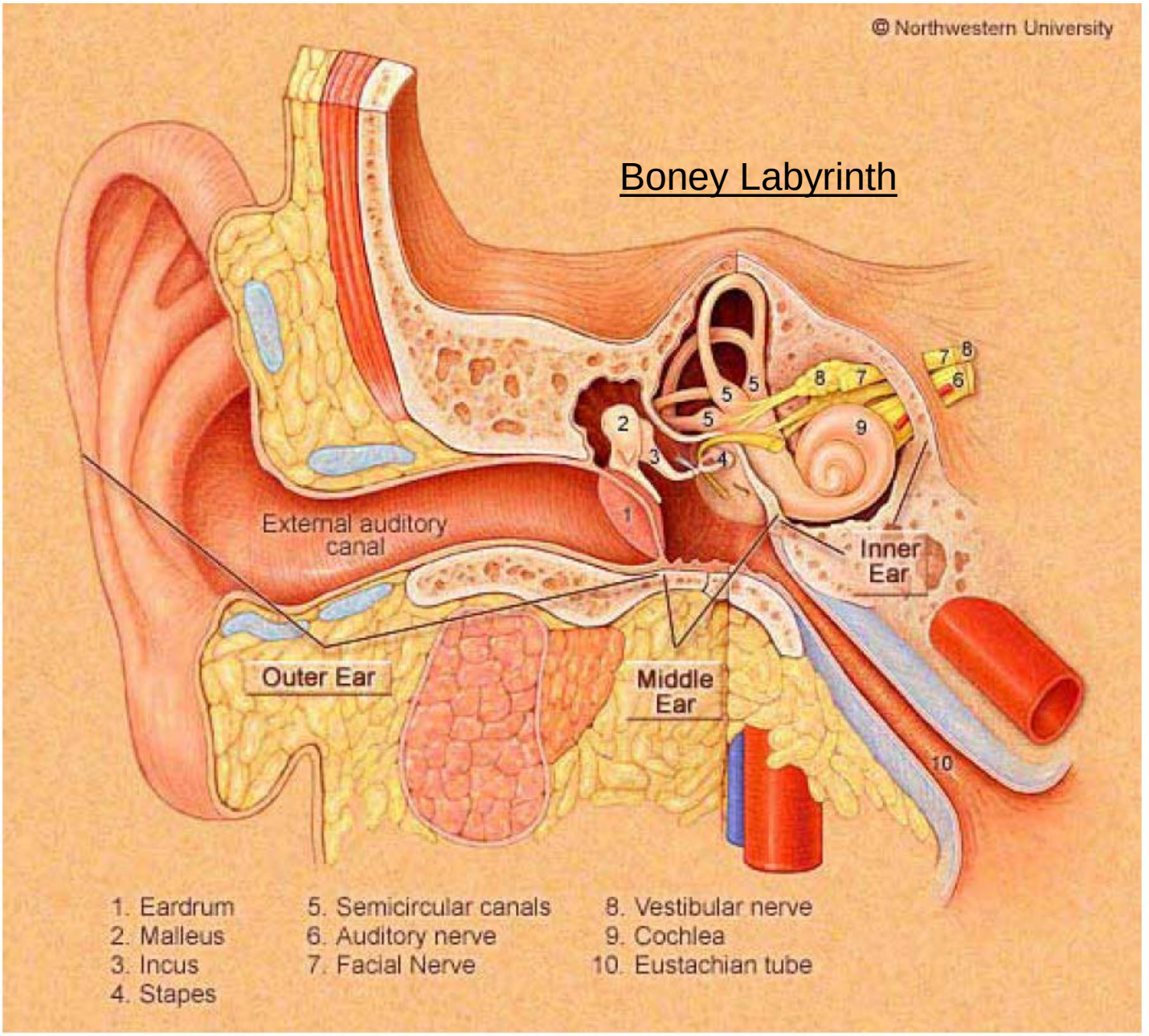
Vestibular/Auditory Systems





Dental Neuroanatomy

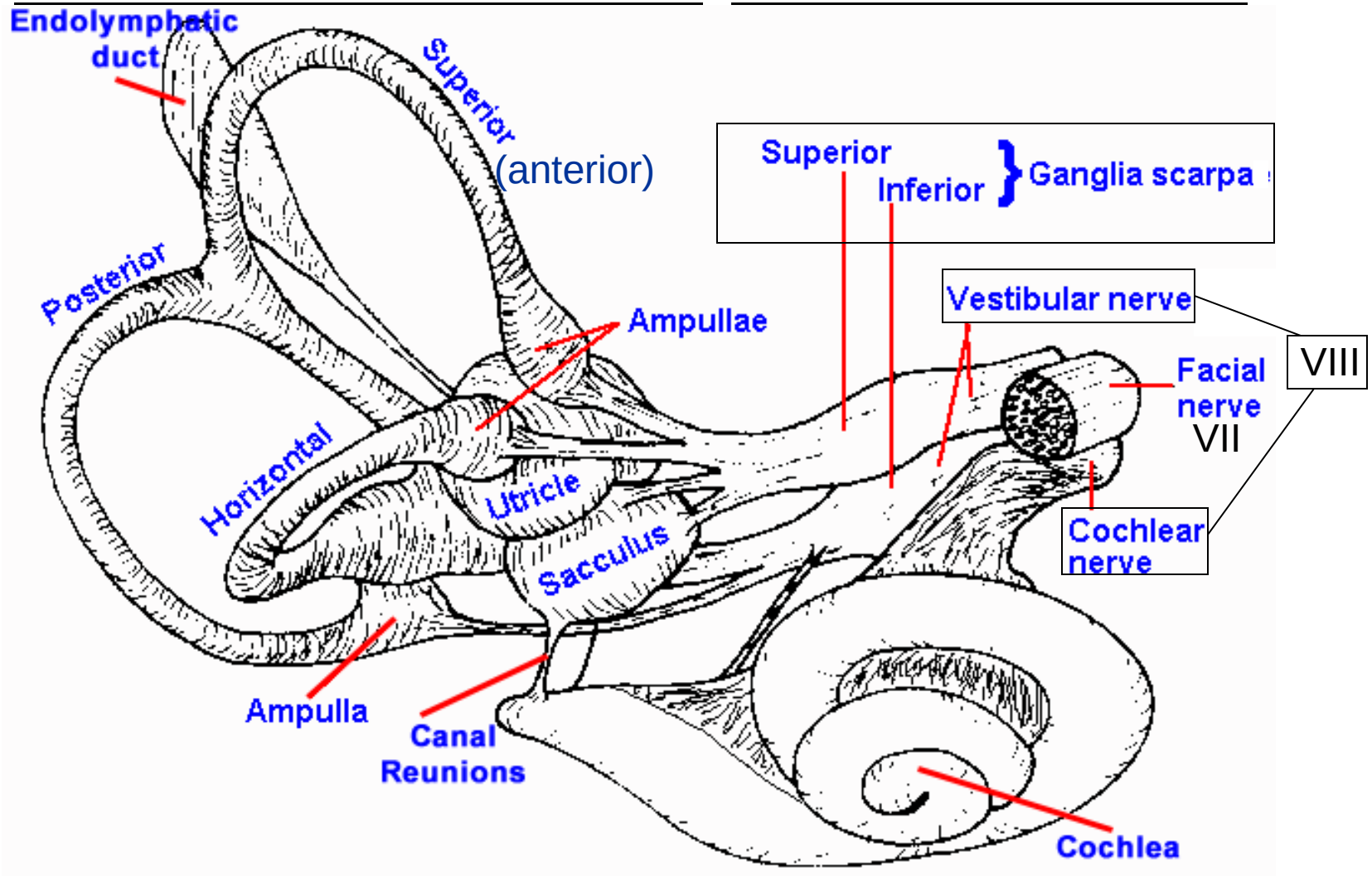
Scott Rogers
Office: SOM 2C132



http://www.tchain.com/otoneurology/images/master-ear.jpg

Two Major Divisions

Vestibular Apparatus | **Cochlea**



Semicircular Canals (**Angular Motion**)

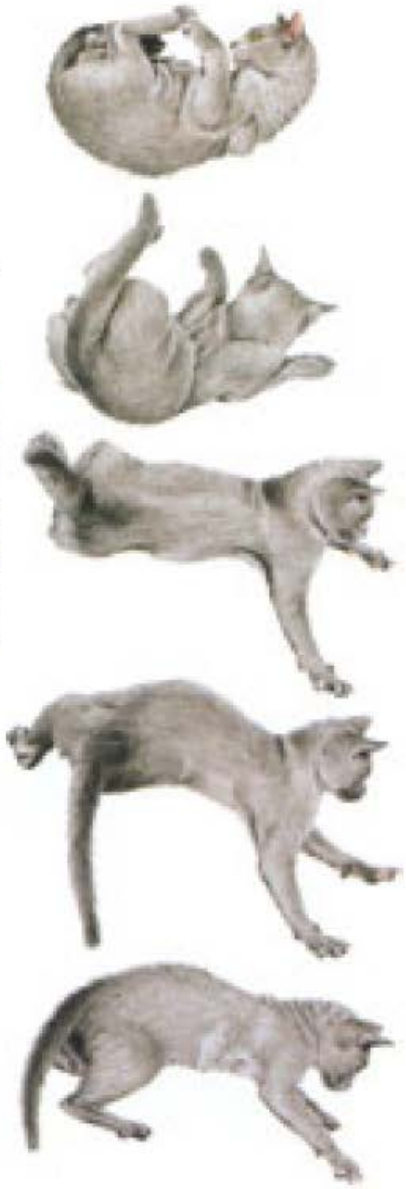
Vestibule (**Linear Motion**)

Vestibular

'Unlike other senses, vestibular signals become immediately multisensory and multimodal.'

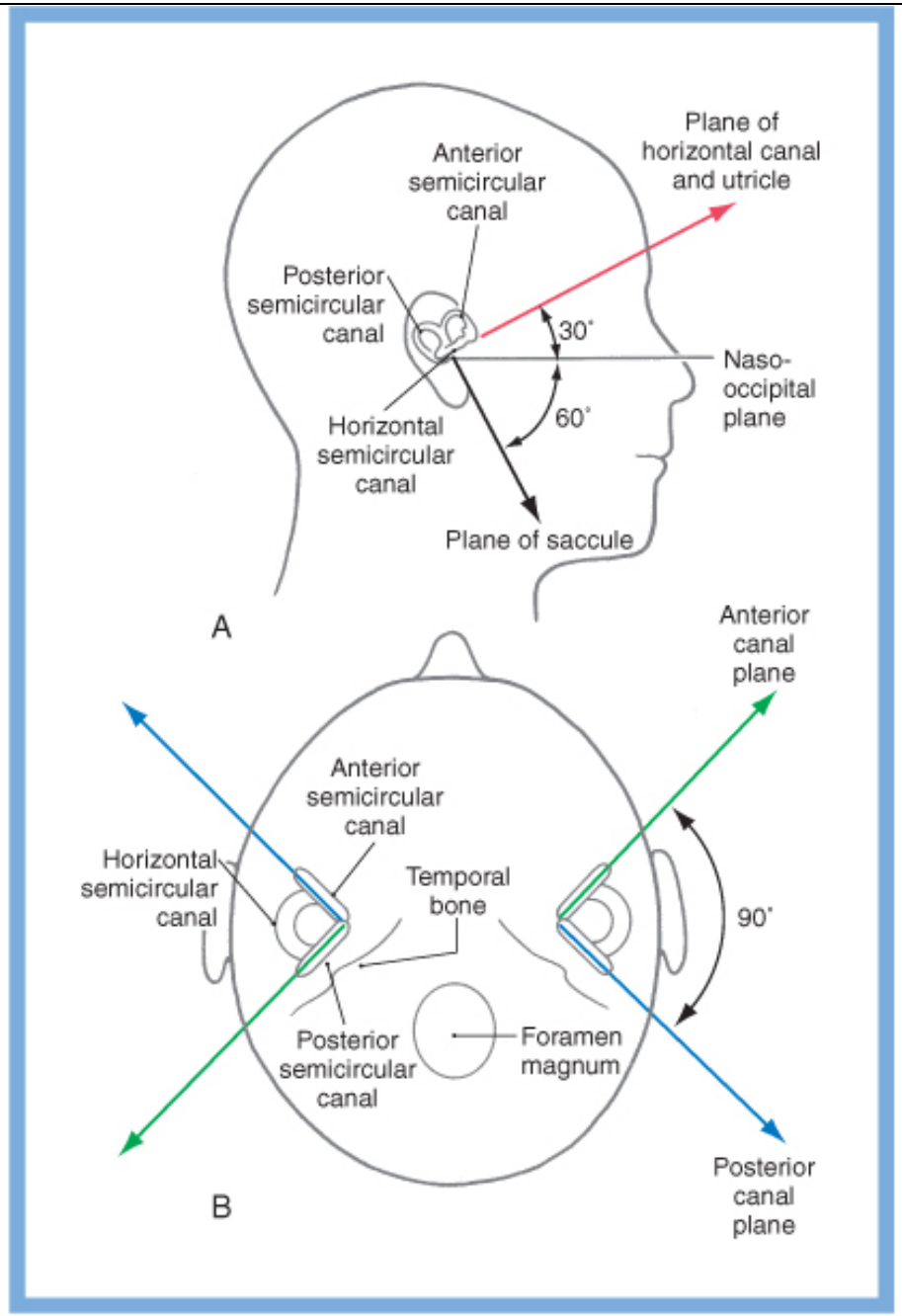
Sensorimotor (multisensory) transformation.

***Righting Response**



Mulitmodal convergence.

***VECTION**



Vestibular System

SIX MAJOR DIVISIONS

1. **Peripheral Receptor Apparatus -- Vestibular Apparatus**
   Structure within the inner complex for transducing motion --- mechanical

2. **Central Vestibular Nuclei**
   Sets of neurons in the brain stem/pons that receive/integrate/distribute information regarding movements and posture

3. **Vestibulo-Ocular Network**
   Coordinate eye movement

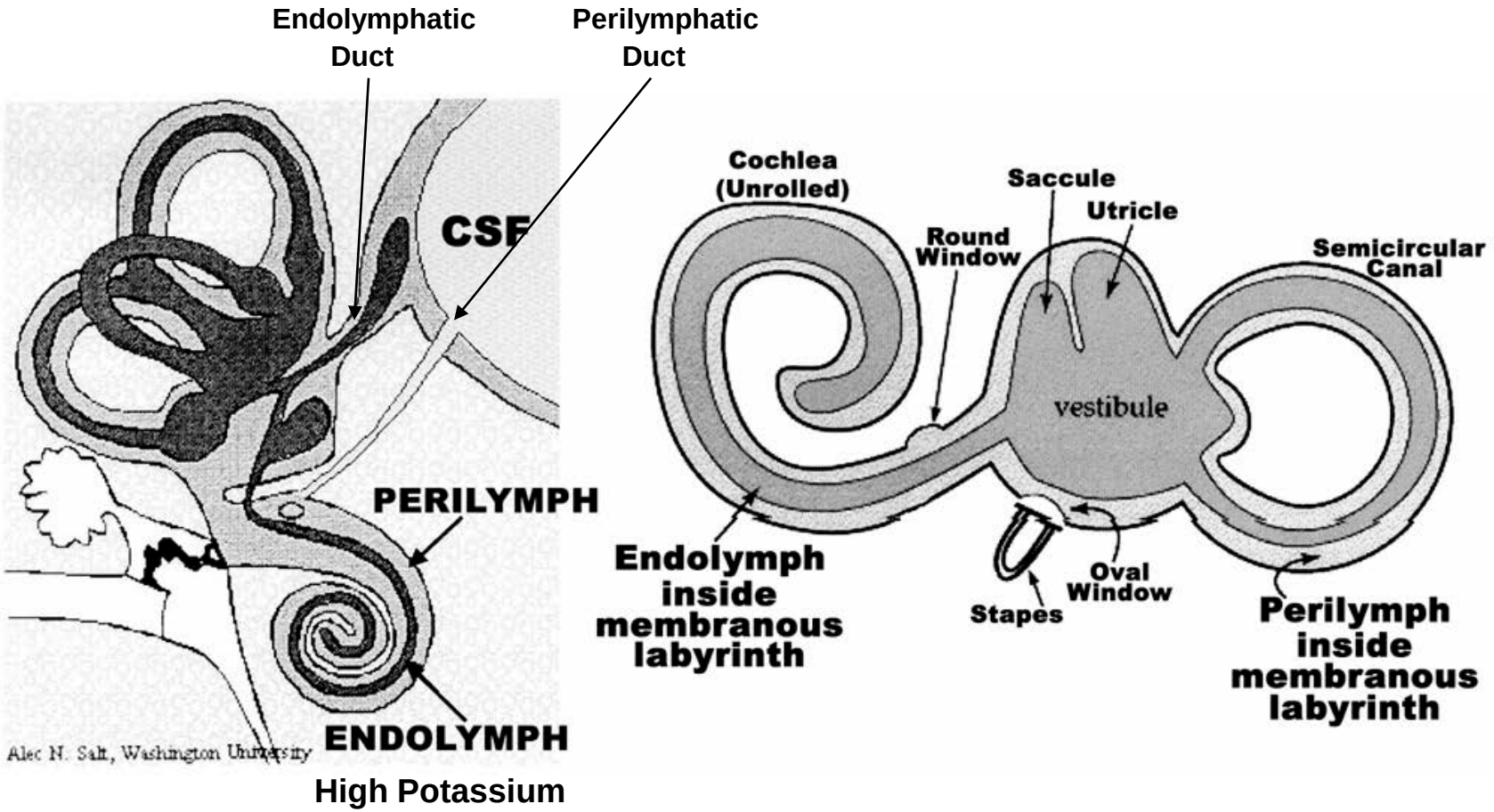
4. **Vestibulo-Spinal Network**
   Coordinate Head movement – Posture – axial muscular coordination

5. **Vestibulo-Cerebellum Network******
   Balance

6. **Vestibulo-Thalamic-Cortical Network**
   Conscious perception of motion – Spatial orientation

1. Peripheral Receptor Apparatus

Boney and Membranous Labyrinth



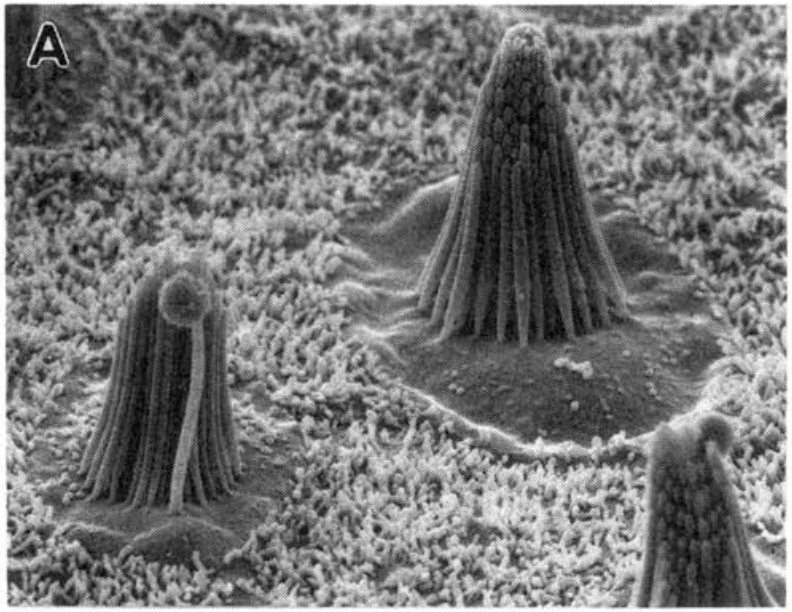
Endolymph versus Perilymph

Hair Cells

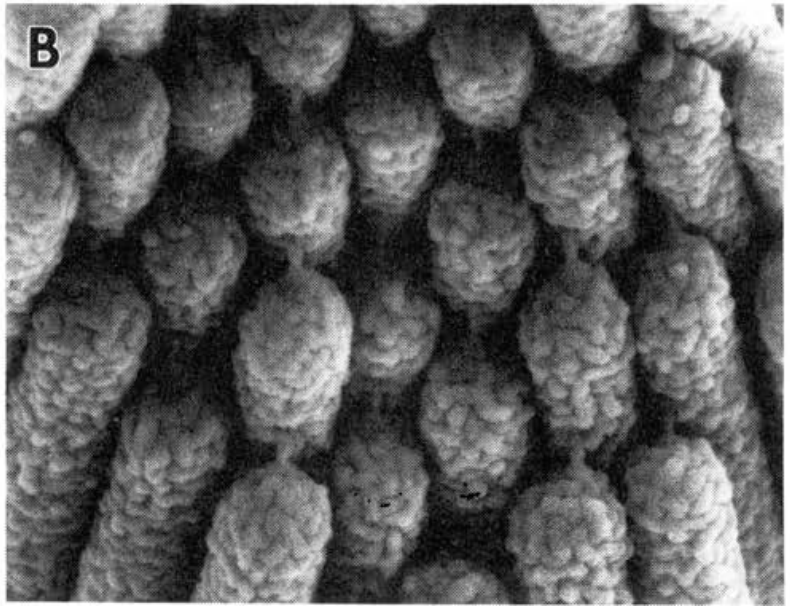
1. Transmitting a Signal

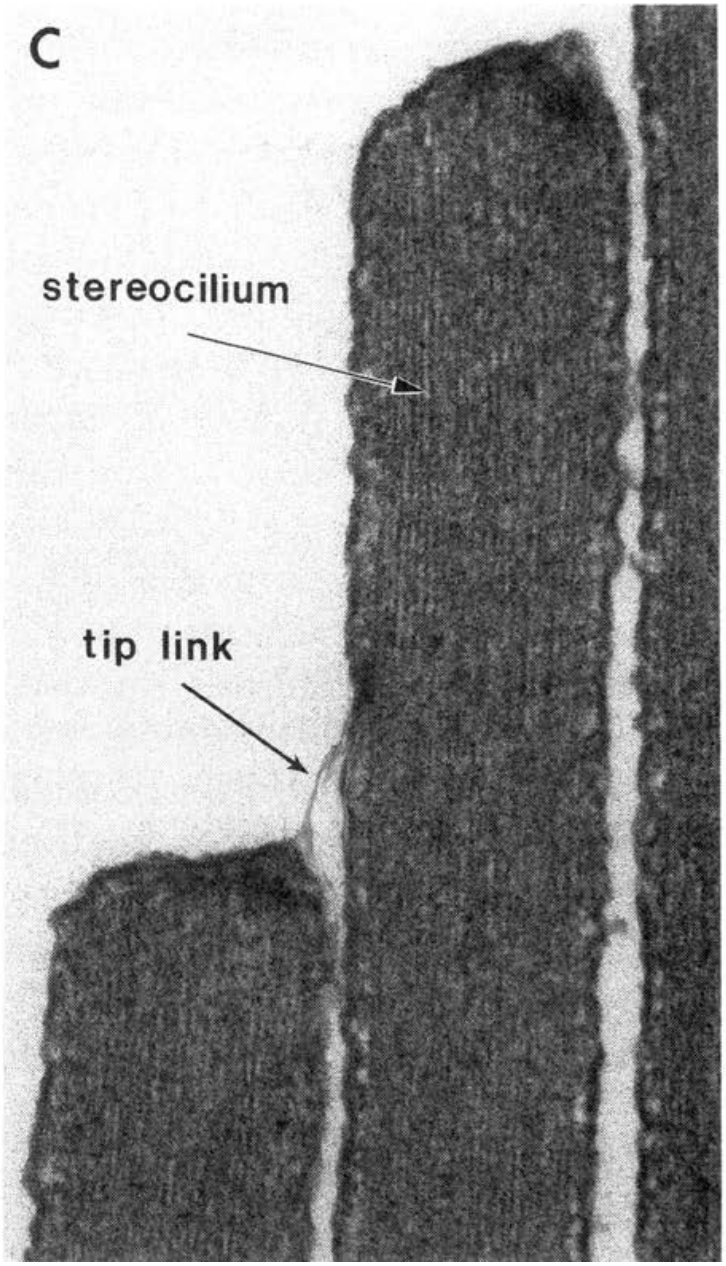
2. Overcome Inertia

Specialized <u>epithelial</u> cell!!



Kinocilium vs Stereocilium

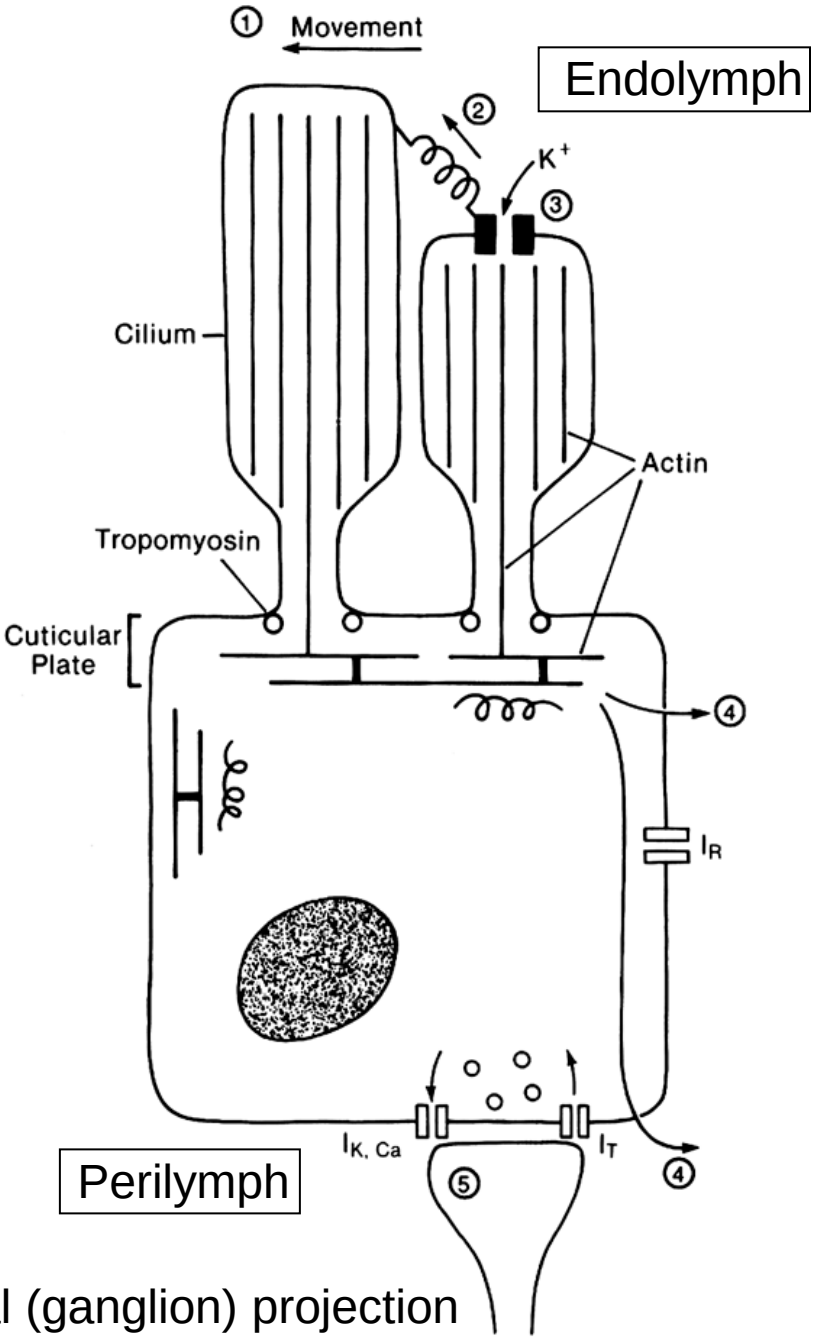




1. Transmitting a Signal

Converting mechanical stress into neurotransmission

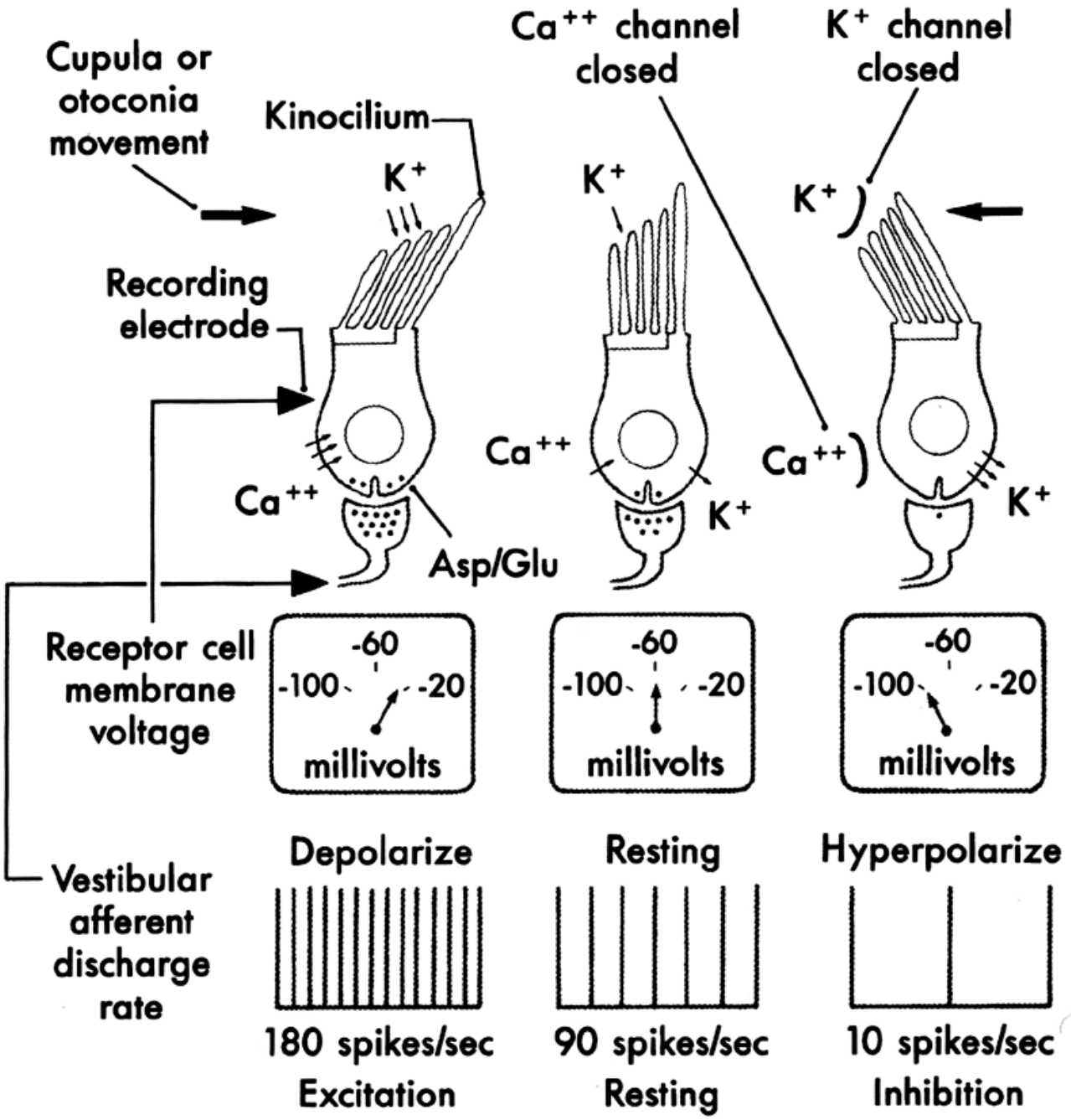
1. Movement
2. Filament is ‘pulled’
3. Potassium Stretch Channels Open
4. Potassium is removed
5. High potassium depolarizes, Calcium channels open and neurotransmitter is released.



Modifying potassium concentration regulates ‘discharge’ rate.

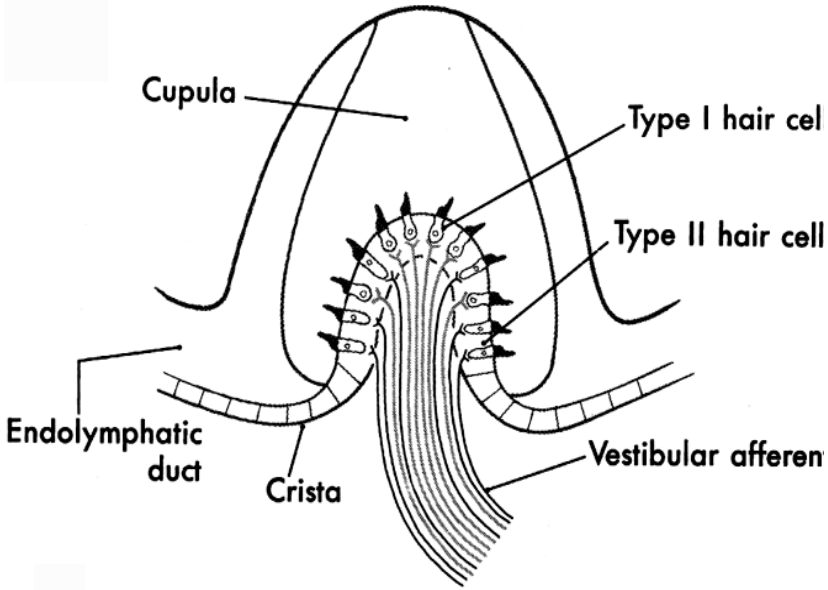
System

‘<u>TONE</u>’

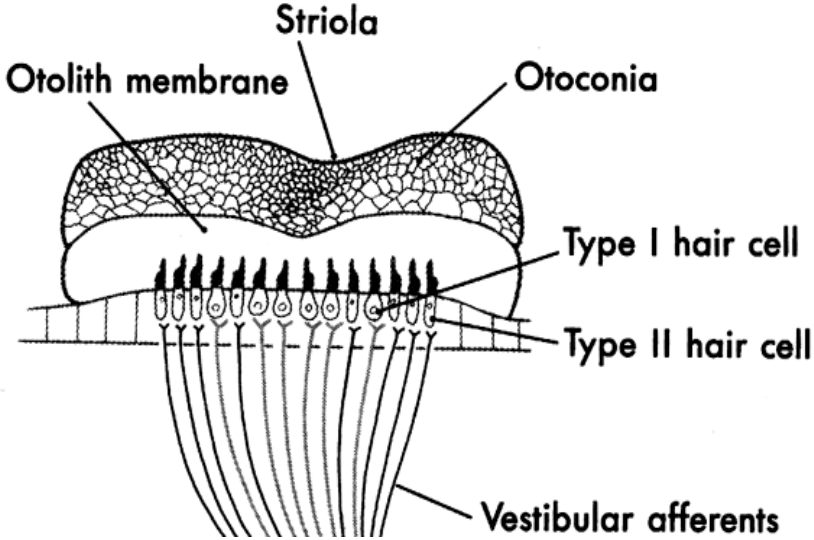


2. Overcoming Inertia

Sensory Hair Displacement

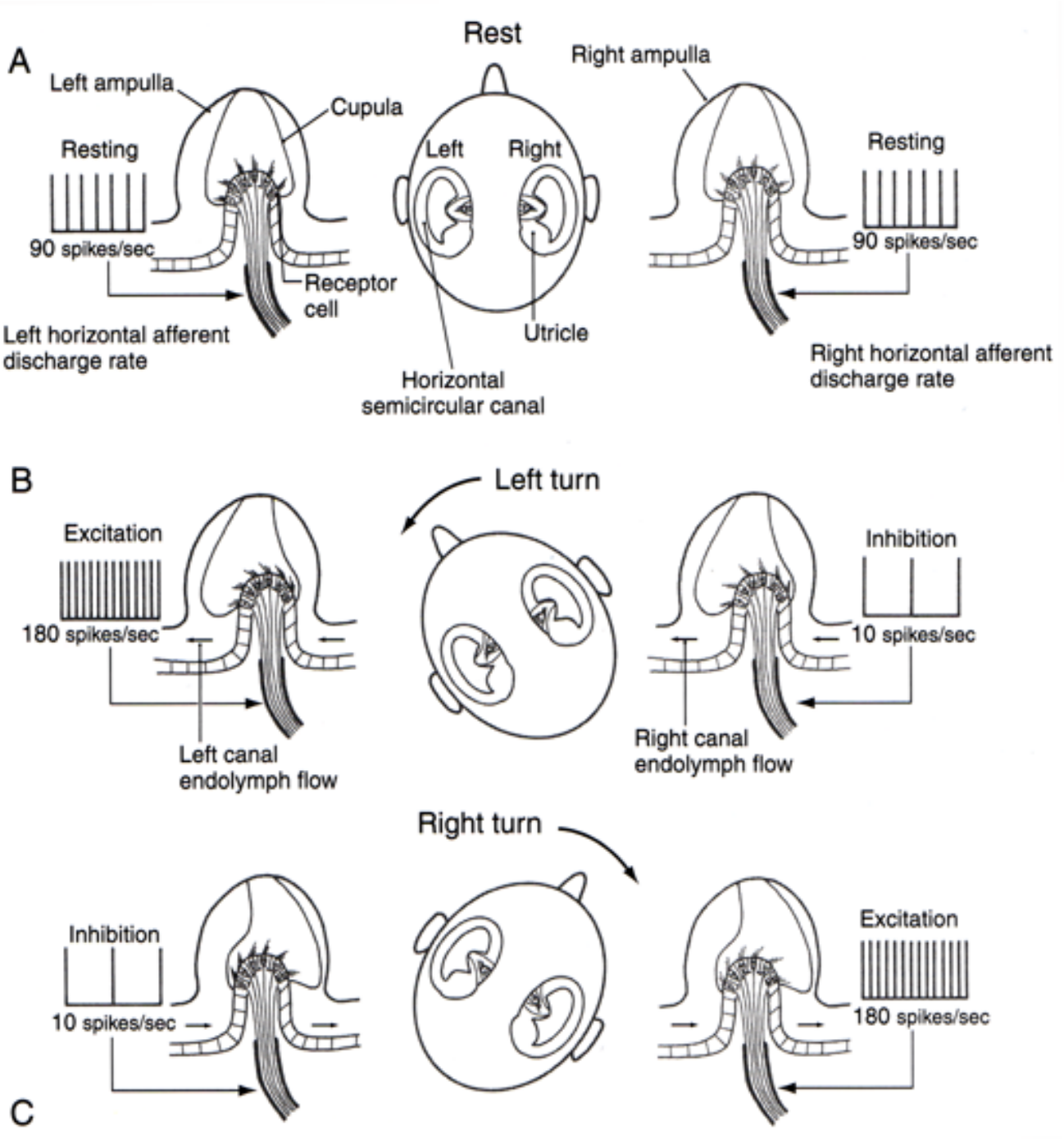


Angular Movement (Rotational)

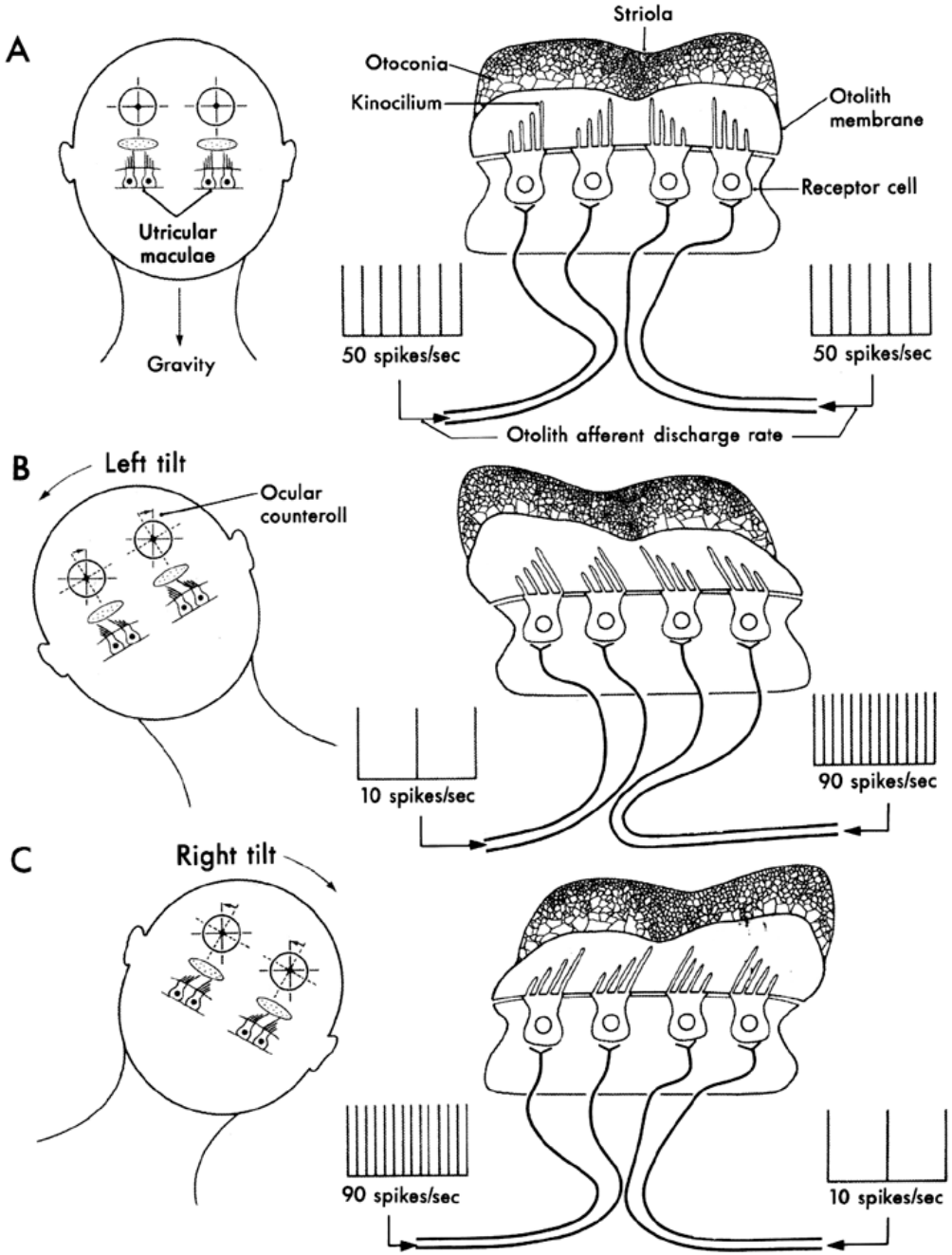


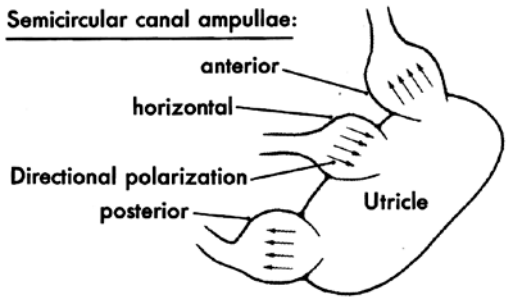
Linear Acceleration (Gravity)

Angular Movement



Linear Acceleration





Form vs. Function

(Size vs Shape)

Standard fluid dynamics notation

In standard fluid dynamics notation:[1][2]

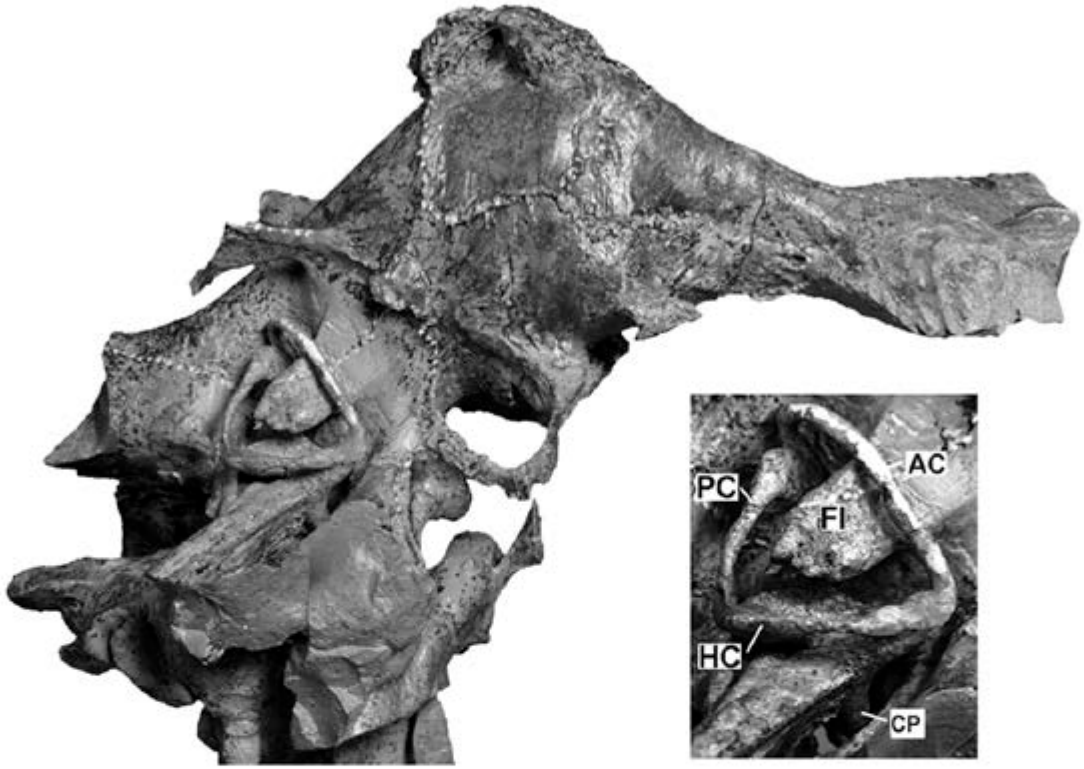
$$\Delta P = \frac{8\mu LQ}{\pi r^4}$$

or

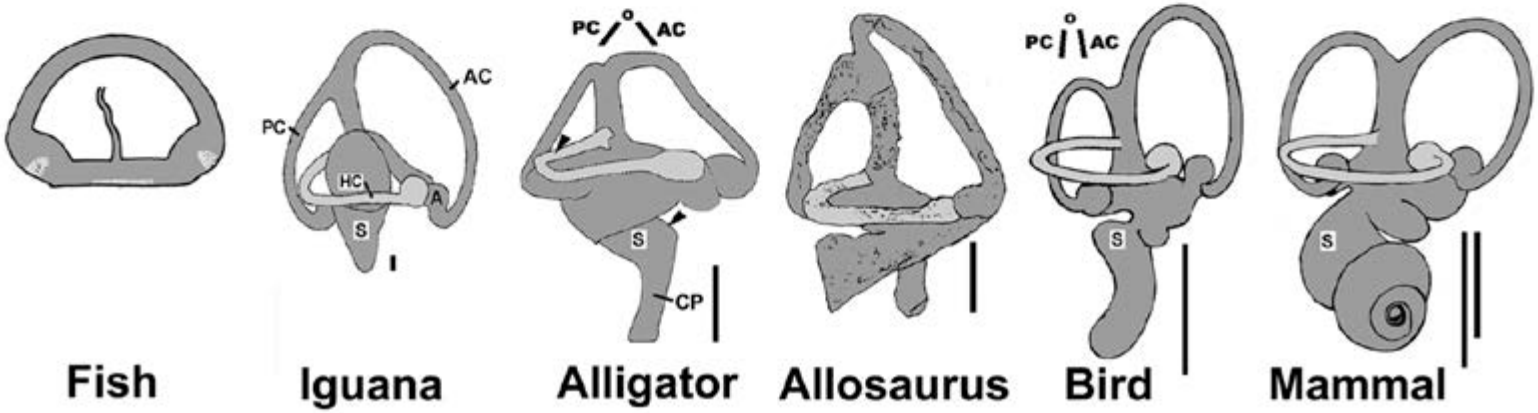
$$\Delta P = \frac{128\mu LQ}{\pi d^4}$$

where:

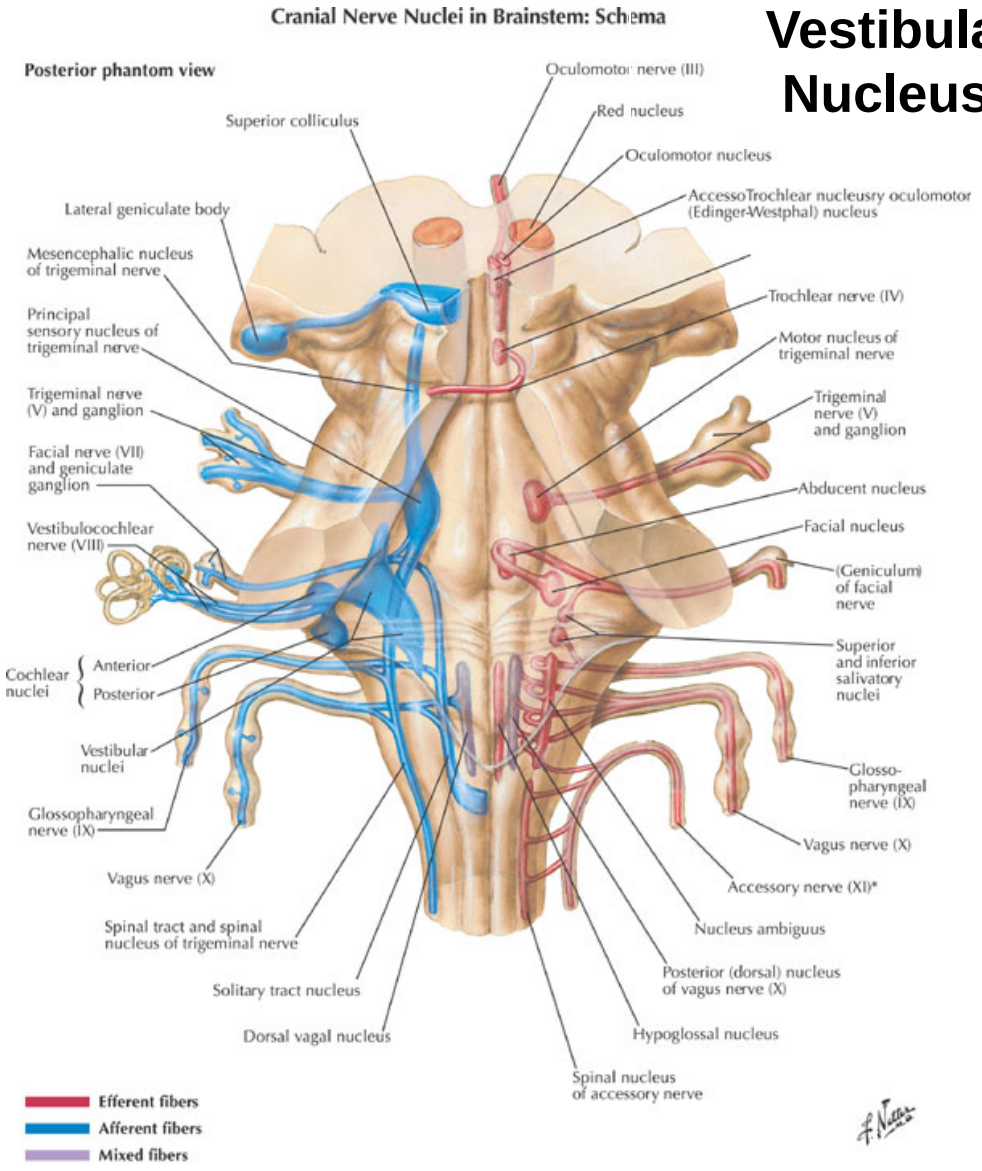
- ΔP is the pressure drop
- L is the length of pipe
- μ is the dynamic viscosity
- Q is the volumetric flow rate
- r is the radius
- d is the diameter
- π is the mathematical constant Pi

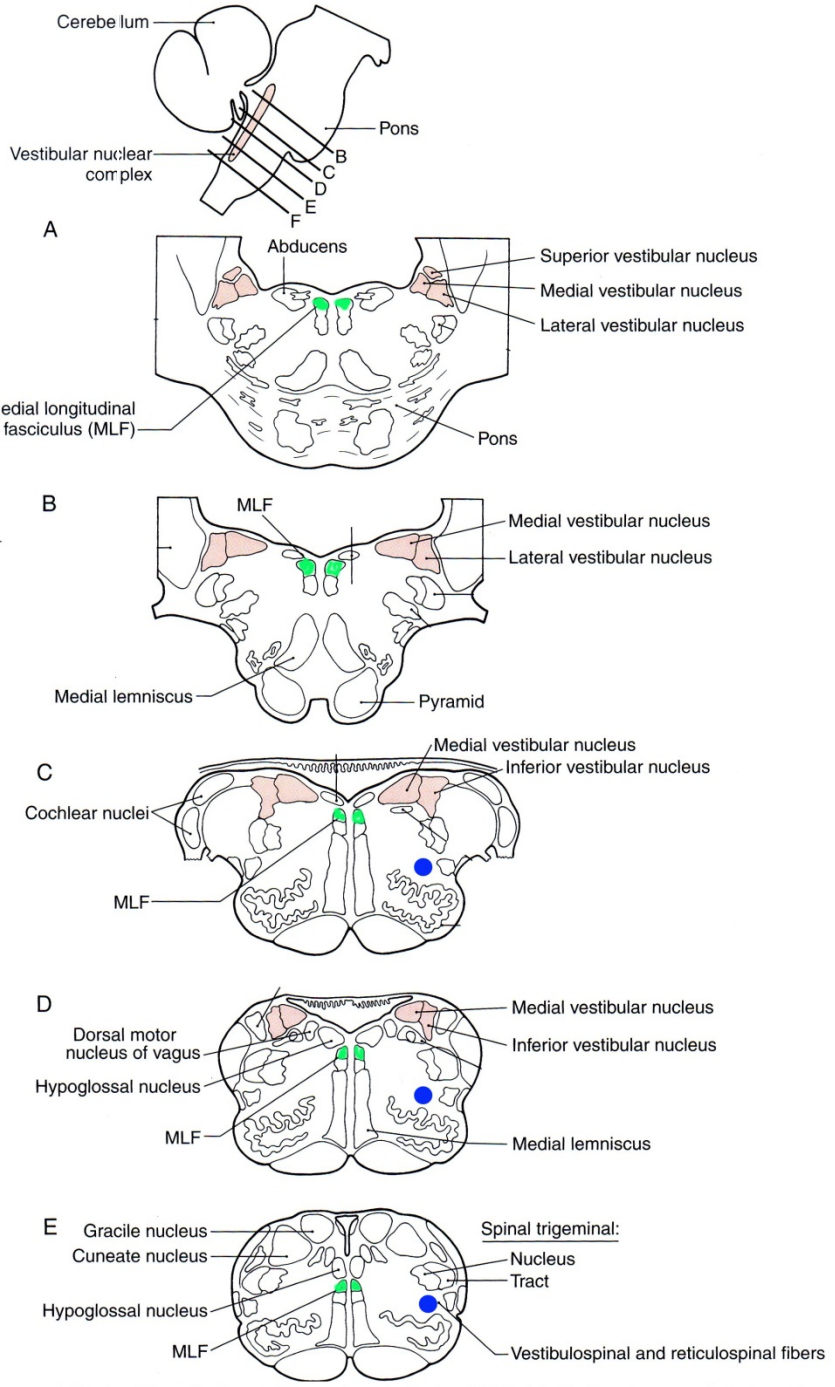


'Not just a good idea, it's the law!'



2. Central Vestibular Nucleus





2. Central Vestibular Nucleus

Ascending & Descending Networks

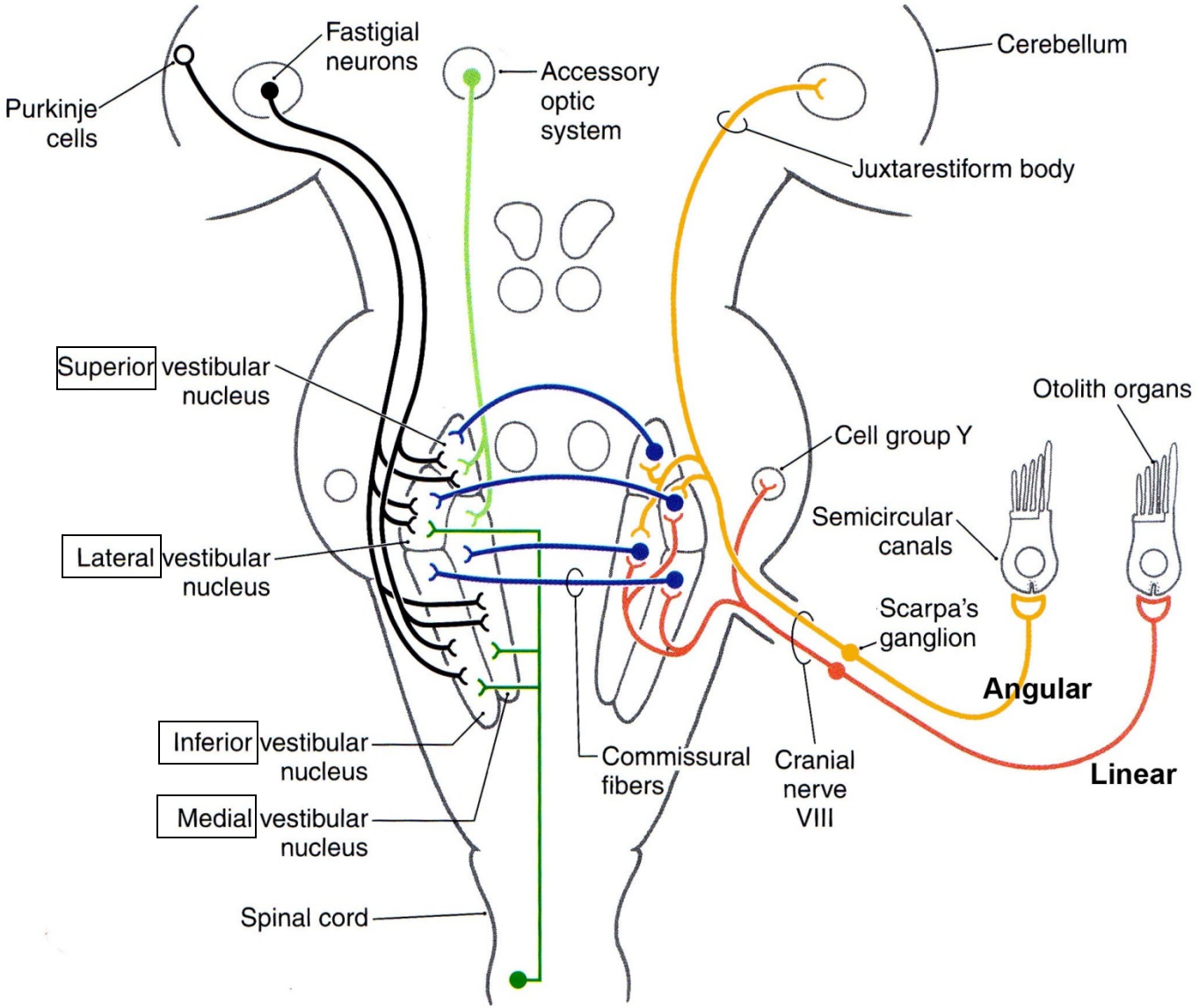
Four major Divisions

2nd order neurons

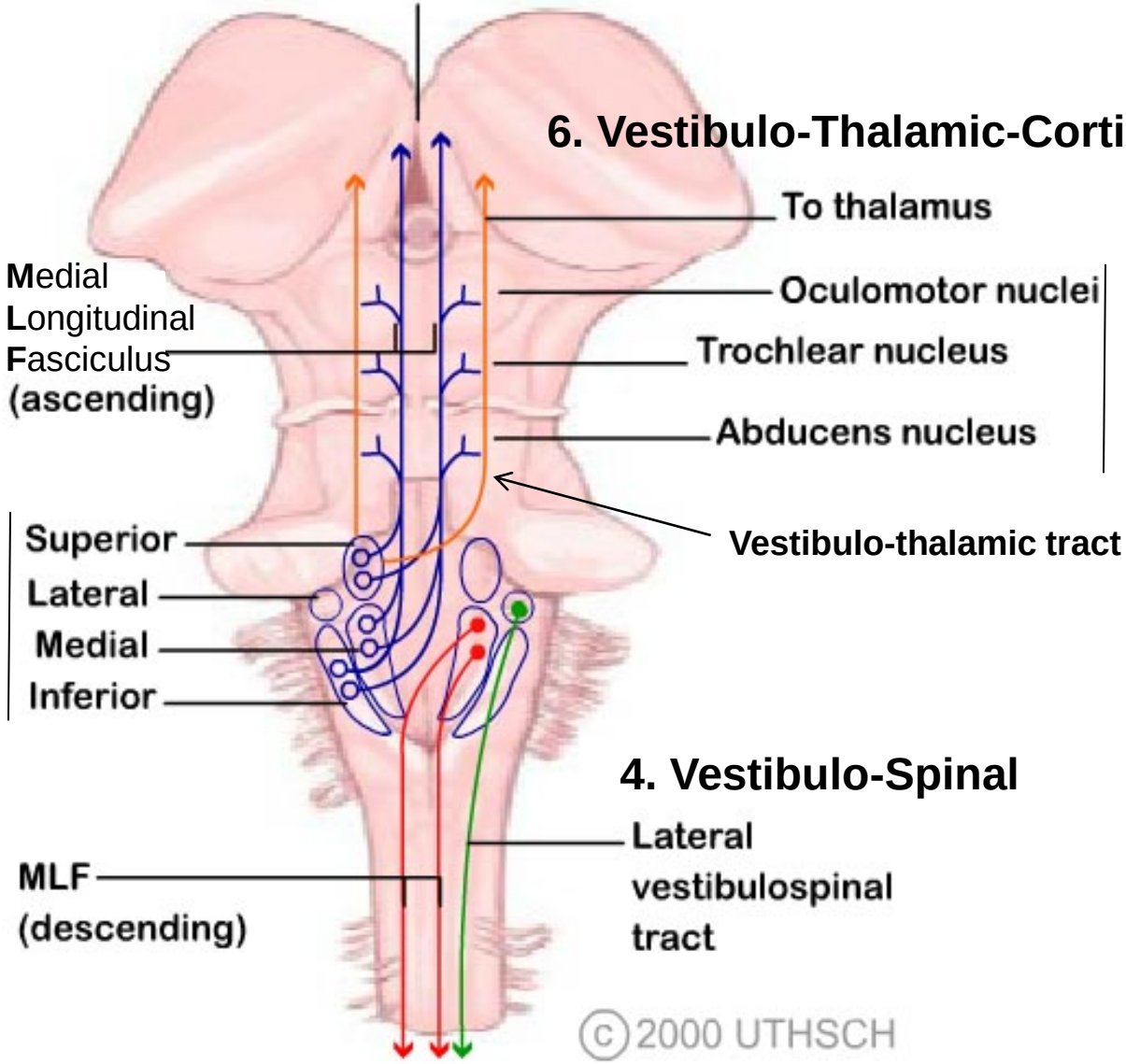
Afferents

Commissural Fibers

Efferents

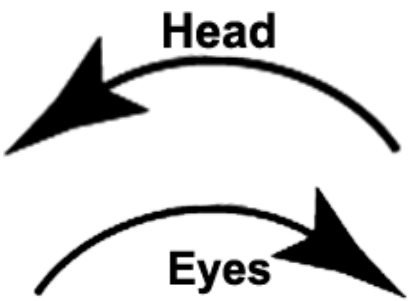


Basic Organization

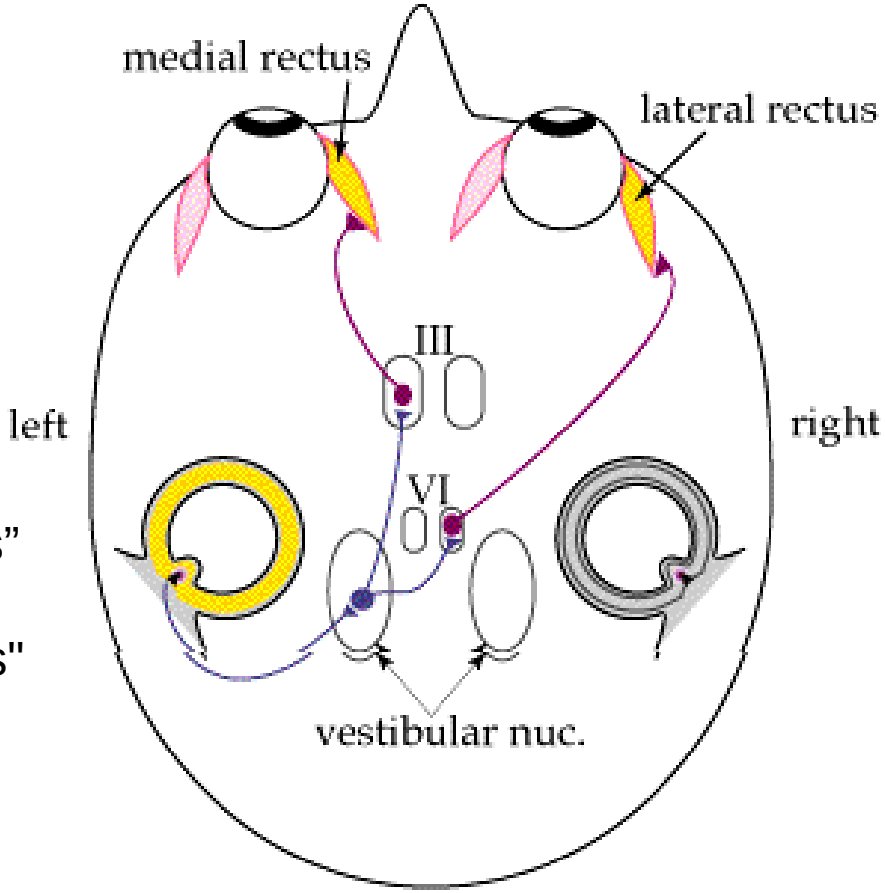


http://neuroscience.uth.tmc.edu/s2/chapter11.html

3. Vestibulo-Ocular



Saccade: 'Fast movement of the Eyes'



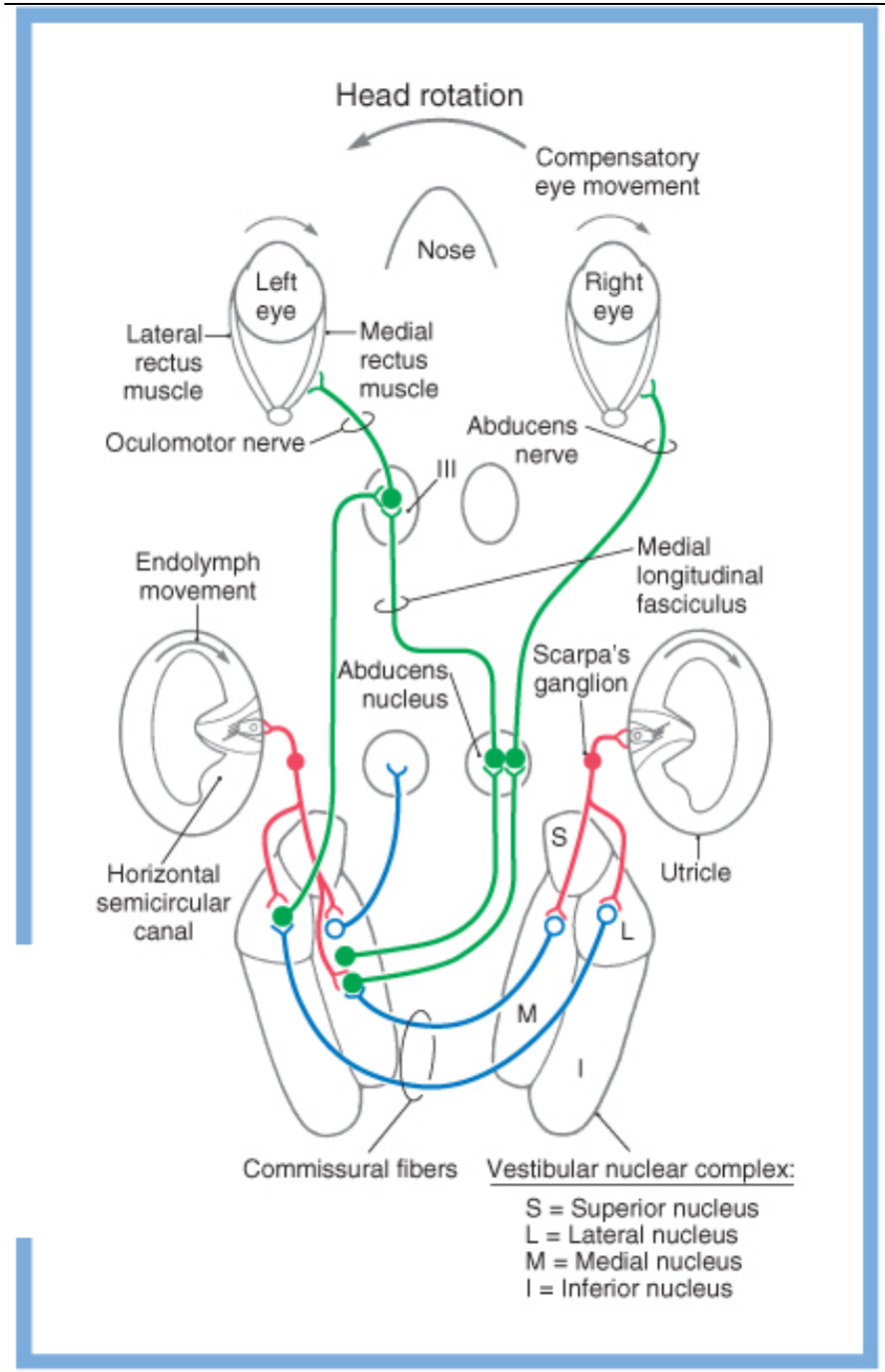
Nystagmus:

"nystagmos" Greek describing wild head movements while sleeping or intoxicated.

Most often a combination of "slow phases" (usually the eye moves off the point of attention); interspersed with "quick phases" of saccade-like movement that brings the eye back to the target.

(e.g., reading)

3. Vestibulo-Ocular



Caloric nystagmus.

Subject tilts head back (horizontal canals are oriented vertically).

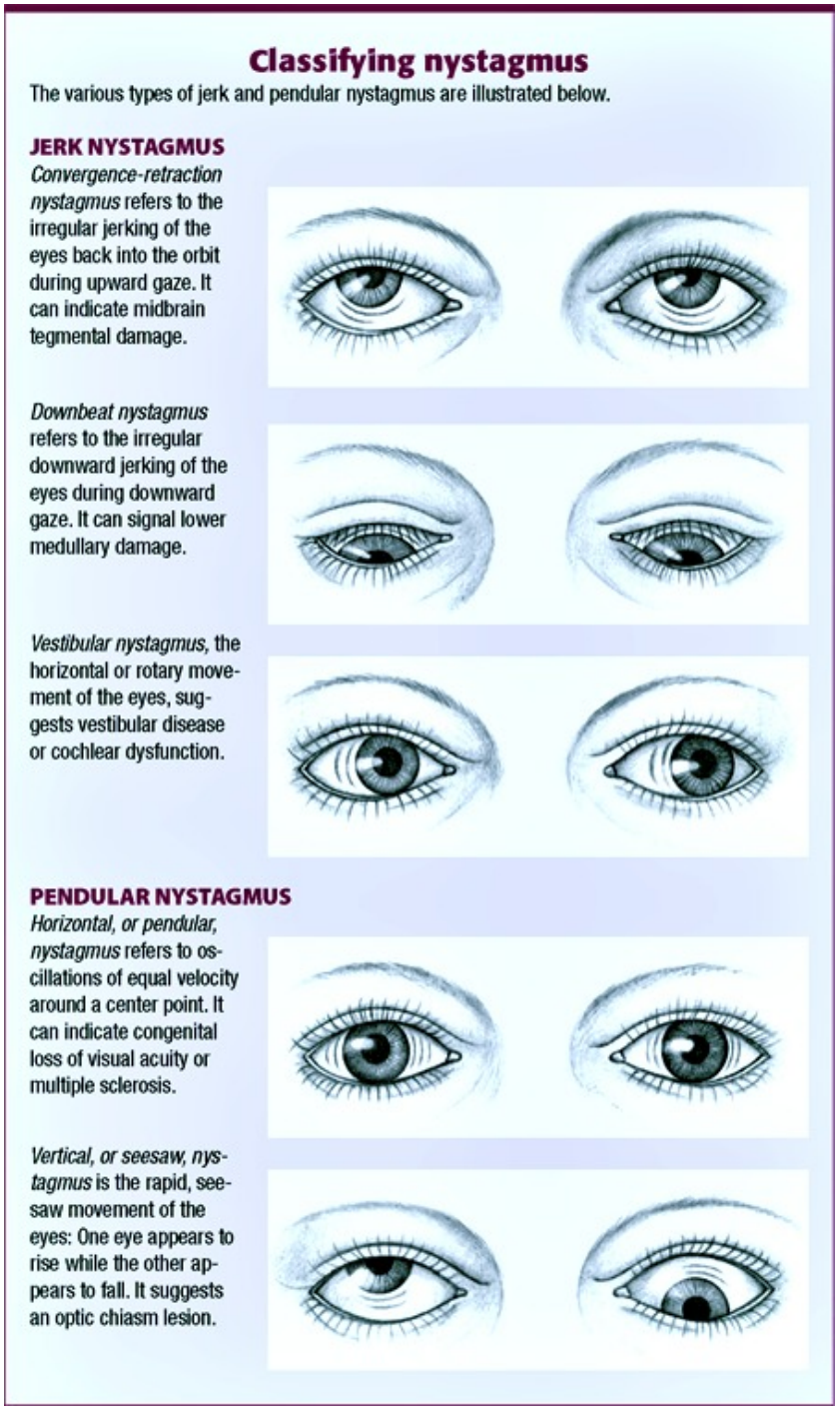
The ear is irrigated with either warm or cold water.

Result: Nystagmus.

Example: WARM water to the RIGHT ear, endolymph will expand (rise) in the RIGHT canal causing motion towards the utricle. The slow phase will move eyes left (initially), but because the Right side now dominates there is a rapid corrective saccade and the fast-phase corrective nystagmus will cause eyes to go to the RIGHT. (Cool water produces the opposite)

COWS = Cold Opposite, Warm Same

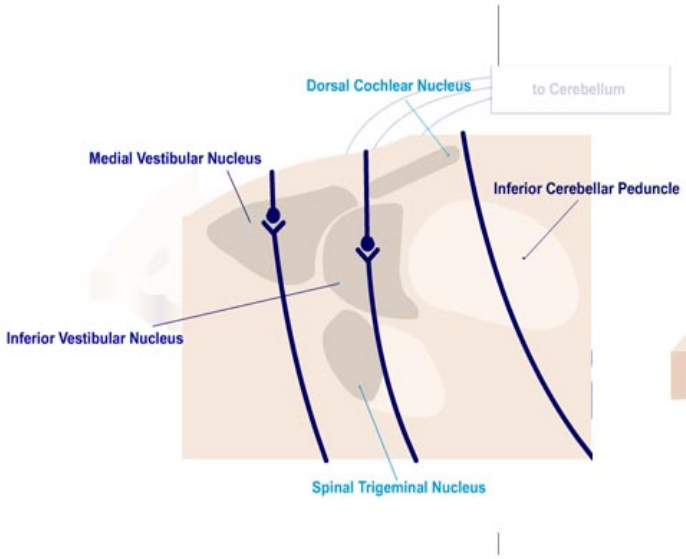
Saccadic oscillations not fitting the normal function are a deviation from a healthy or normal condition.

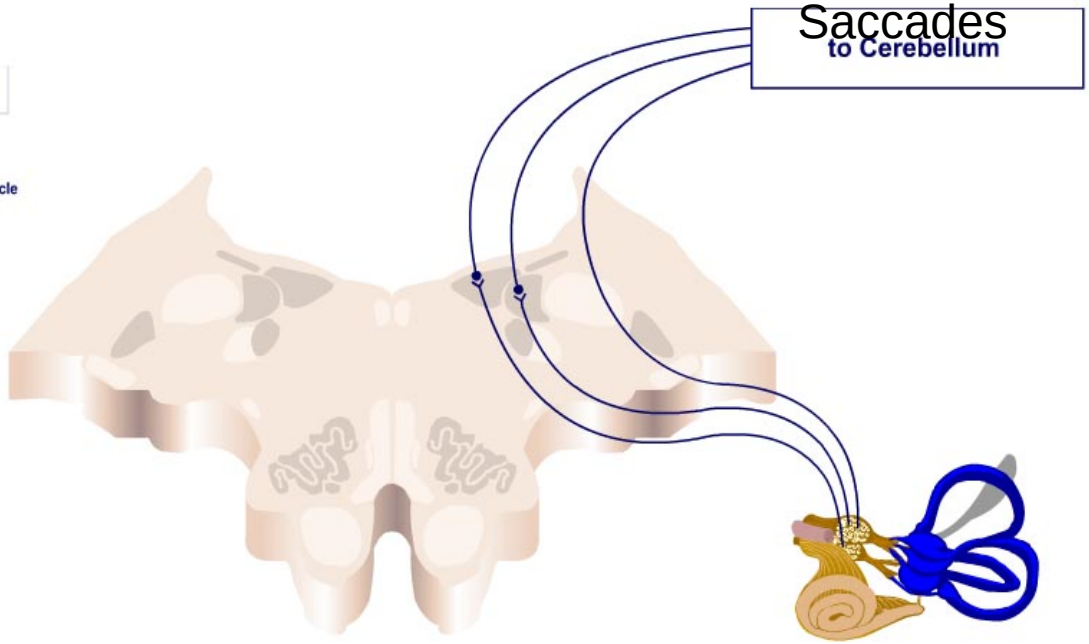


5. Vestibulo-Cerebellum Network

Juxtarestiform
&
Cell Group Y

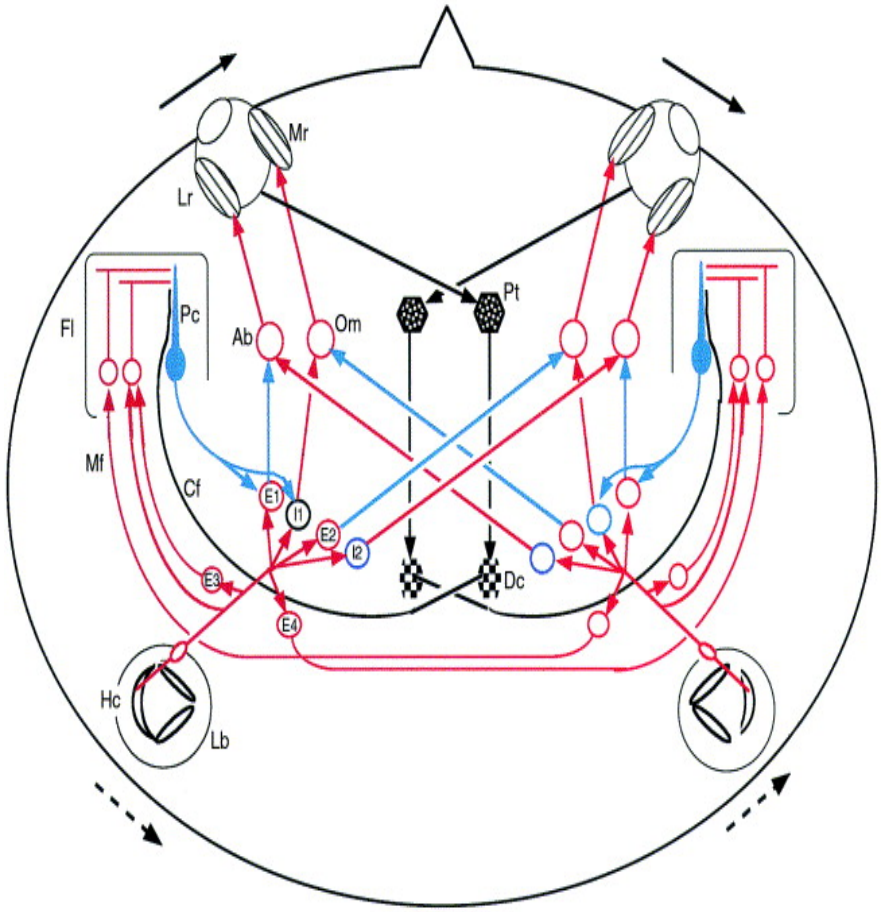
Control of Saccades





http://neuroscience.uth.tmc.edu/s2/chapter11.html

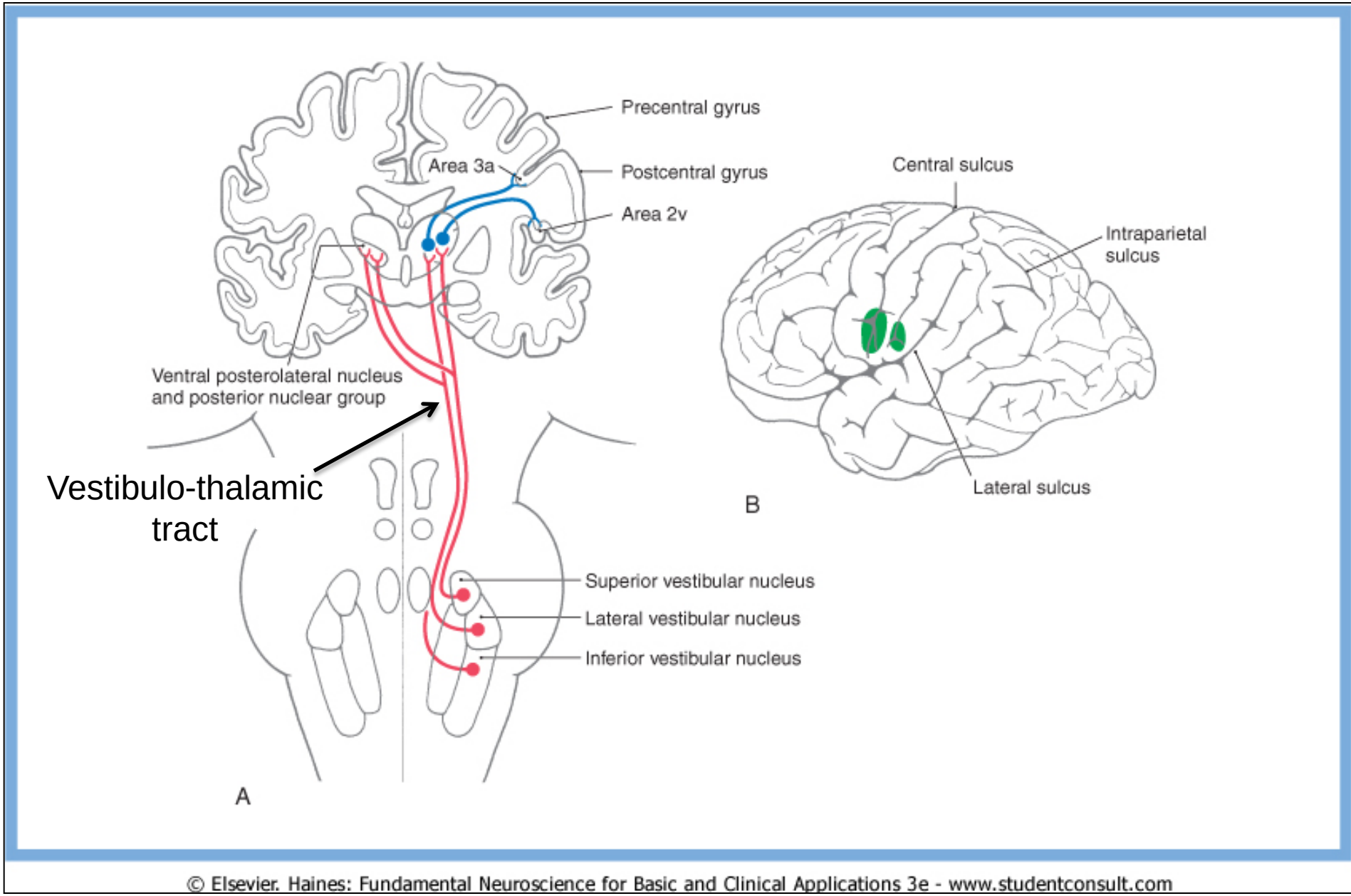
Systems 3 and 5 Interact to Coordinate ‘Involuntary’ Eye Movements



Neuronal circuits for horizontal VOR. Connections from bilateral labyrinths to bilateral eyes serving for the horizontal VOR are shown, but internuclear connections between abducens and oculomotor nuclei, and commissural connections between bilateral vestibular nuclei are omitted for simplicity. Ab, abducens motor neuron; Cf, climbing fiber; Dc, dorsal cap; E1, E2, E3, E4, secondary vestibular neurons of an excitatory nature; Fl, flocculus; Hc, horizontal canal; I1, I2, secondary vestibular neurons of an inhibitory nature; Lb, labyrinth; Lr, lateral rectus muscle; Mf, mossy fiber; Mr, medial rectus muscle; Om, oculomotor neuron for Mr; Pc, Purkinje cell; Pt, pretectal region. Red lines and arrows indicate excitatory action, and blue ones inhibitory action.

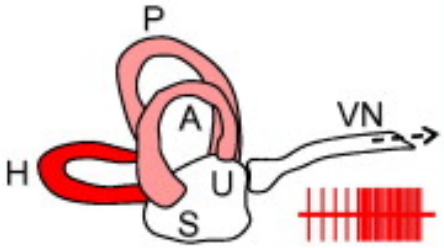
Cerebellar learning in the vestibulo–ocular reflex
Trends Cog. Sci. 2:313-321, 1998

6. Vestibulo-Thalamic-Cortical



A caloric vestibular stimulation (CVS)

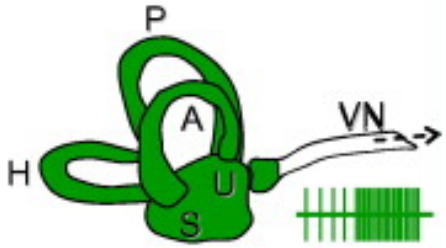
Injection of cold (0,4,10,20°C) or warm (44°C) water or gas into the external auditory canal.



Warm water increases firing rate mainly in the afferents of the horizontal semicircular canals.
A weaker contribution of vertical canals and an interaction with the neural processing of otolithic signals have been demonstrated.

B galvanic vestibular stimulation (GVS)

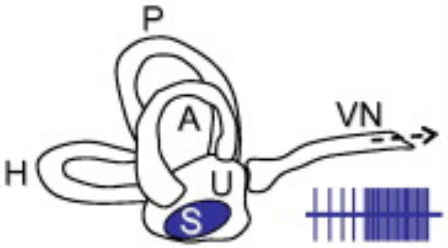
Application of a percutaneous current through an anode and a cathode placed on the opposite mastoid processes.



Firing rate increases in the vestibular afferents ipsilateral to the cathode and decreases to the side of the anode.

C sound-induced vestibular stimulation

Presentation of 102 dB clicks (1 ms long, at 1 Hz) or short tone bursts (10 ms long, 500 Hz, at 3 Hz) through headphones.



Air-conducted sounds preferentially activate saccular receptors.
A weaker contribution of other otolithic receptors and semicircular canals has also been proposed.

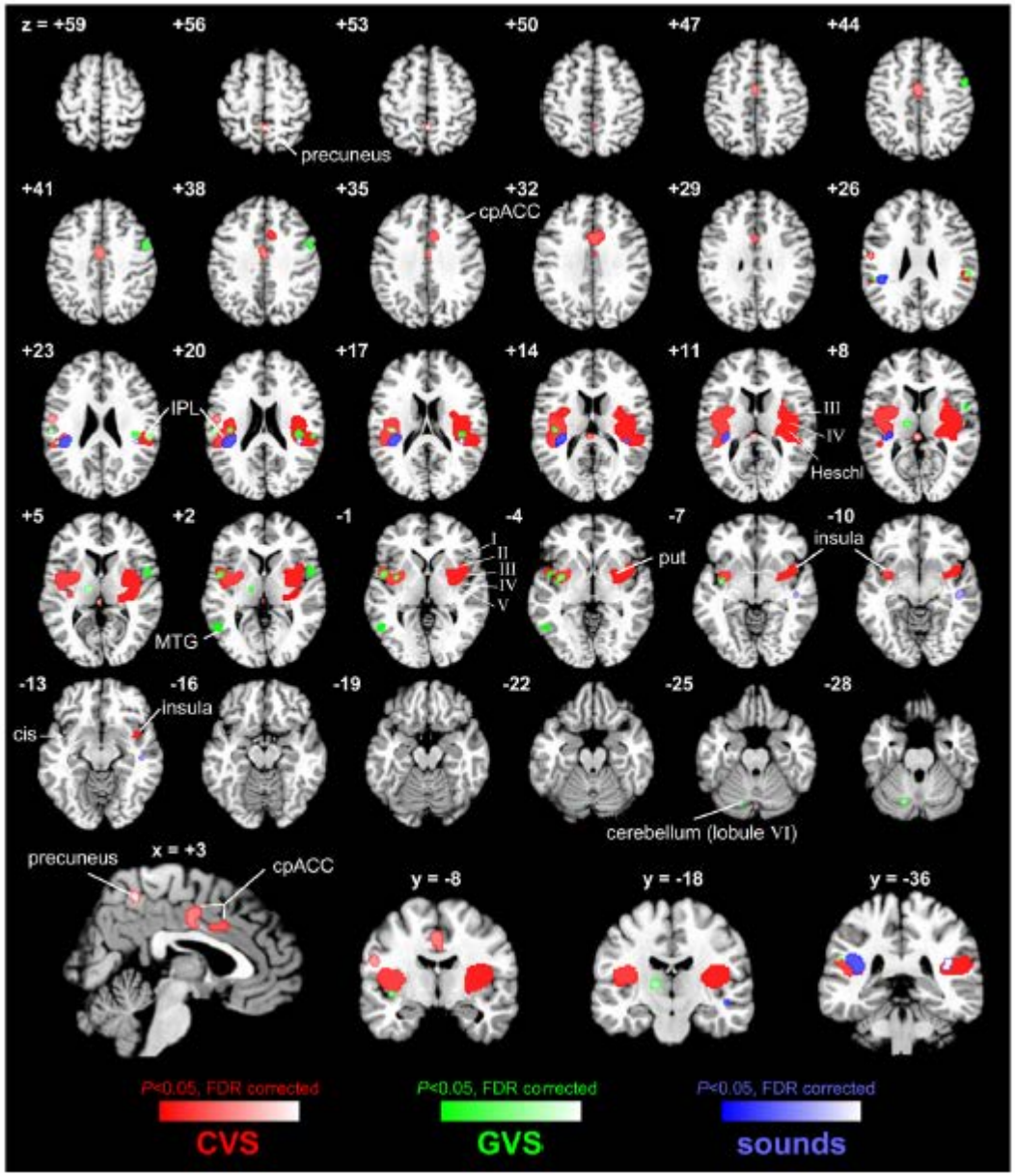


Fig. 2. Localization of significant clusters identified by the meta-analysis for CVS (Analysis 1), GVS (Analysis 2), and sounds (Analysis 3) irrespective of the side of the stimulation. All results are displayed on selected brain slices from a single subject template in the MNI space. All values are corrected for false discovery rate (P <0.05).

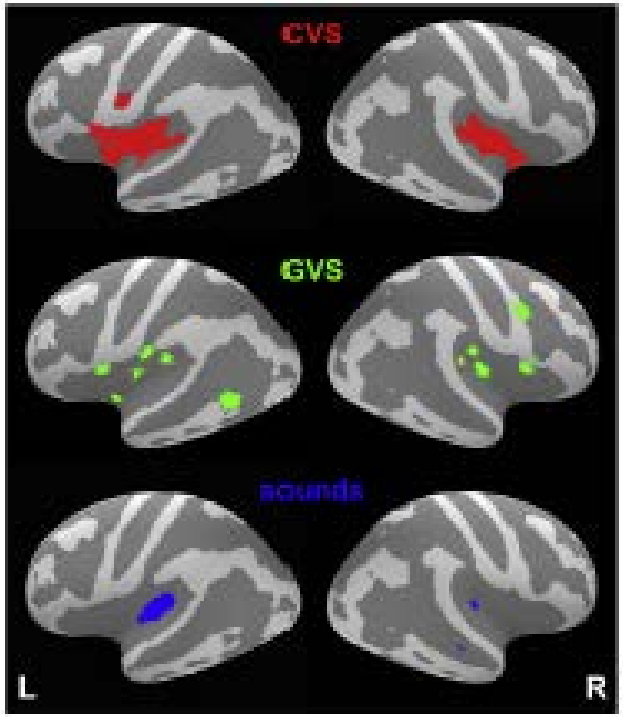
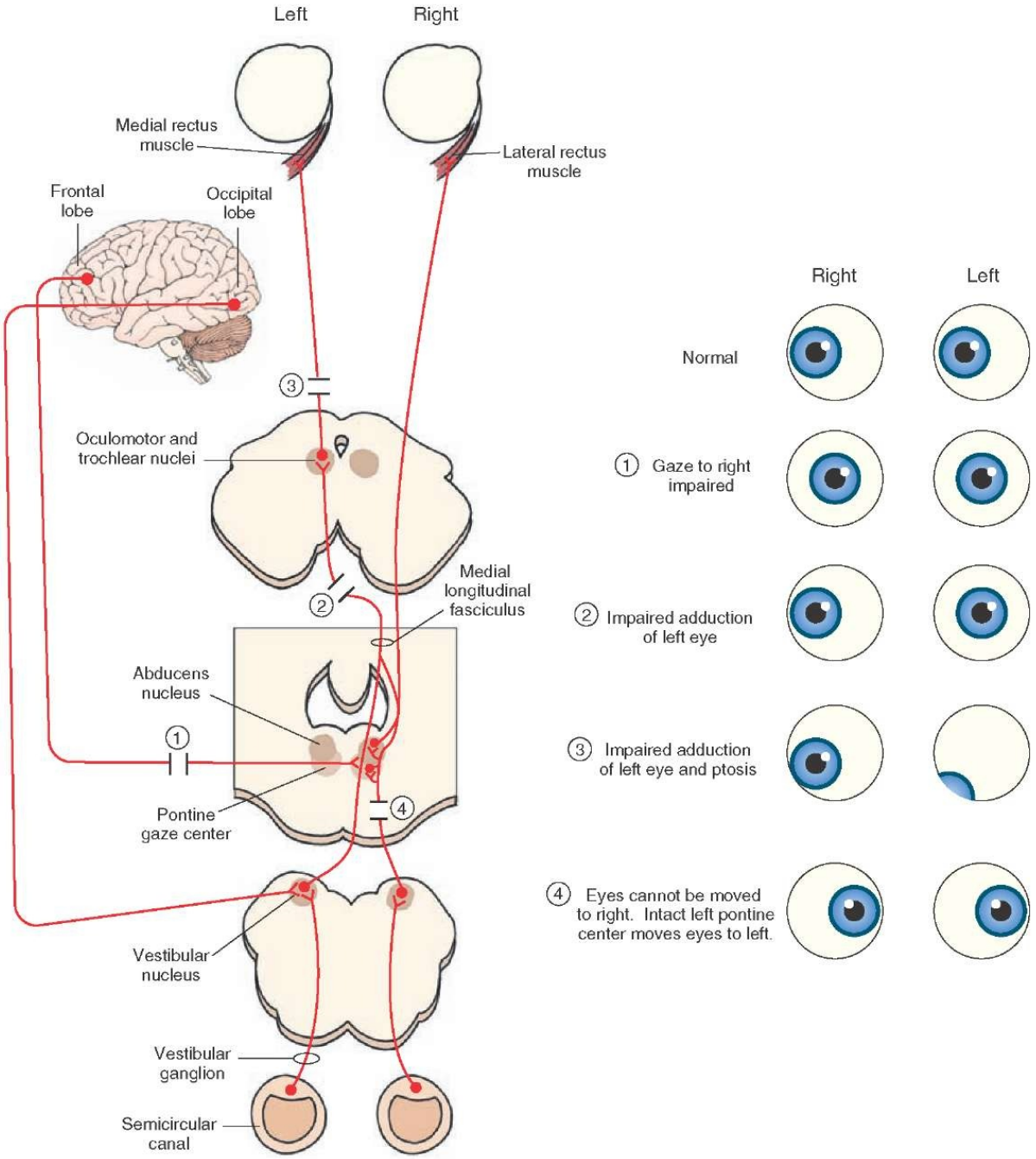
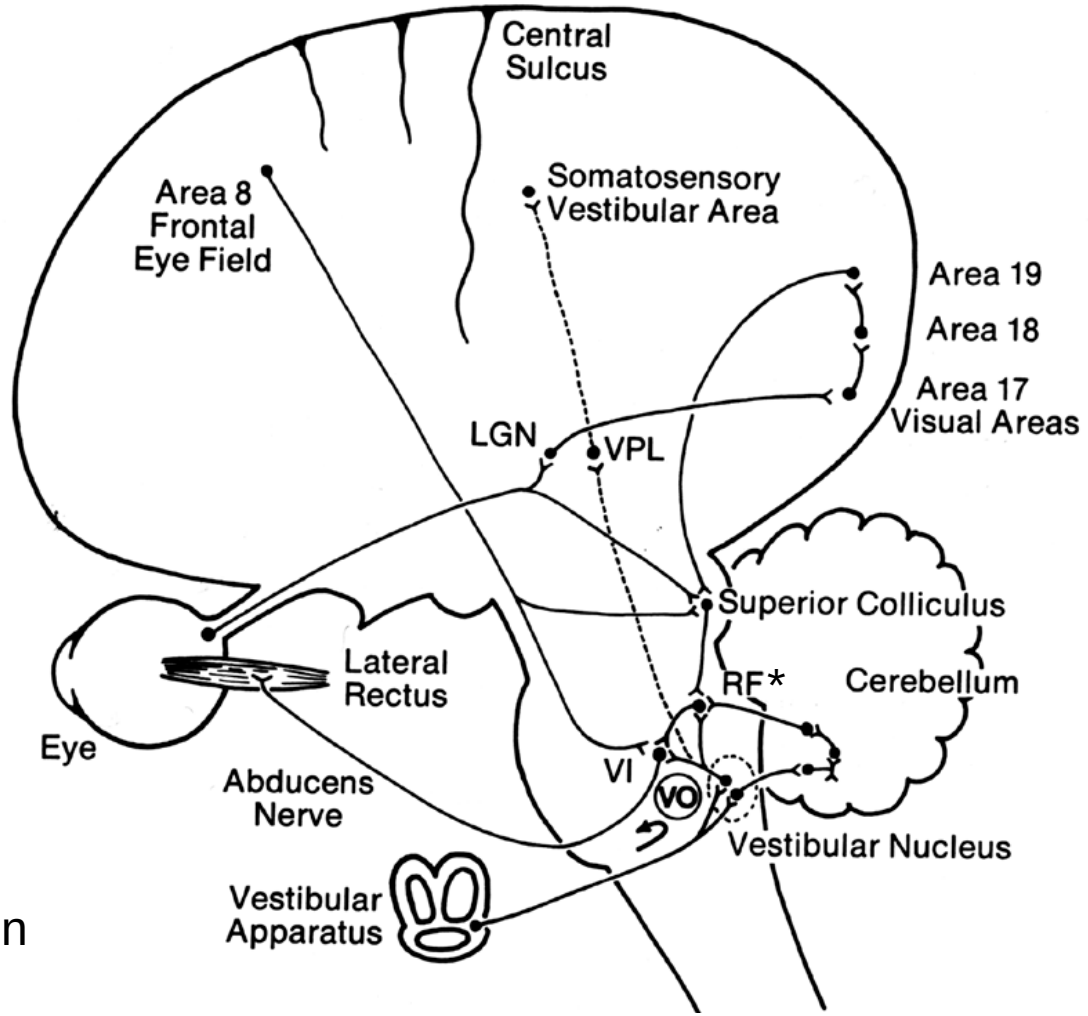


Fig. 3. Localization of significant clusters identified by the meta-analysis for CVS (Analysis 1), GVS (Analysis 2), and sounds (Analysis 3) irrespective of the side of the stimulation. Results are displayed on inflated hemispheres to reveal activations in the Sylvian fissure. All values are corrected for false discovery rate (P<0.05).


Left
Right
Medial rectus muscle
Lateral rectus muscle
Frontal lobe
Occipital lobe
3
Oculomotor and trochlear nuclei
2
Medial longitudinal fasciculus
Abducens nucleus
1
Pontine gaze center
4
Vestibular nucleus
Vestibular ganglion
Semicircular canal
Right
Left
Normal
1 Gaze to right impaired
2 Impaired adduction of left eye
3 Impaired adduction of left eye and ptosis
4 Eyes cannot be moved to right. Intact left pontine center moves eyes to left.

Multisensory -- Multimodal



Trans-saccadic memory:

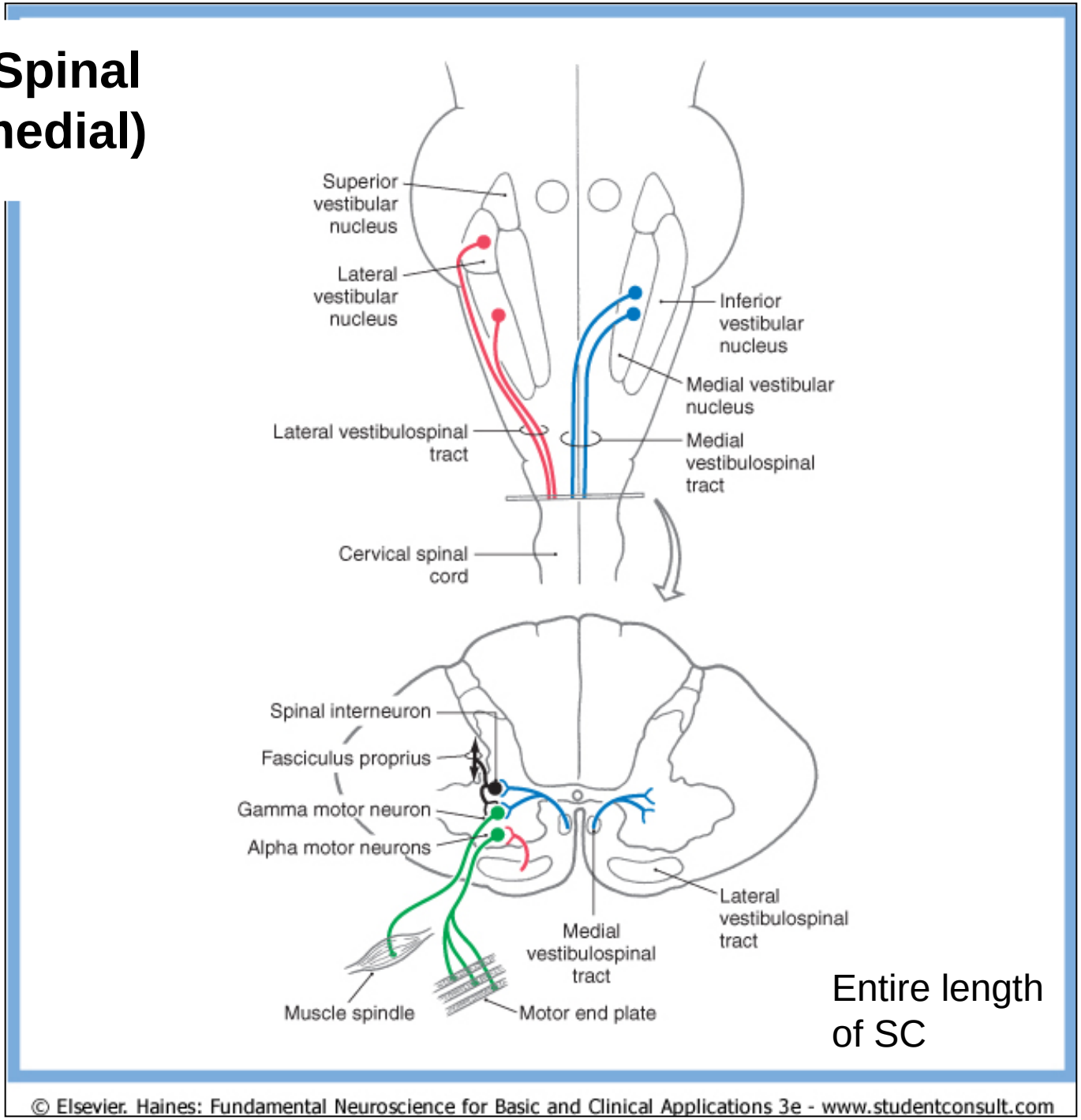
The process of retaining information across a saccade.

Trans-saccadic integration:

The process of integrating information from multiple saccades.

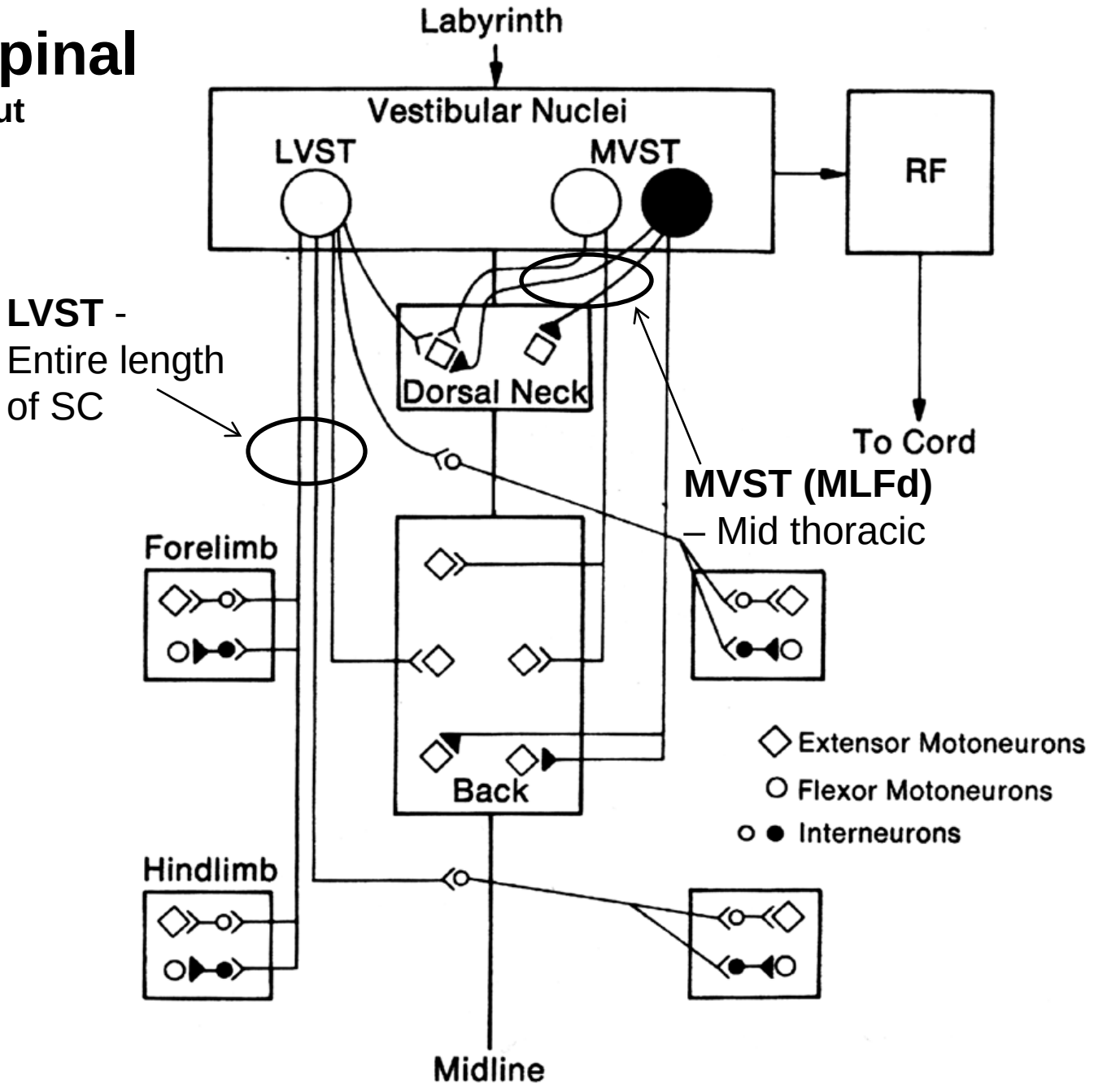
* Paramedian Pontine Reticular Formation (PPRF)

4. Vestibulo-Spinal (lateral & medial)

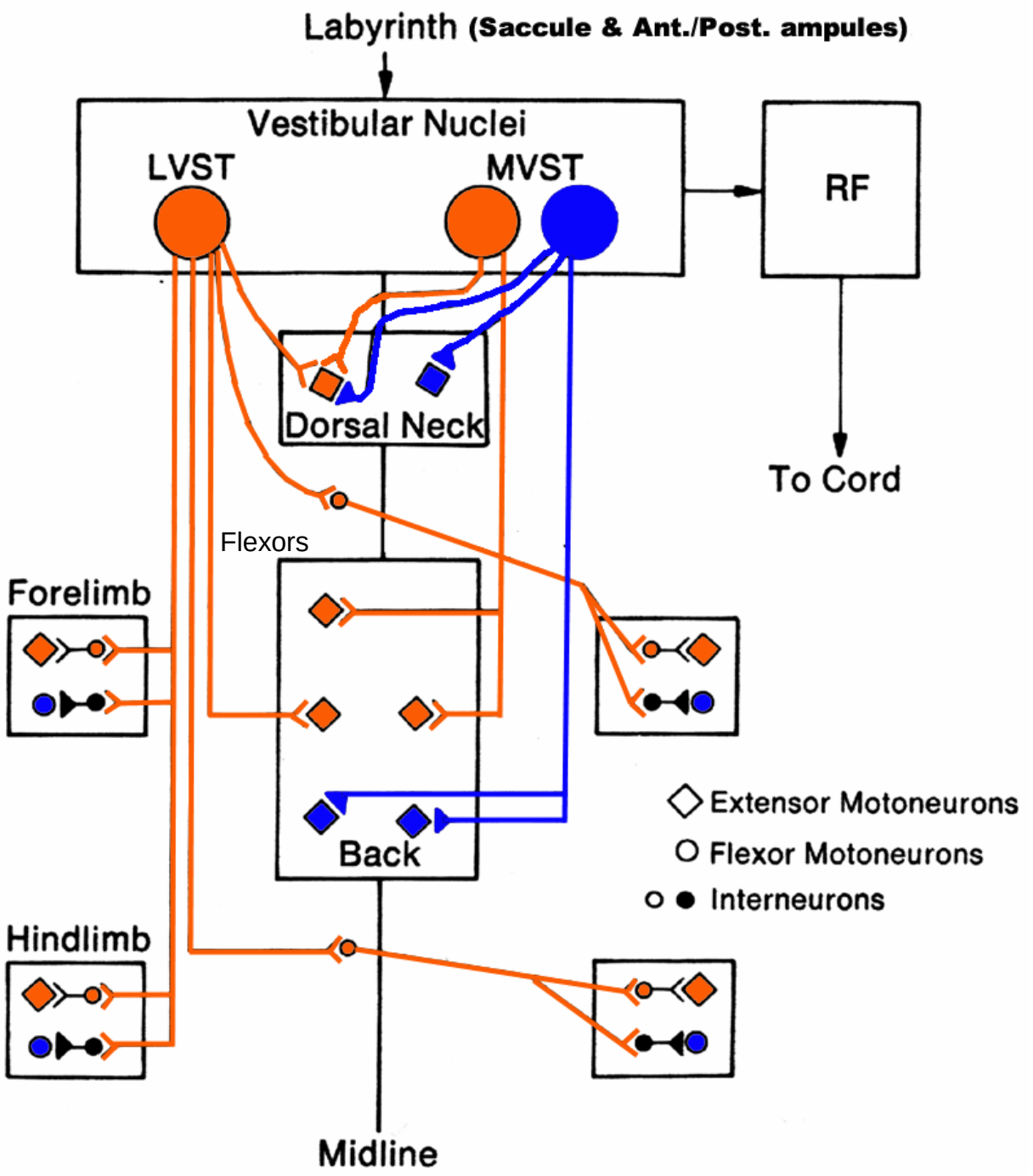


4. Vestibulo-spinal

(don't forget about this system)



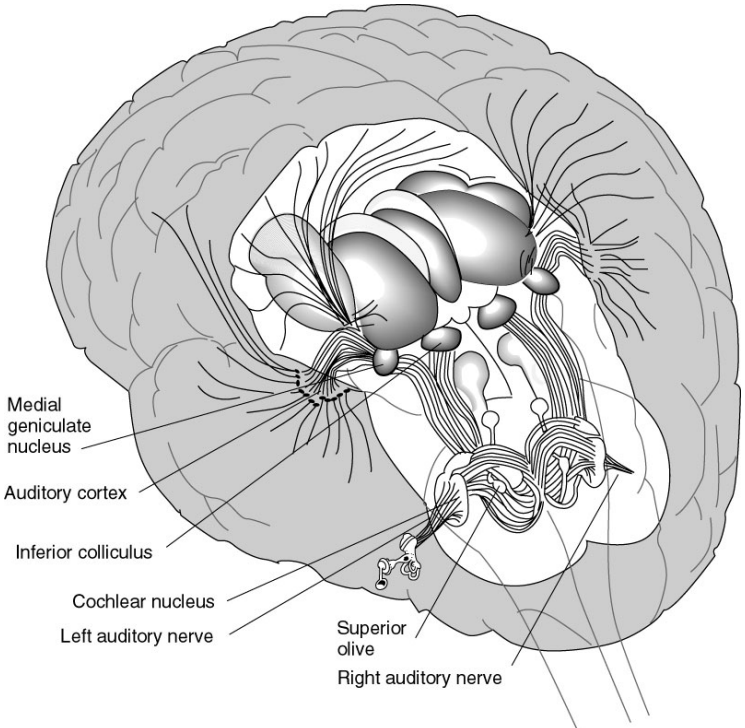
4. Vestibulo-Spinal



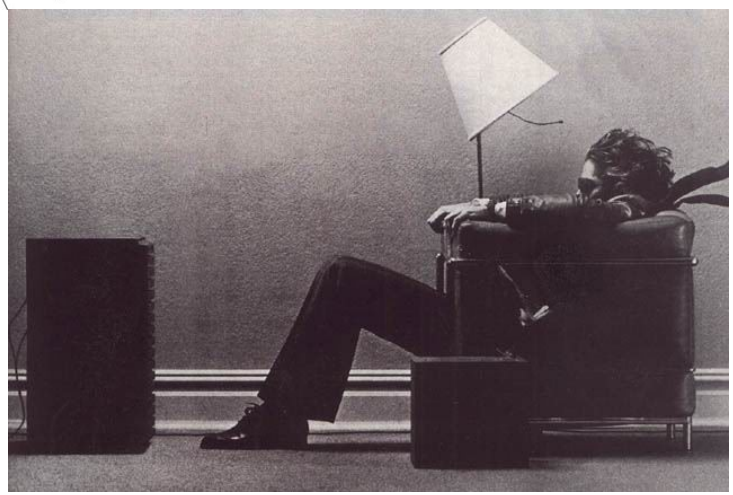
A PERSON WITH A LEFT NYSTAGMUS (LEFT SIDE DOMONATES) WILL FALL OR STUMBLE TO THE RIGHT.

Auditory System

FEAR & Localization!

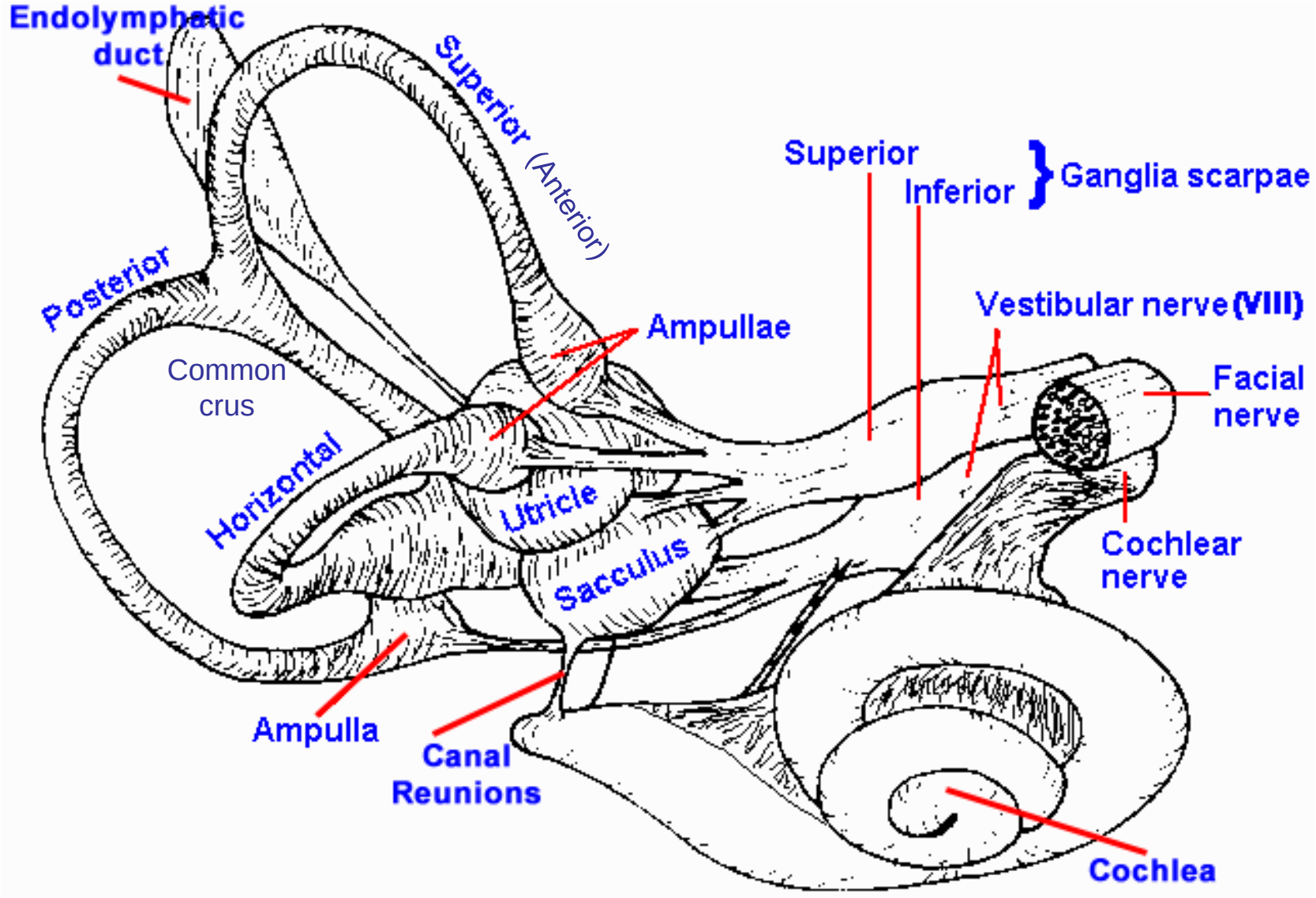


Signal Integration & Interpretation

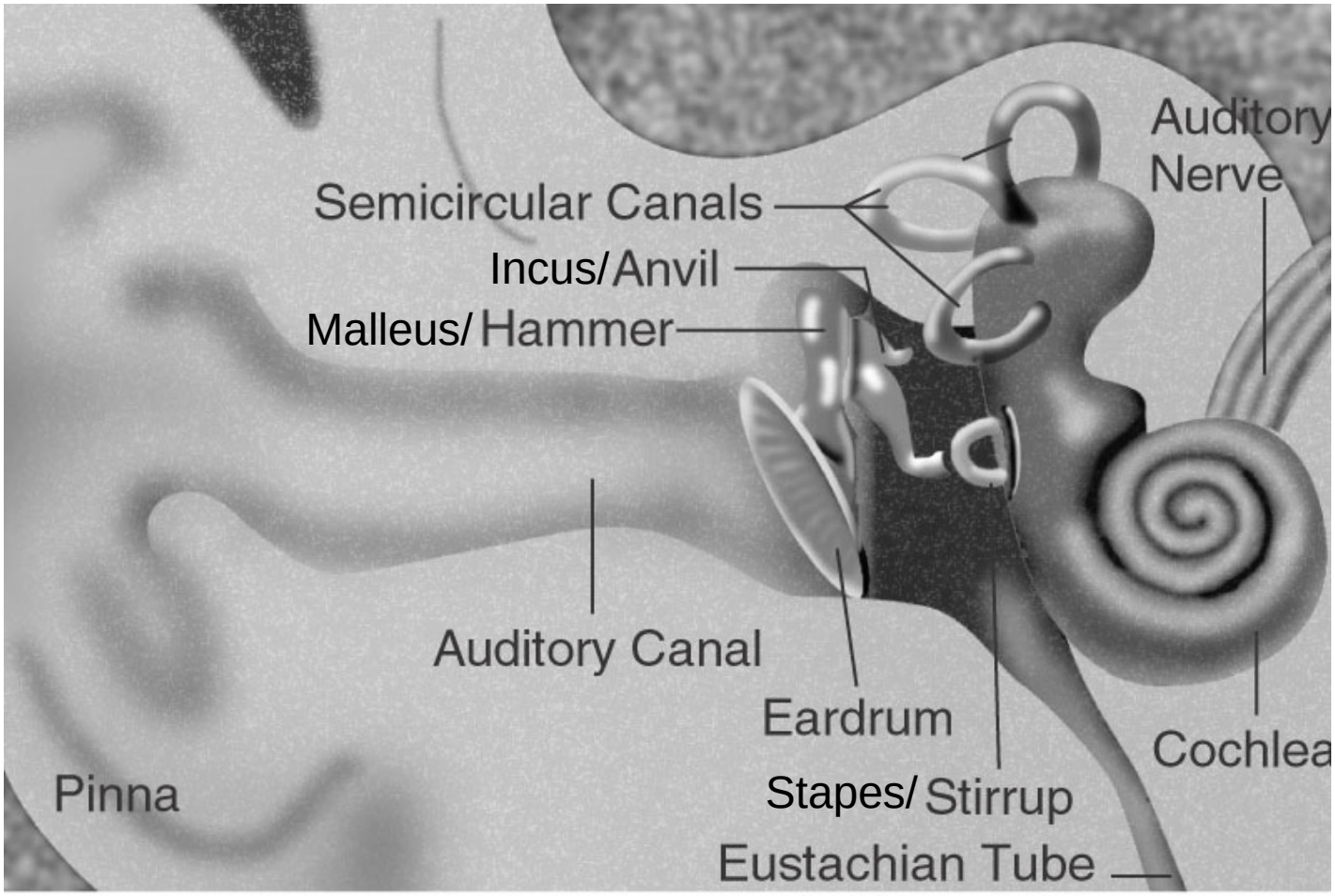


Vestibular Apparatus

Cochlea



Air
To
Fluid
(Impedance)



impedance matching

problem: inner ear is filled with fluid -

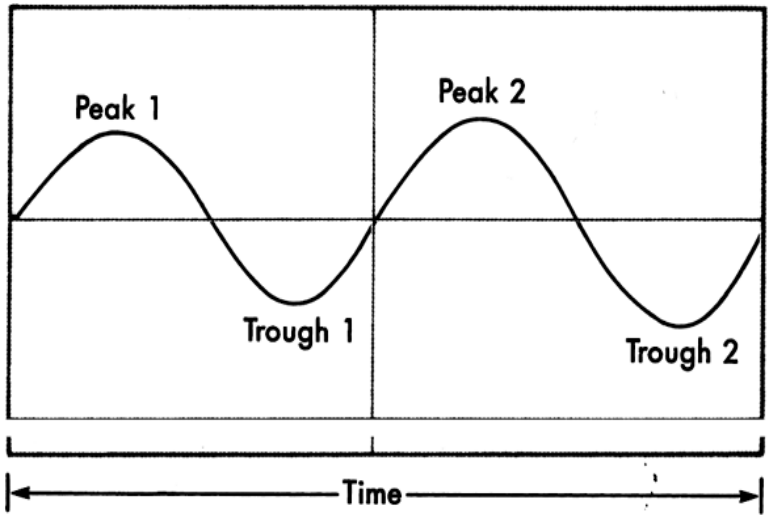
1) cannot be compressed;

2) reduction in energy of 30 dB

solution: (1) eardrum and window;

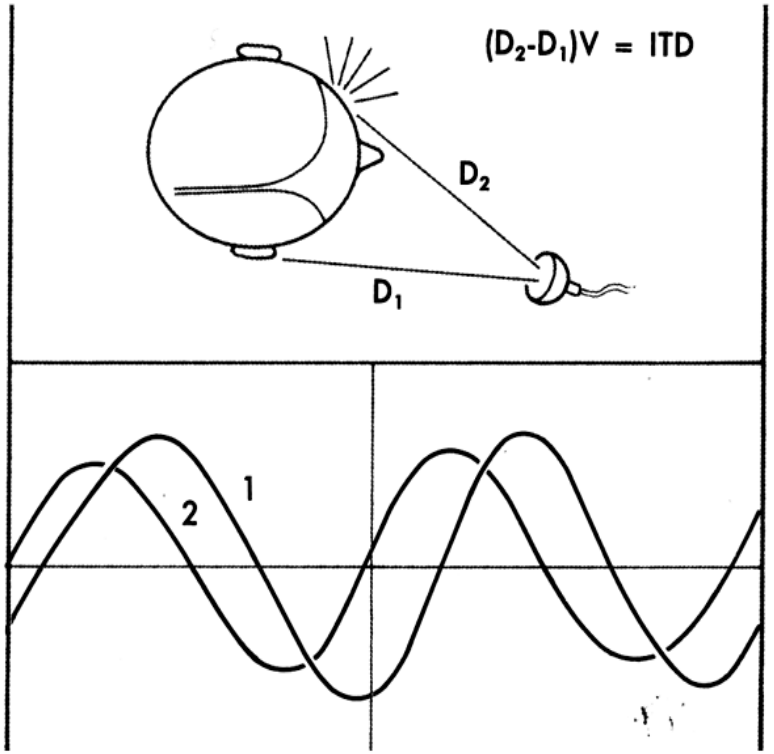
(2) lever action of ossicles

Amplitude
(Decibels)



(Hertz)

50 – 16,000 Hz
1000 – 3000 (optimal)
100 – 8000 (speech)

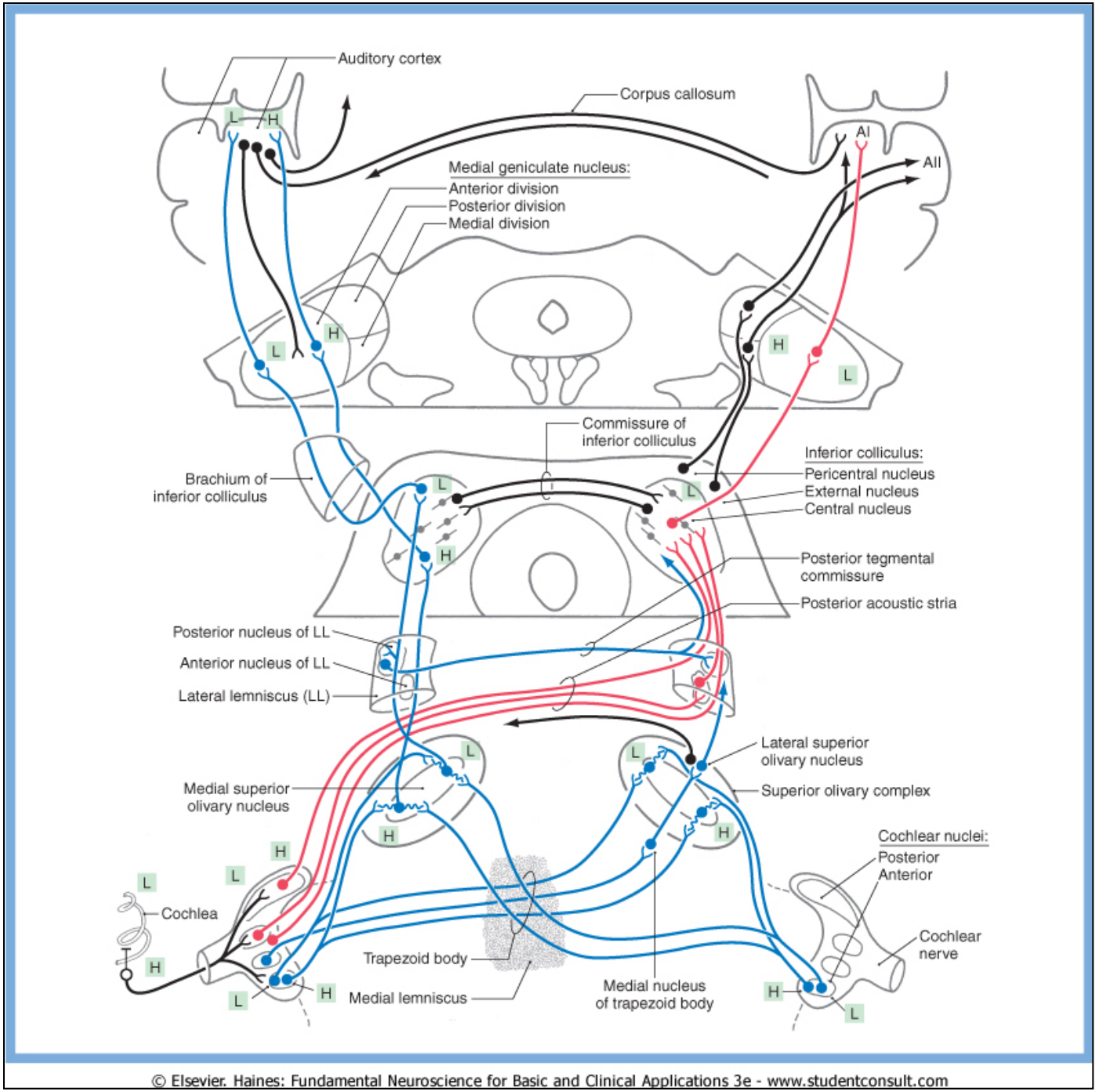


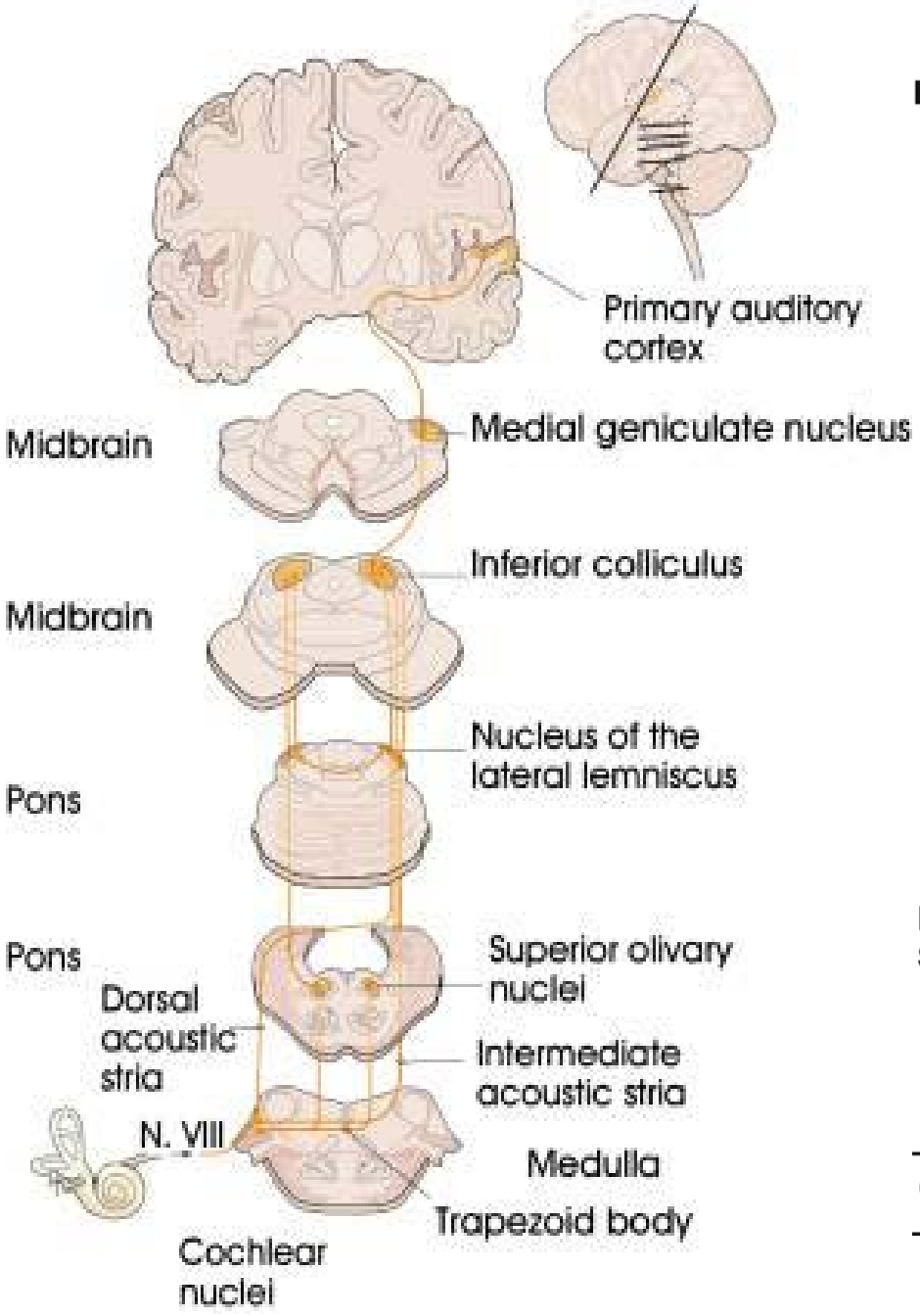
‘Interaural Distance’

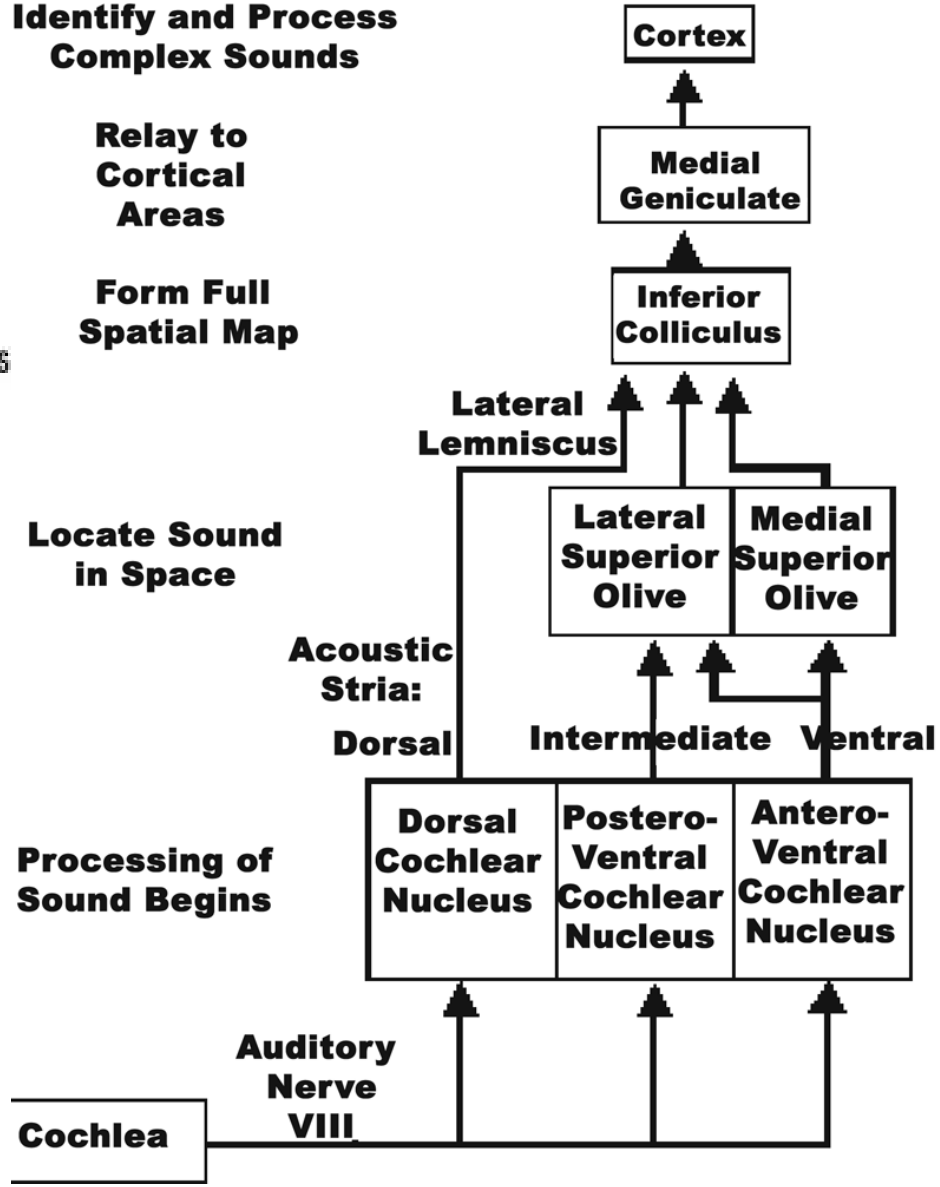
(mostly LOW Frequency)

General Plan

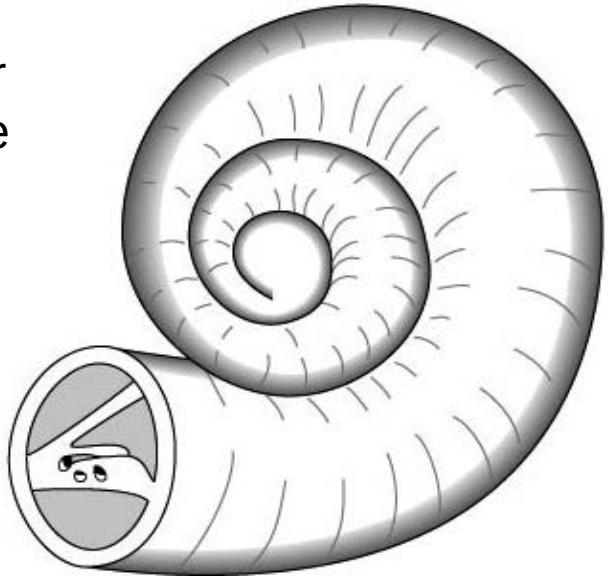
Timing
Processing
Commissures

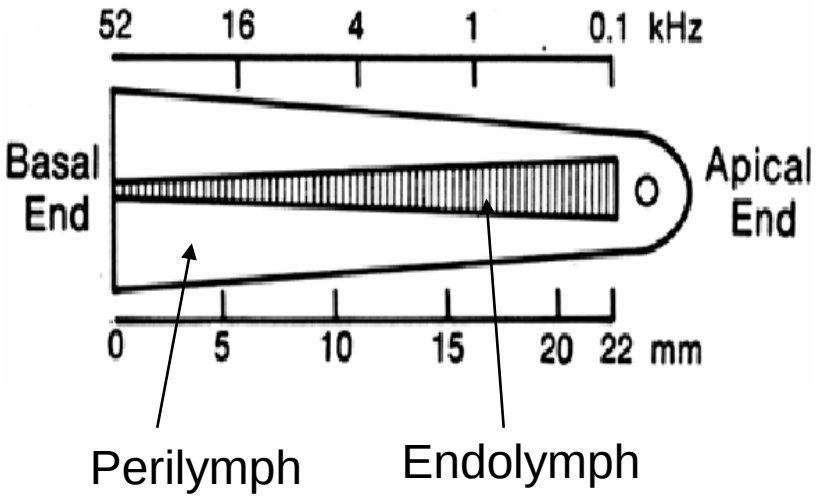


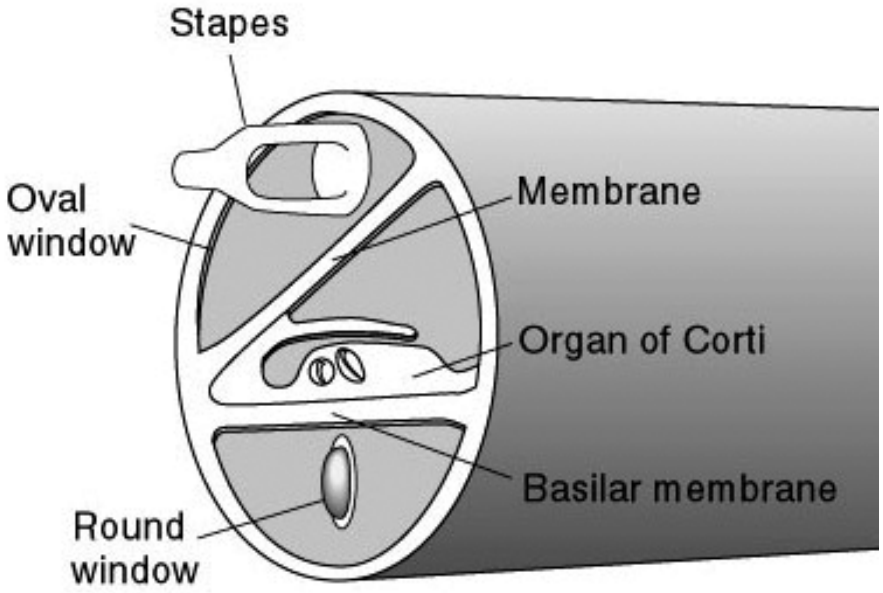

Primary auditory cortex
Midbrain
Medial geniculate nucleus
Midbrain
Inferior colliculus
Pons
Nucleus of the lateral lemniscus
Pons
Superior olivary nuclei
Dorsal acoustic stria
Intermediate acoustic stria
N. VIII
Medulla
Trapezoid body
Cochlear nuclei

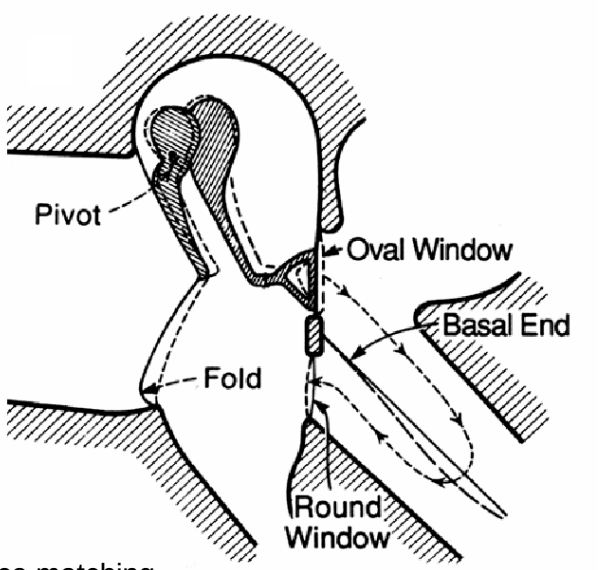

Identify and Process Complex Sounds
Relay to Cortical Areas
Form Full Spatial Map
Locate Sound in Space
Processing of Sound Begins
Cortex
Medial Geniculate
Inferior Colliculus
Lateral Lemniscus
Lateral Superior Olive
Medial Superior Olive
Acoustic Stria:
Dorsal
Intermediate
Ventral
Dorsal Cochlear Nucleus
Postero-Ventral Cochlear Nucleus
Antero-Ventral Cochlear Nucleus
Auditory Nerve VIII
Cochlea
YOU ARE HERE

Cochlear Structure







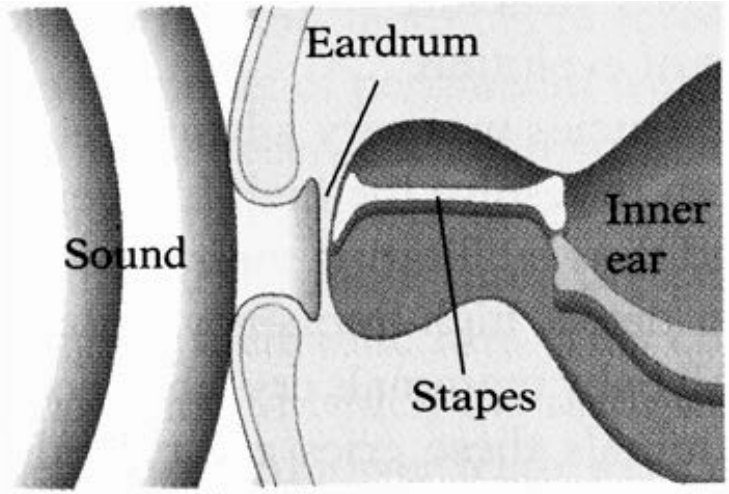


impedance matching

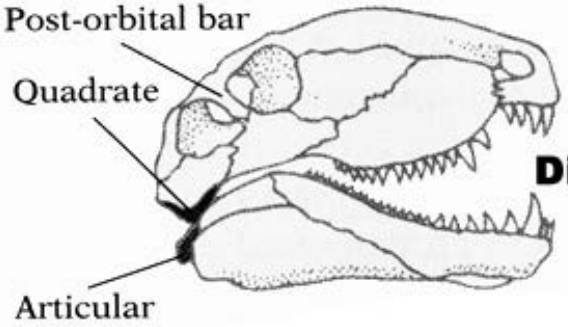
problem: inner ear is filled with fluid -
1) cannot be compressed;
2) reduction in energy of 30 dB

solution: (1) eardrum and window;
(2) lever action of ossicles

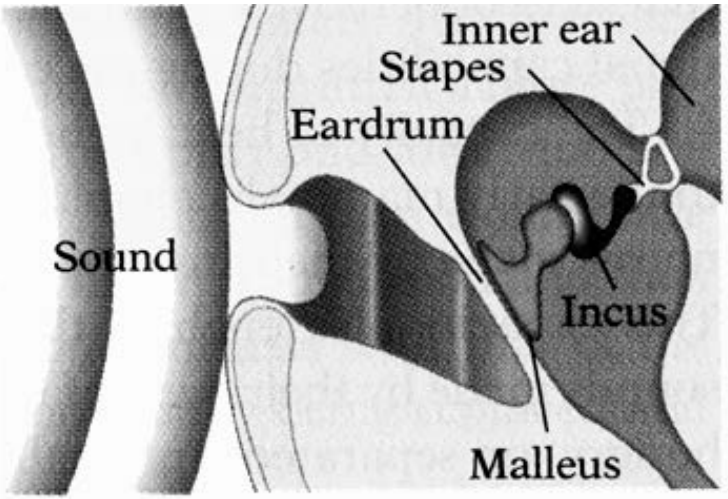
Future Dentist Alert!!!



Archosaur

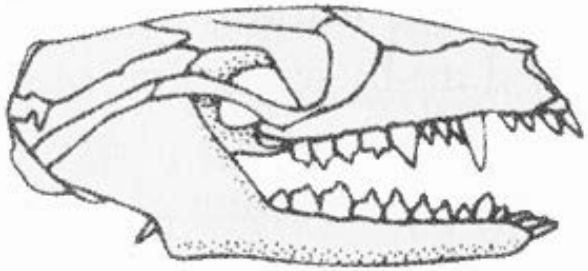


Dimetrodon

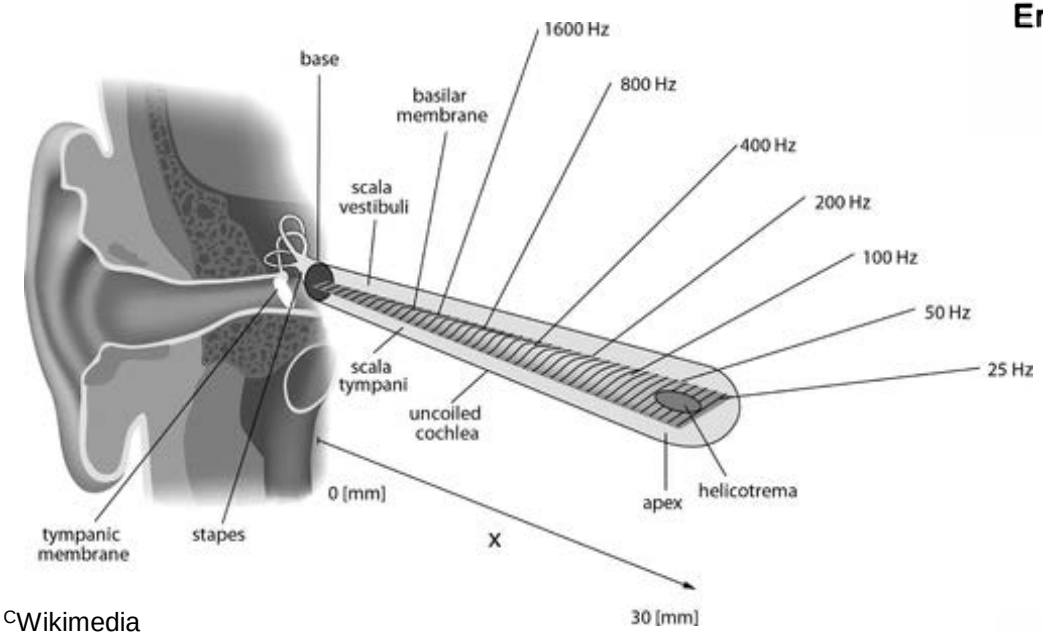


Mammal

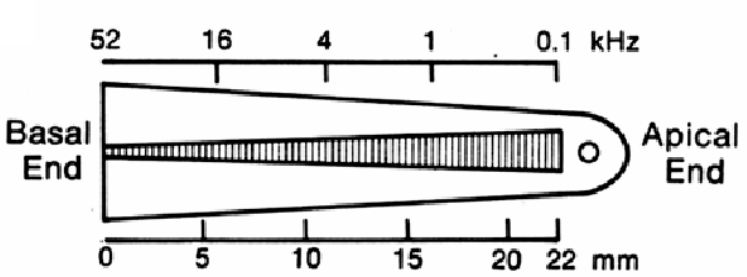
Early Mammal



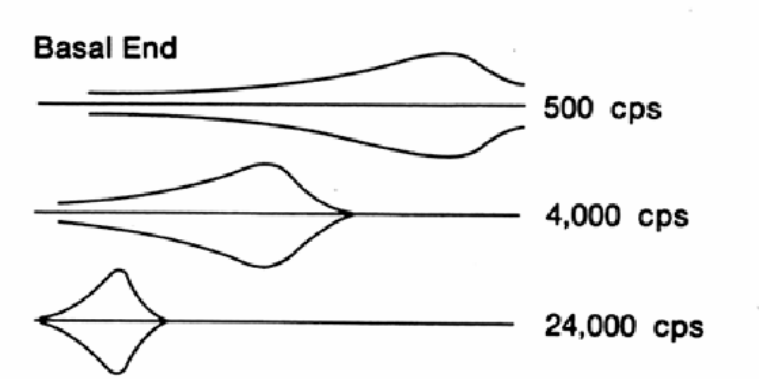
Tonotopic Organization

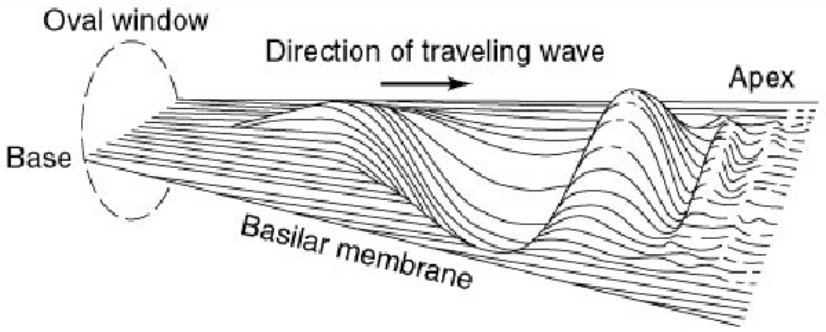


[C]Wikimedia



Narrow/Stiff Wide/Flexible





Form Versus Function

(Size vs Shape)

Standard fluid dynamics notation

In standard fluid dynamics notation:[1][2]

$$\Delta P = \frac{8\mu LQ}{\pi r^4}$$

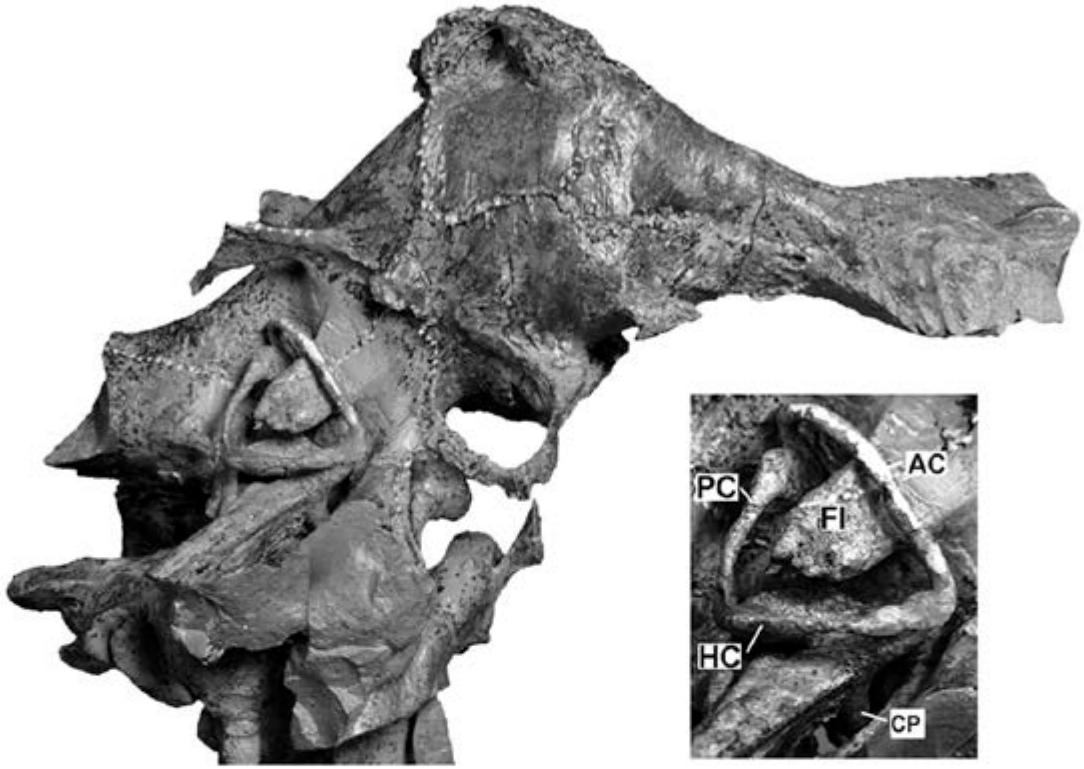
or

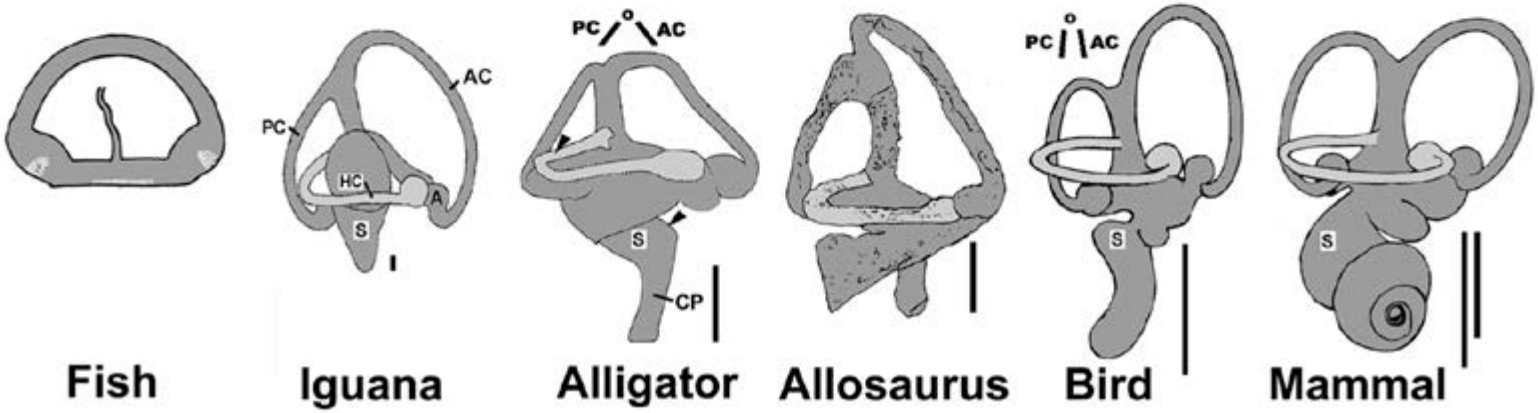
$$\Delta P = \frac{128\mu LQ}{\pi d^4}$$

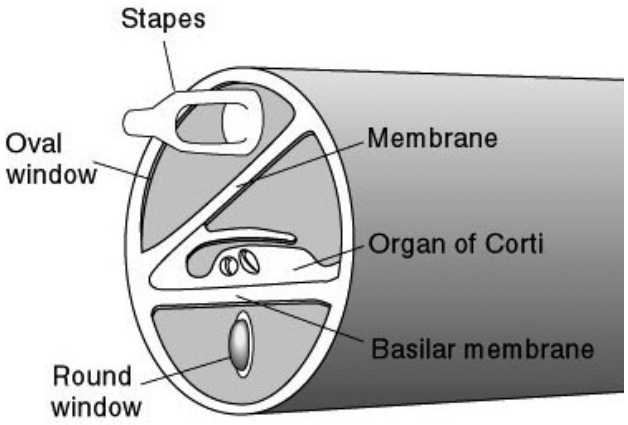
where:

- ΔP is the pressure drop
- L is the length of pipe
- μ is the dynamic viscosity
- Q is the volumetric flow rate
- r is the radius
- d is the diameter
- π is the mathematical constant Pi

Not just a good idea, it's the law!



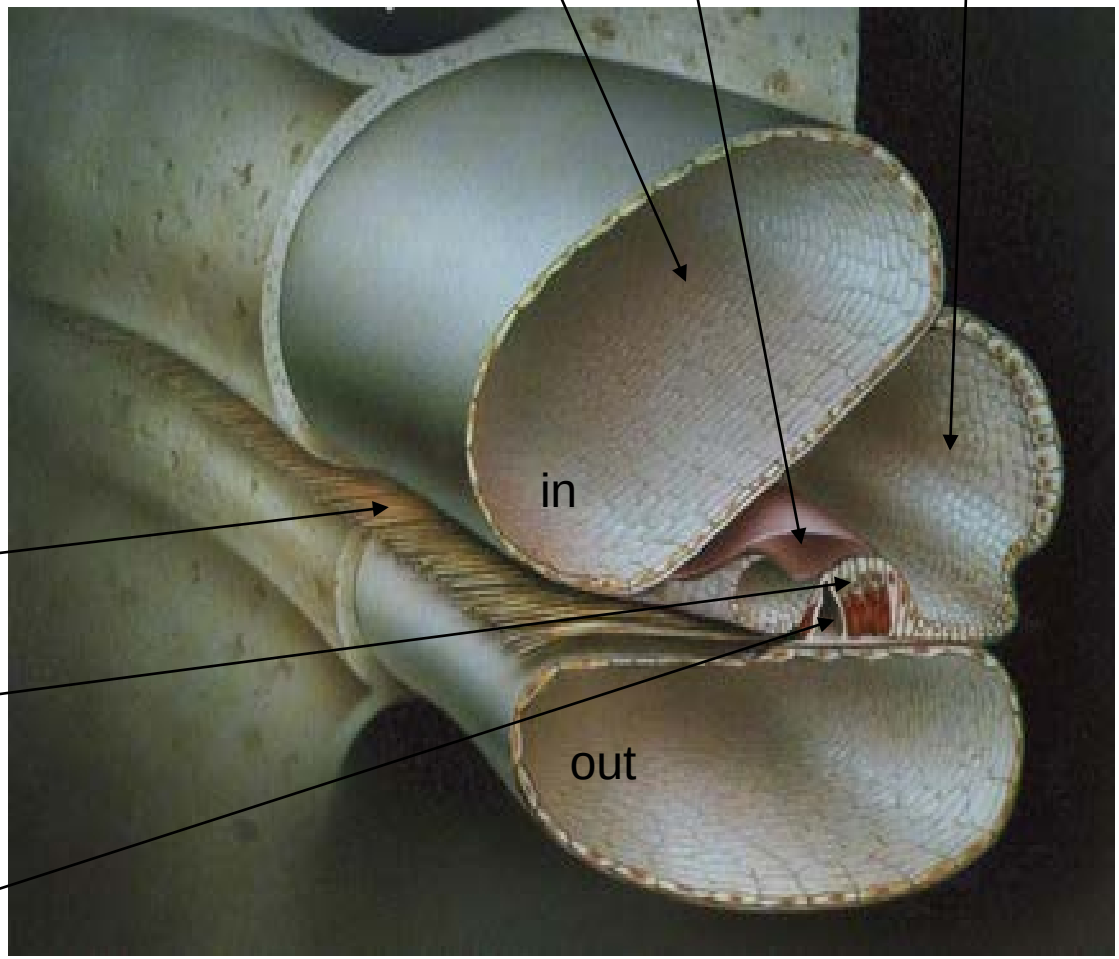




Tectorial Membrane

Scala vestibuli
Perilymph

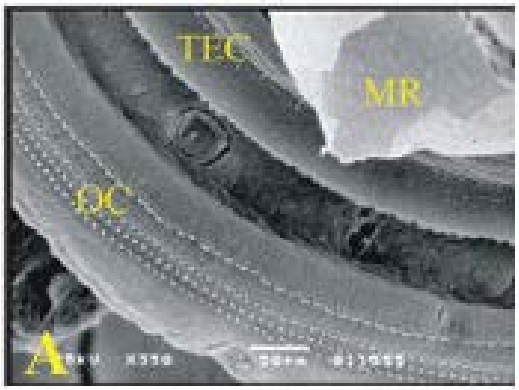
Cochlear duct
Endolymph

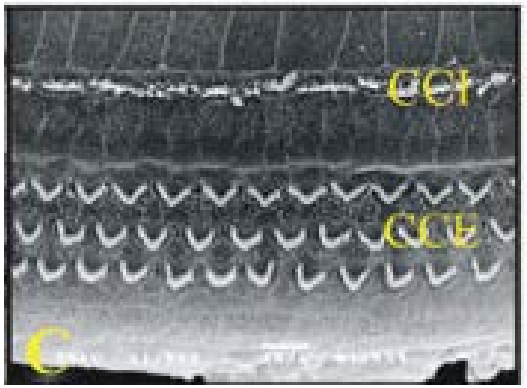


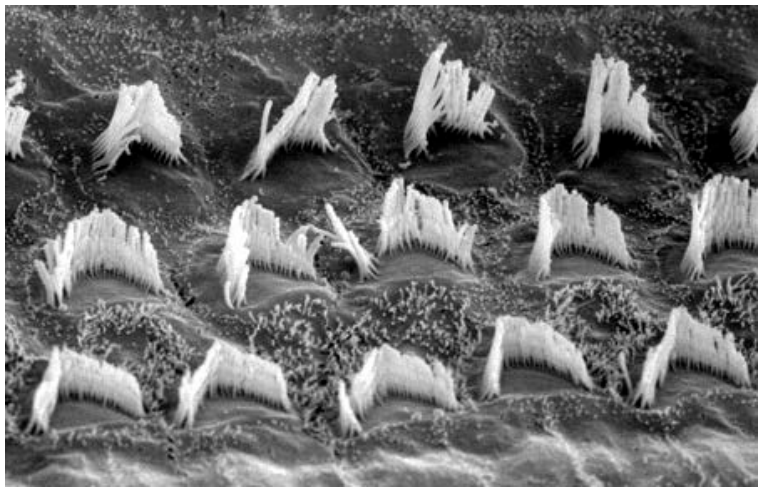
Efferents/Afferents

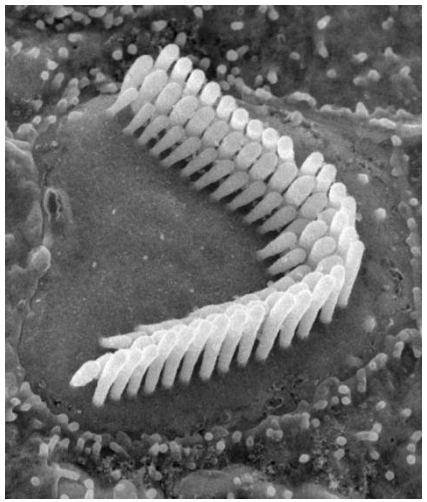
Organ of Corti
(Specialized sensory epithelium)

Tunnel of Corti

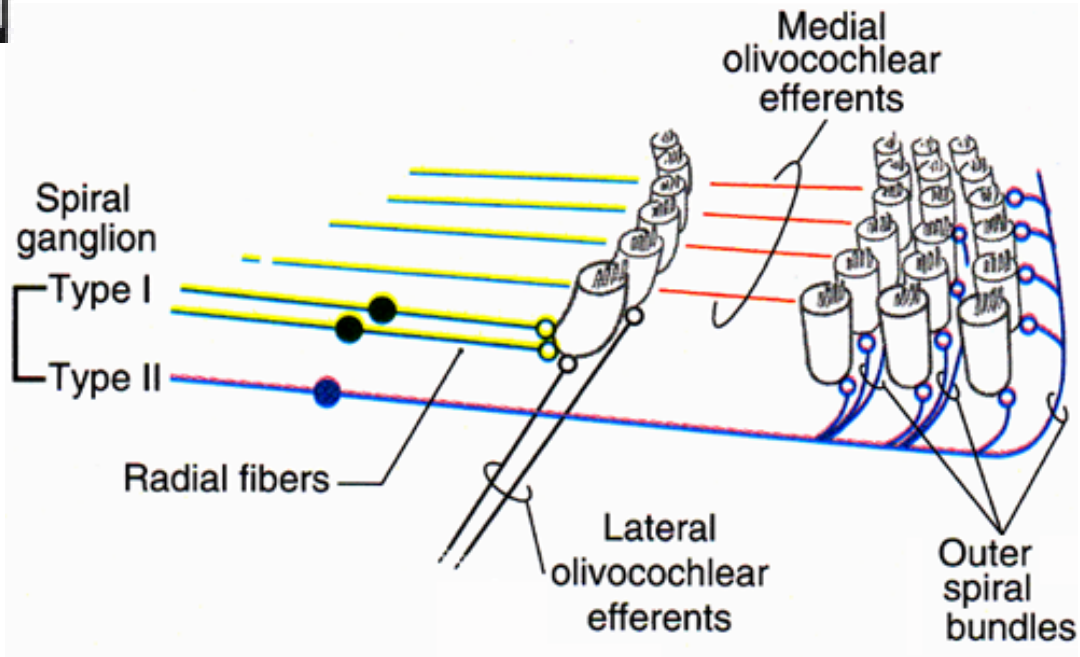


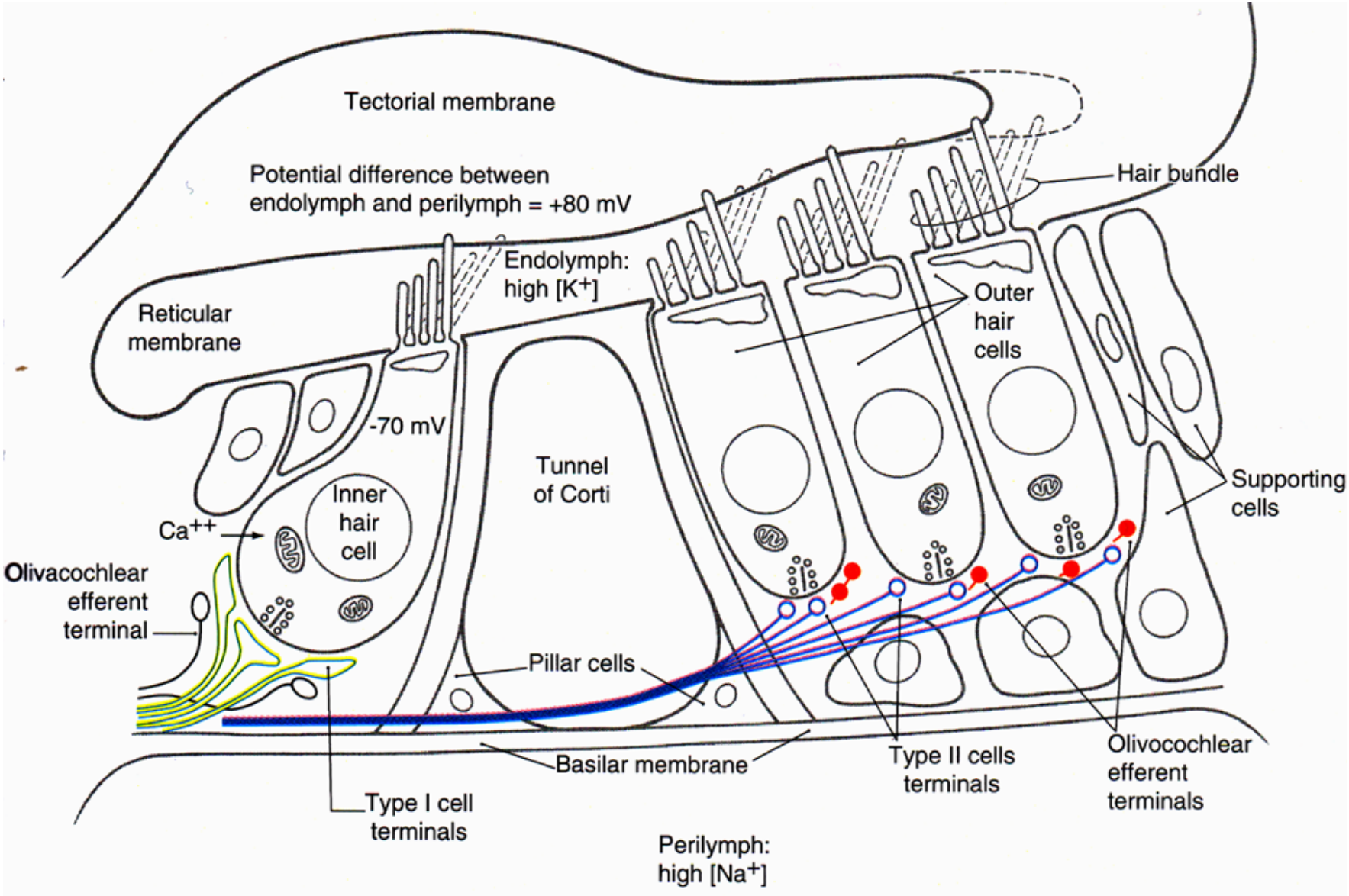




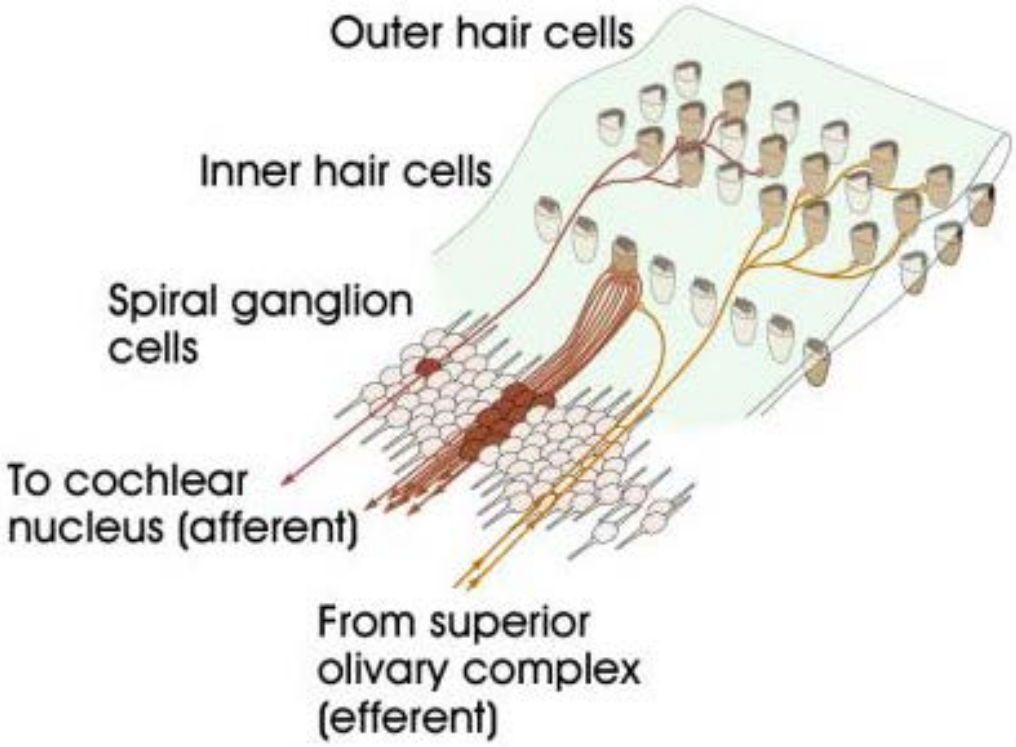


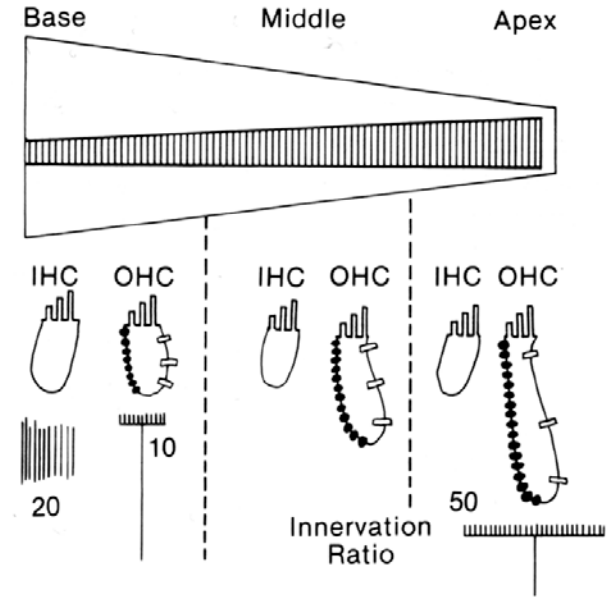
Brazil J. Otorohinolary. 75:2009




Tectorial membrane
Potential difference between endolymph and perilymph = +80 mV
Hair bundle
Endolymph: high [K+]
Reticular membrane
Outer hair cells
-70 mV
Tunnel of Corti
Supporting cells
Inner hair cell
Ca++
Olivacochlear efferent terminal
Pillar cells
Basilar membrane
Type II cells terminals
Olivocochlear efferent terminals
Type I cell terminals
Perilymph: high [Na+]

Sensory Innervation and Scaling





	OHC		
Input Conductance (G_N)	50 ns		10 ns
Time Constant (τ)	200 μs		1 ms
Channel Density	60 μm^{-2}		6 μm^{-2}
Gating Charge Density	5000 μm^{-2}		5000 μm^{-2}
Innervation Ratio	10		50
Cell Length	30 μm	50 μm	70 μm

Phase Locking

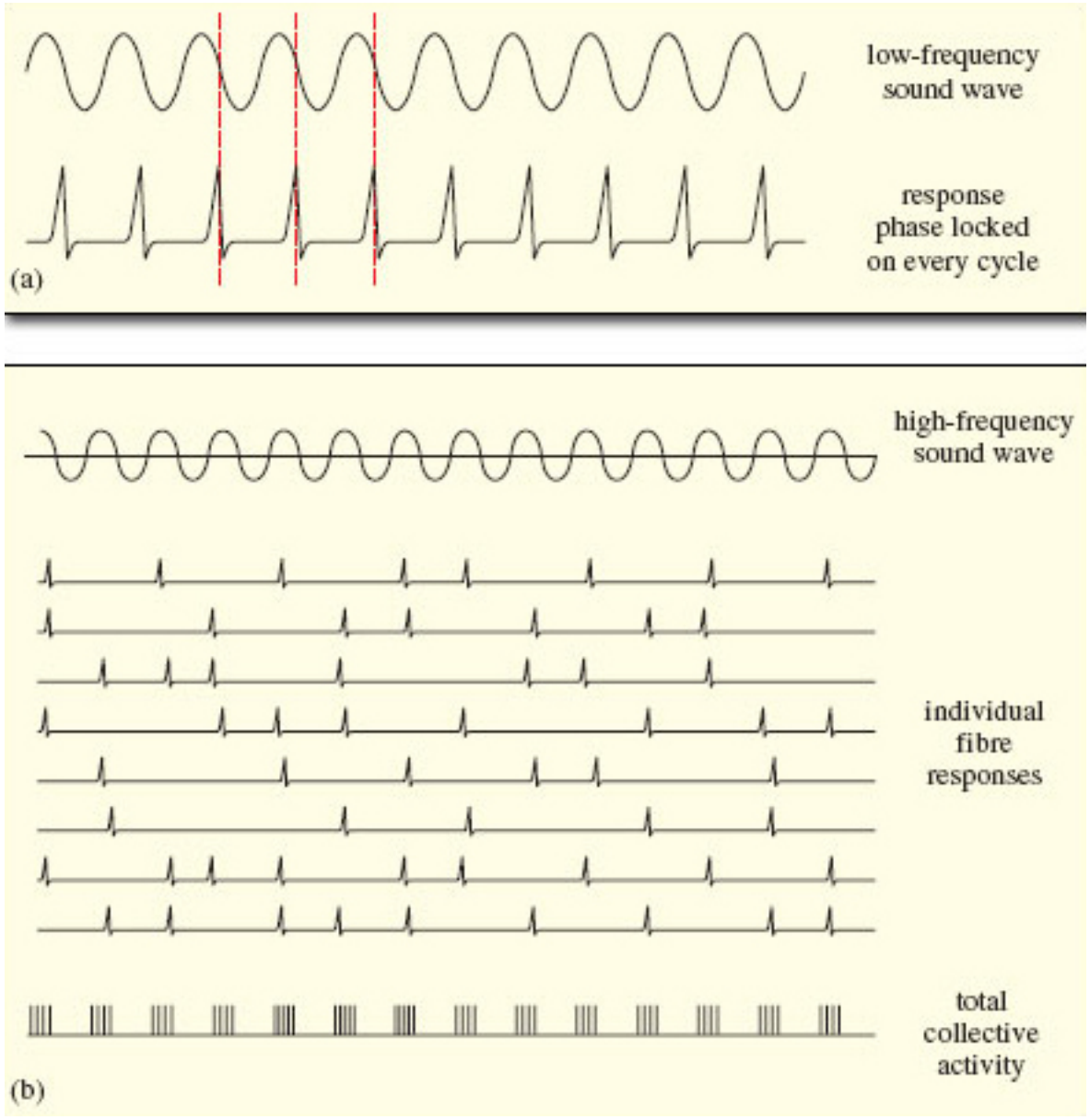
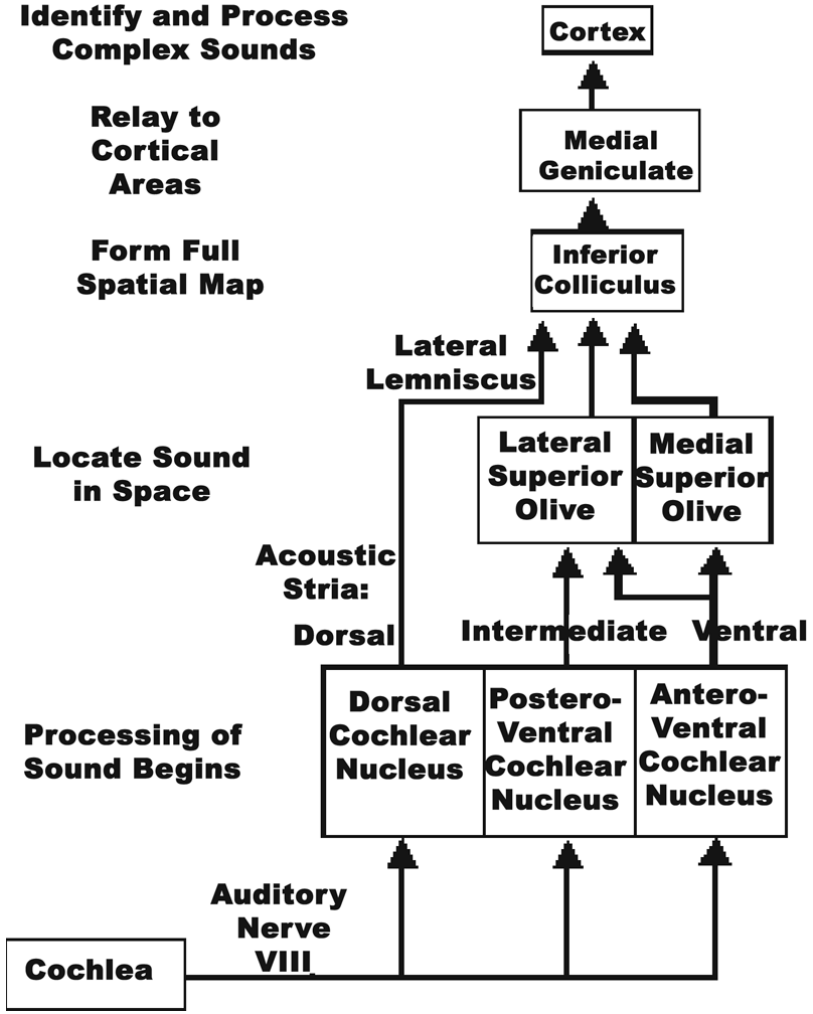


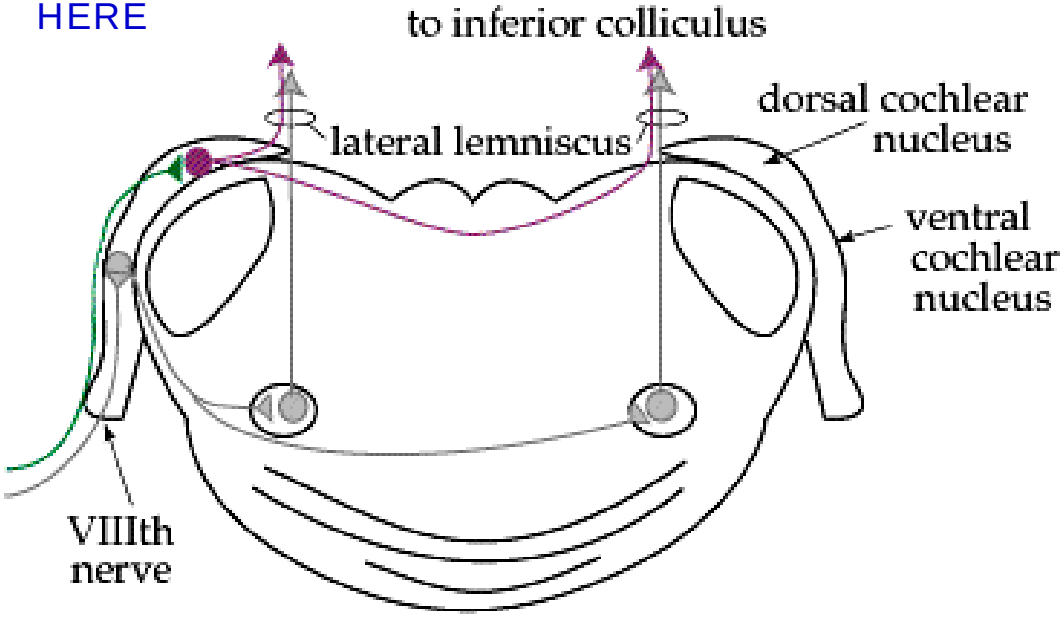
Figure 24 Phase locking. (a) The neuron is phase locked to the same point in every cycle of the pure tone stimulus. (b) The volley principle. The ensemble of fibre responses shown at the bottom of the figure has a pattern of firing that corresponds to the frequency of the input sound wave

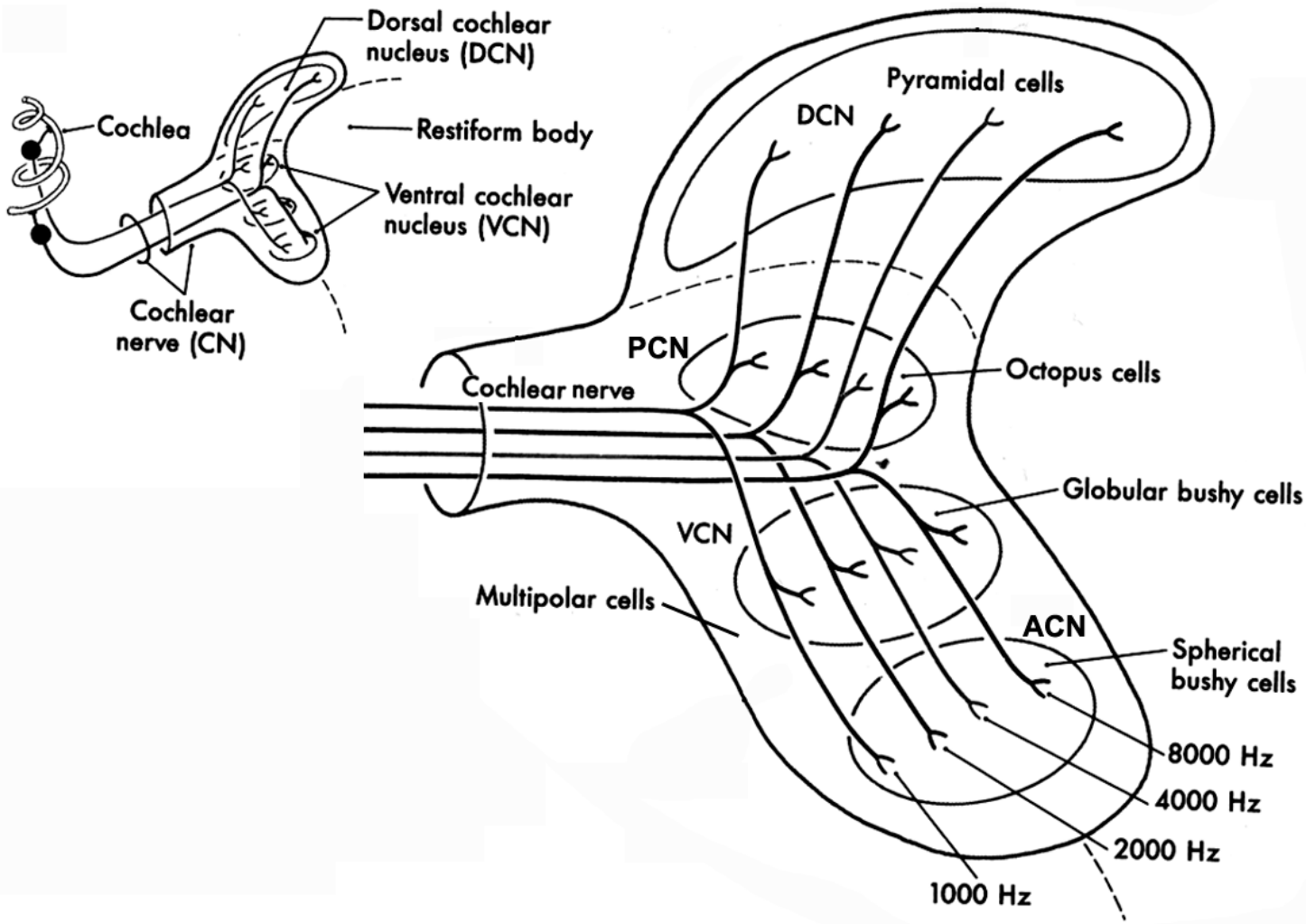
Long description

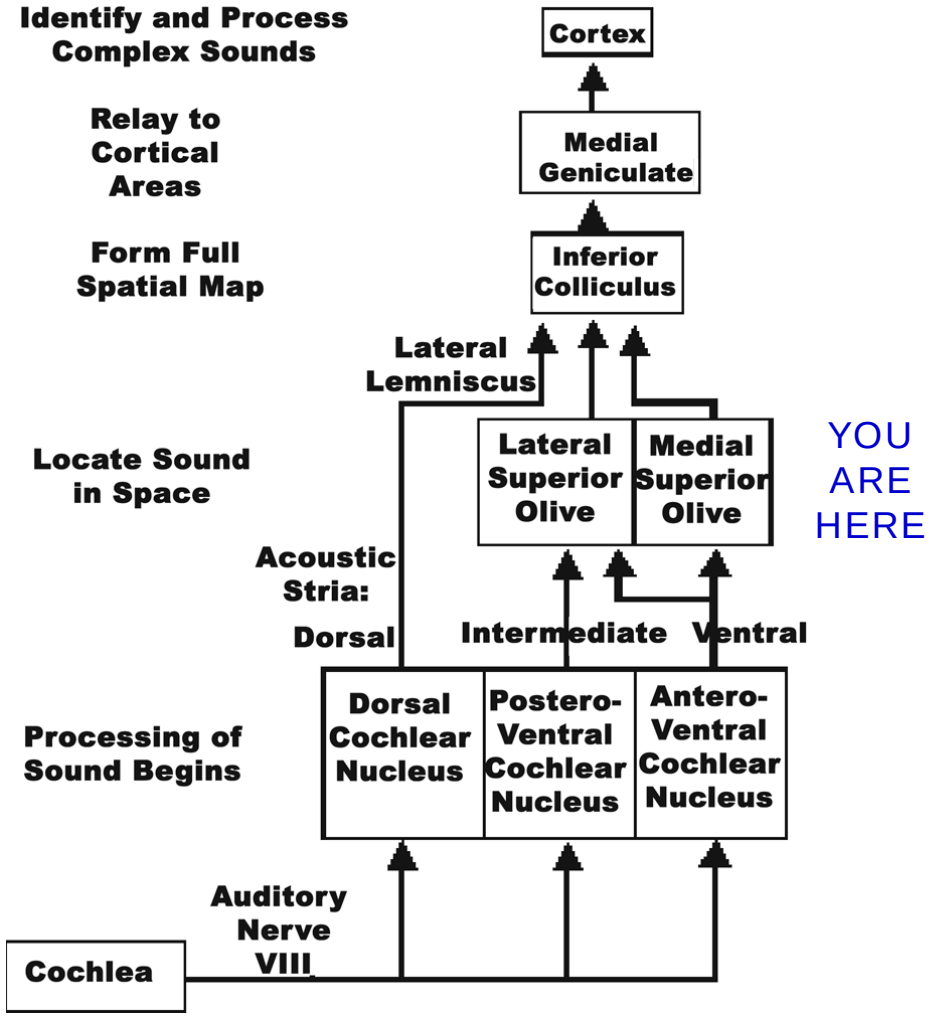
openlearn.open.ac.uk/mod/oucontent/view.php?id=398672&section=5.2


Identify and Process Complex Sounds
Cortex
Relay to Cortical Areas
Medial Geniculate
Form Full Spatial Map
Inferior Colliculus
Lateral Lemniscus
Locate Sound in Space
Lateral Superior Olive
Medial Superior Olive
Acoustic Stria:
Dorsal
Intermediate
Ventral
Processing of Sound Begins
Dorsal Cochlear Nucleus
Postero-Ventral Cochlear Nucleus
Antero-Ventral Cochlear Nucleus
Auditory Nerve VIII
Cochlea

YOU ARE HERE


to inferior colliculus
lateral lemniscus
dorsal cochlear nucleus
ventral cochlear nucleus
VIIIth nerve


Dorsal cochlear nucleus (DCN)
Cochlea
Restiform body
Ventral cochlear nucleus (VCN)
Cochlear nerve (CN)
Pyramidal cells
DCN
PCN
Cochlear nerve
Octopus cells
Globular bushy cells
VCN
Multipolar cells
ACN
Spherical bushy cells
8000 Hz
4000 Hz
2000 Hz
1000 Hz


Identify and Process Complex Sounds
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Inferior Colliculus
Lateral Lemniscus
Locate Sound in Space
Lateral Superior Olive
Medial Superior Olive
YOU ARE HERE
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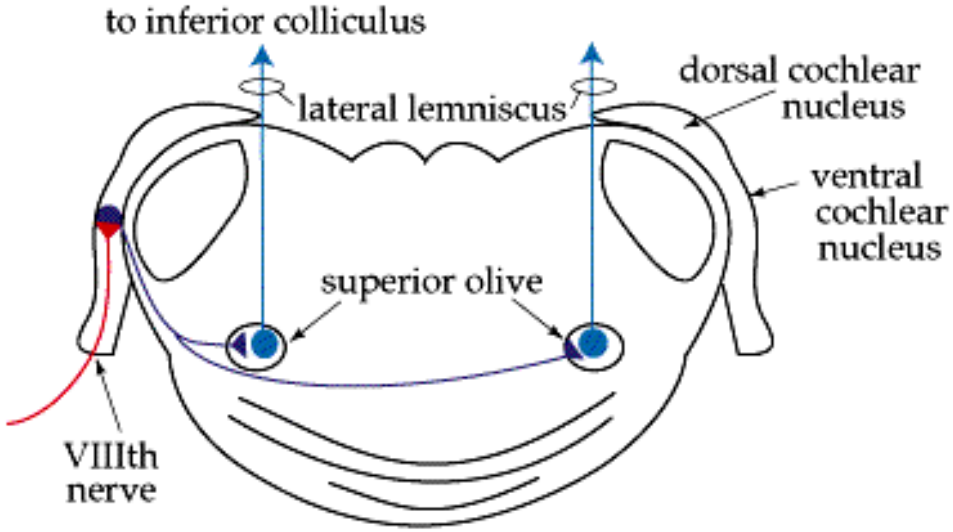
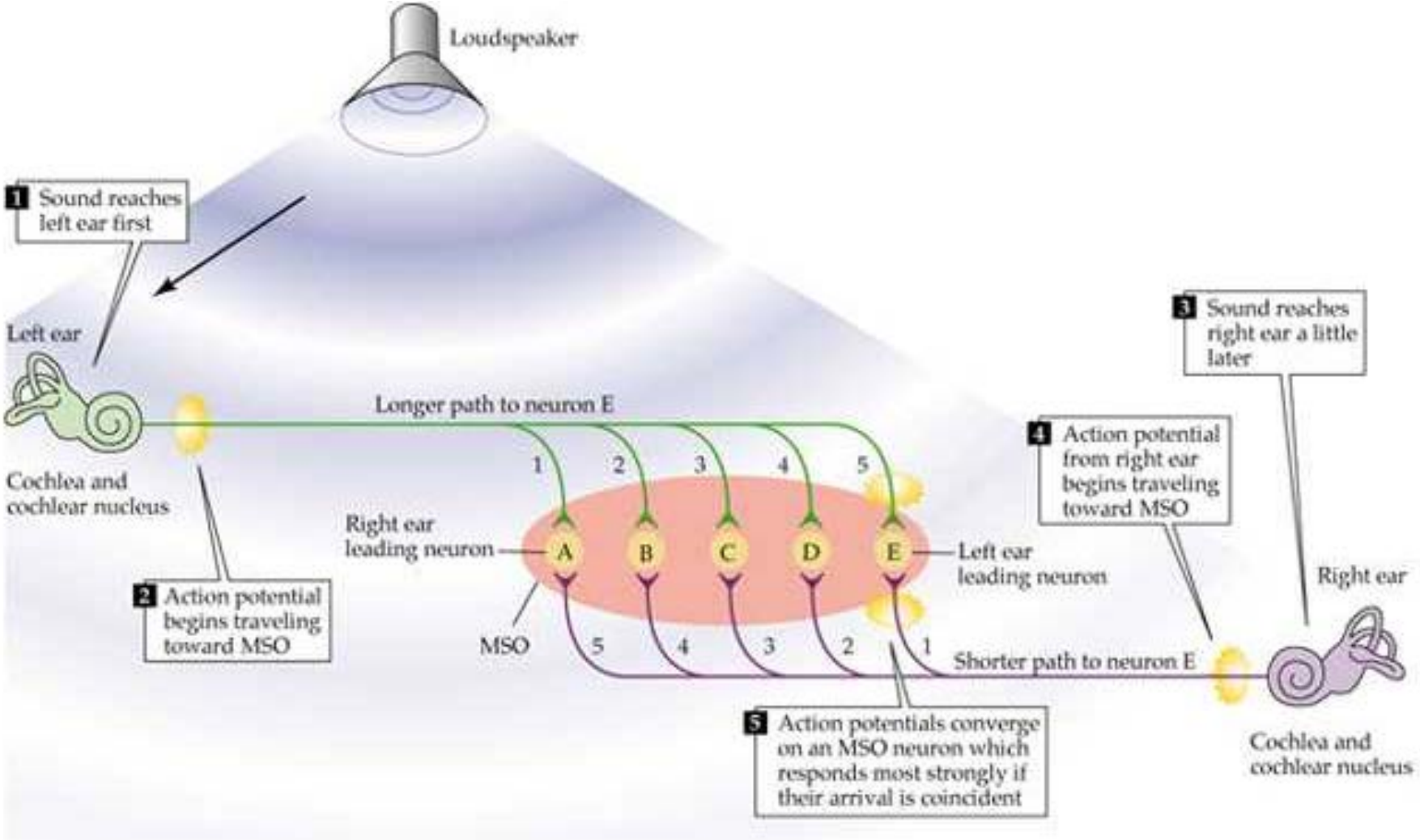
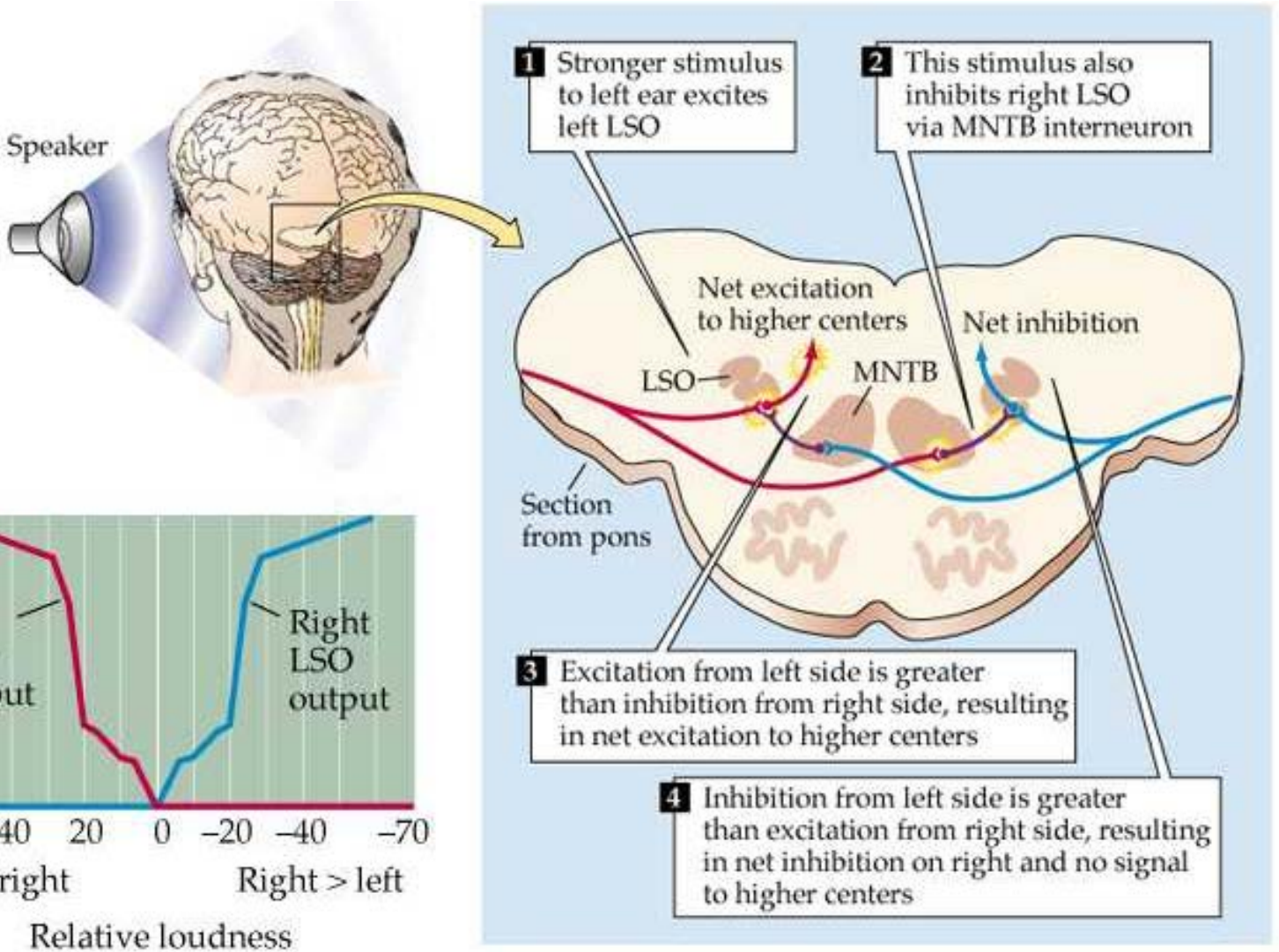
Intermediate
Ventral
Processing of Sound Begins
Dorsal Cochlear Nucleus
Postero-Ventral Cochlear Nucleus
Antero-Ventral Cochlear Nucleus
Auditory Nerve VIII
Cochlea

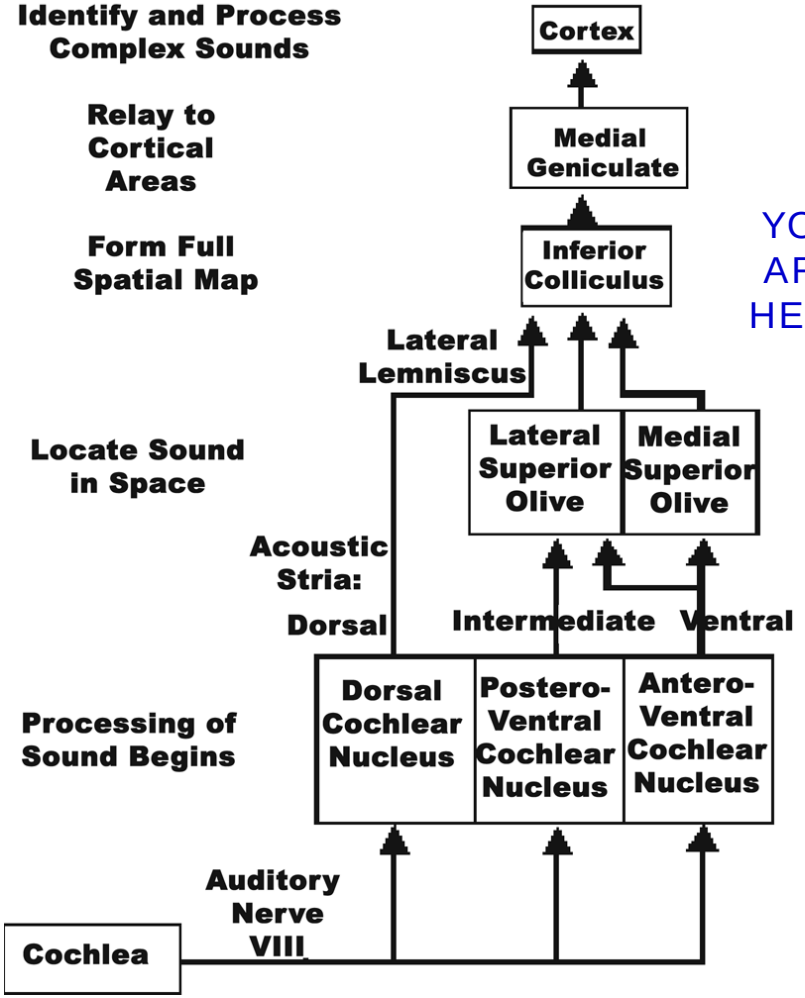

to inferior colliculus
lateral lemniscus
dorsal cochlear nucleus
ventral cochlear nucleus
superior olive
VIIIth nerve

Medial Superior Olive (Timing)



Lateral Superior Olive (Intensity)




Identify and Process Complex Sounds
Cortex
Relay to Cortical Areas
Medial Geniculate
Form Full Spatial Map
Inferior Colliculus
YOU ARE HERE
Lateral Lemniscus
Locate Sound in Space
Lateral Superior Olive
Medial Superior Olive
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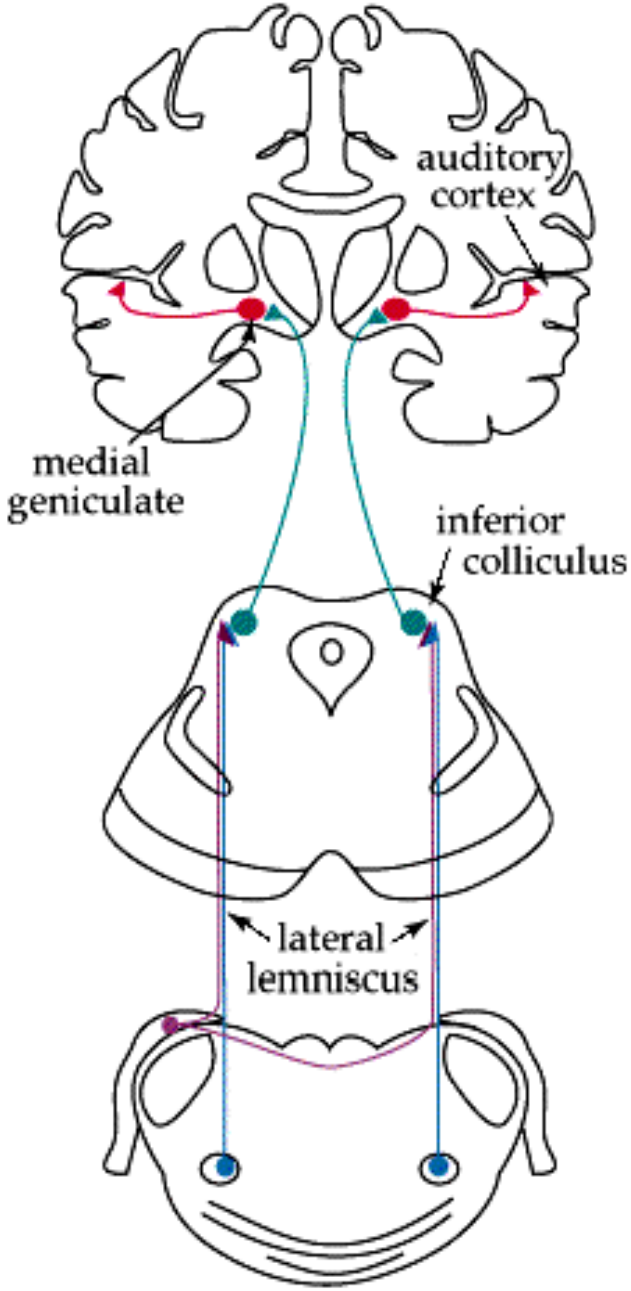
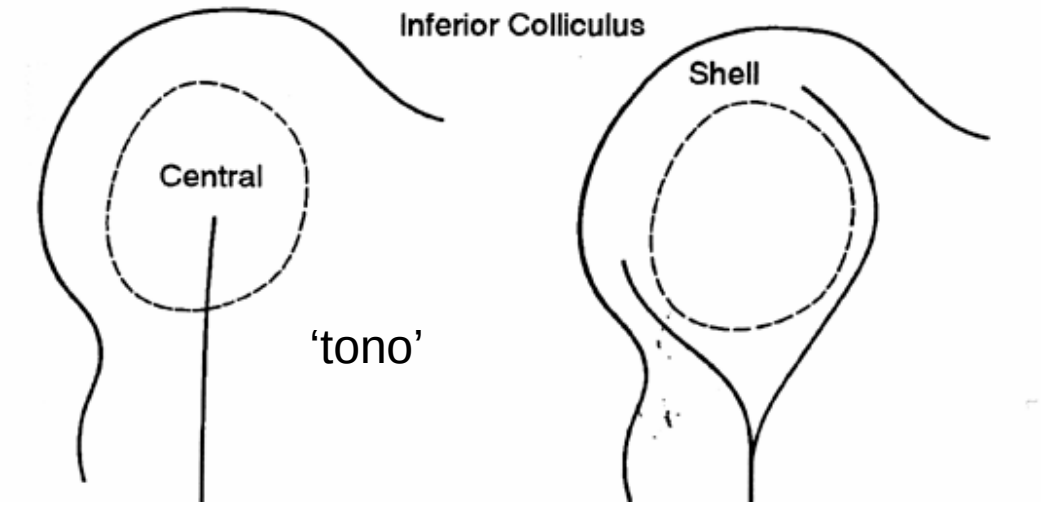
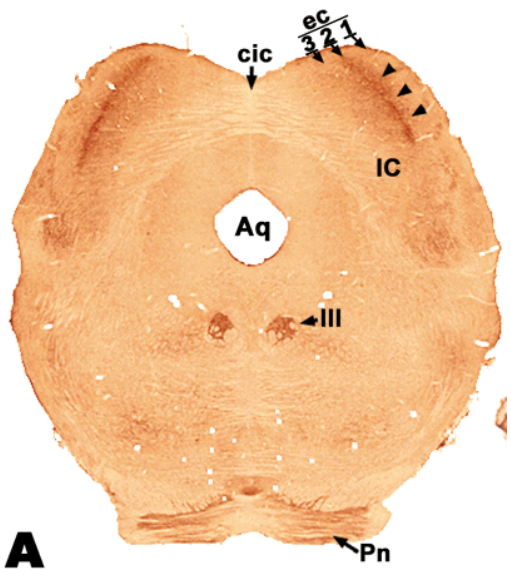
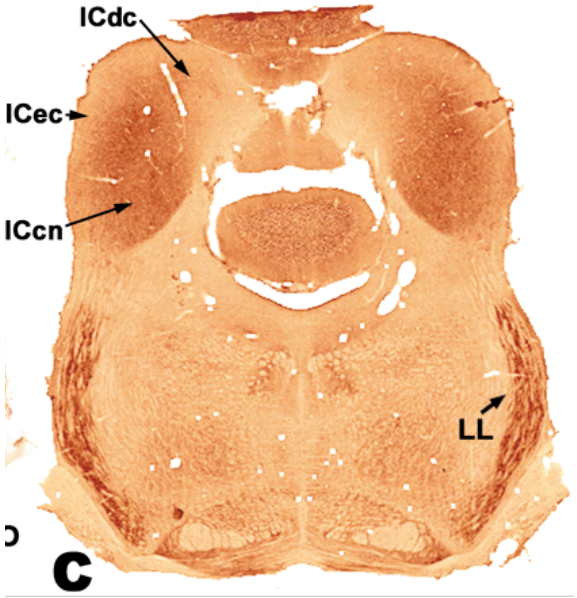
Antero-Ventral Cochlear Nucleus
Auditory Nerve VIII
Cochlea


auditory cortex
medial geniculate
inferior colliculus
lateral lemniscus







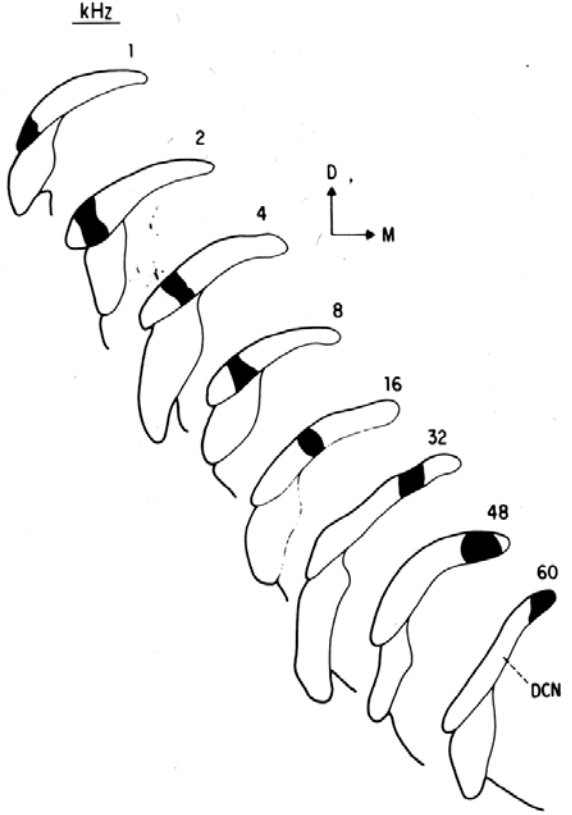
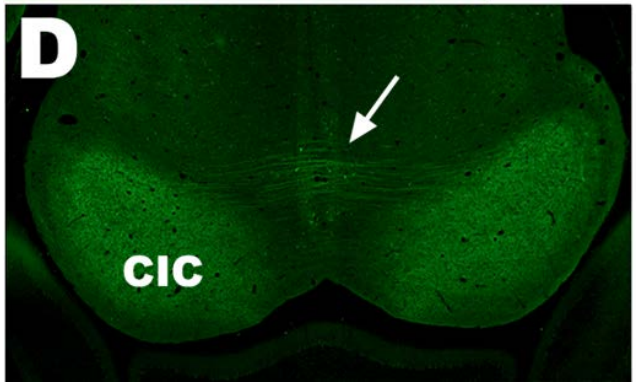
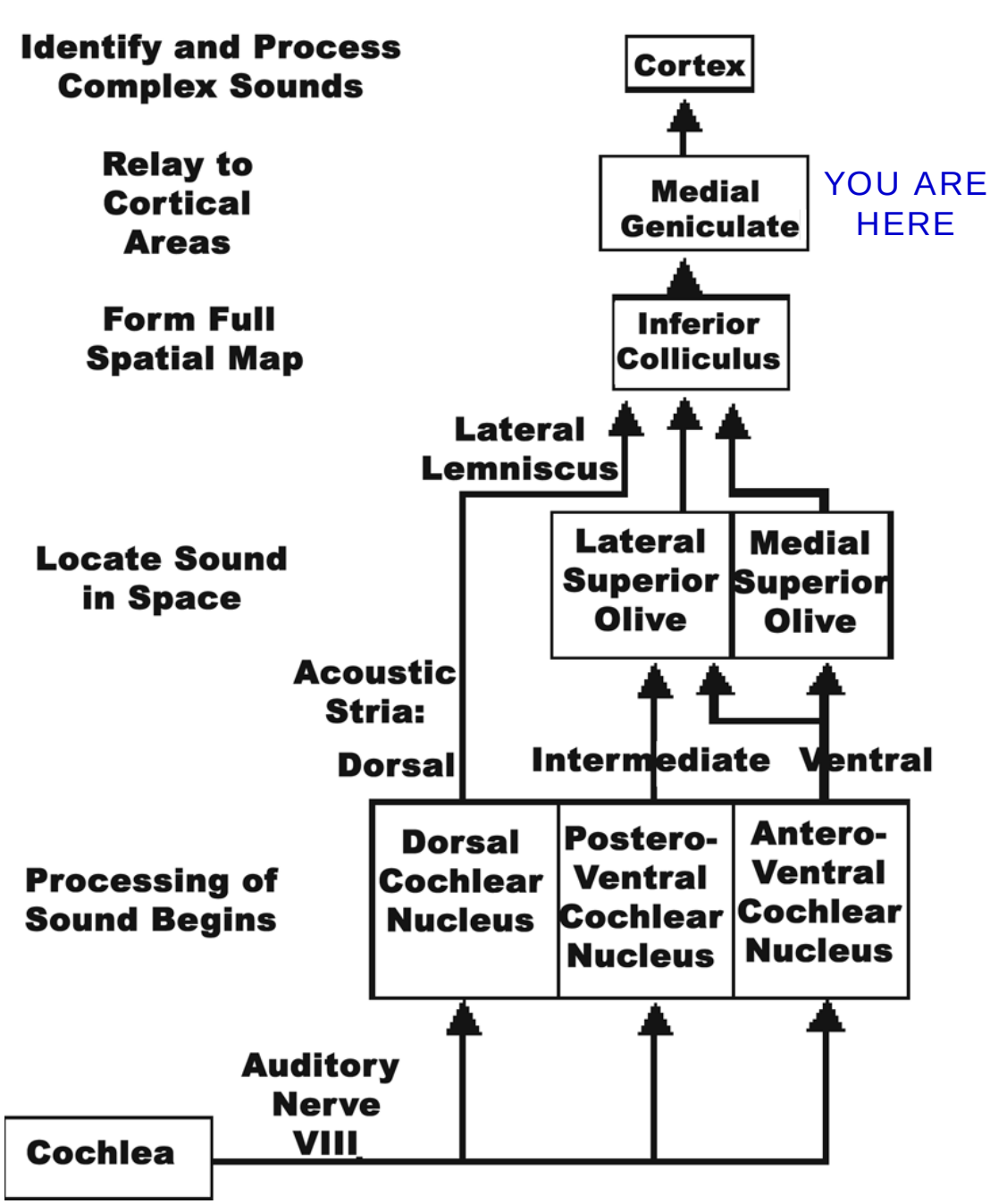


Figure 5 Camera lucida drawings illustrating the pattern of 2-DG uptake observed for the DCN at the A–P one-half location for pure tones in the range of reported single-unit CFs for the rat (Ryan *et al.*, 1988).




Identify and Process Complex Sounds
Cortex
Relay to Cortical Areas
Medial Geniculate
YOU ARE HERE
Form Full Spatial Map
Inferior Colliculus
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Locate Sound in Space
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Dorsal Cochlear Nucleus
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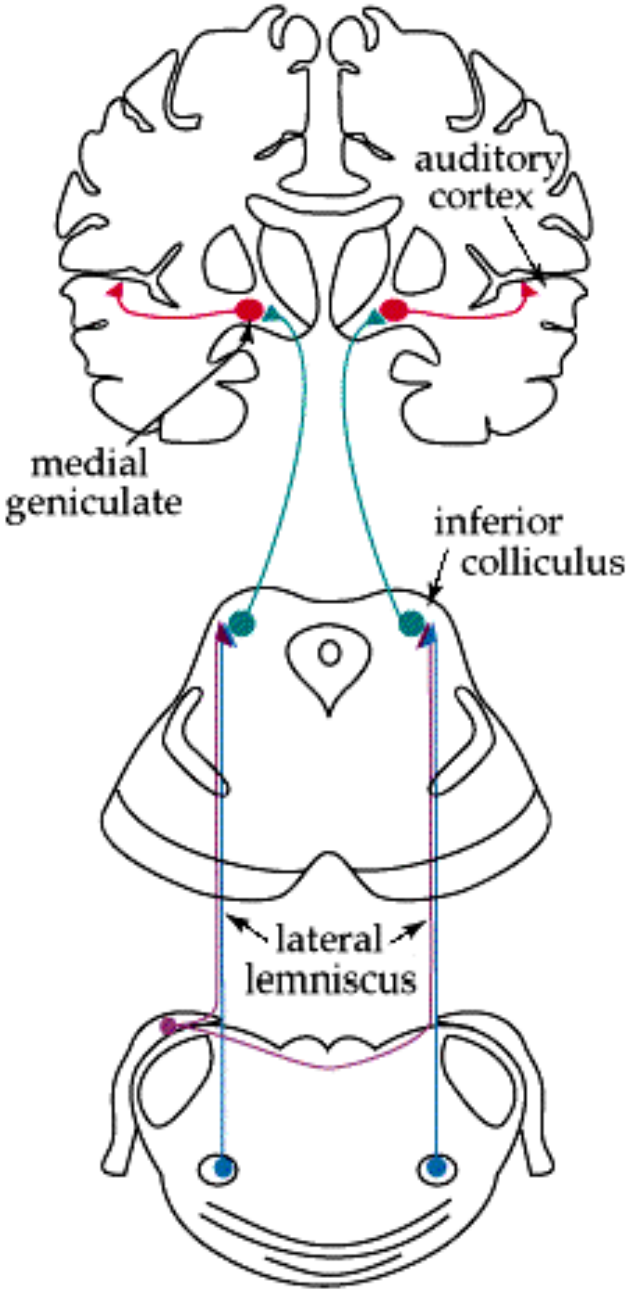
Antero-Ventral Cochlear Nucleus
Auditory Nerve VIII
Cochlea


auditory cortex
medial geniculate
inferior colliculus
lateral lemniscus

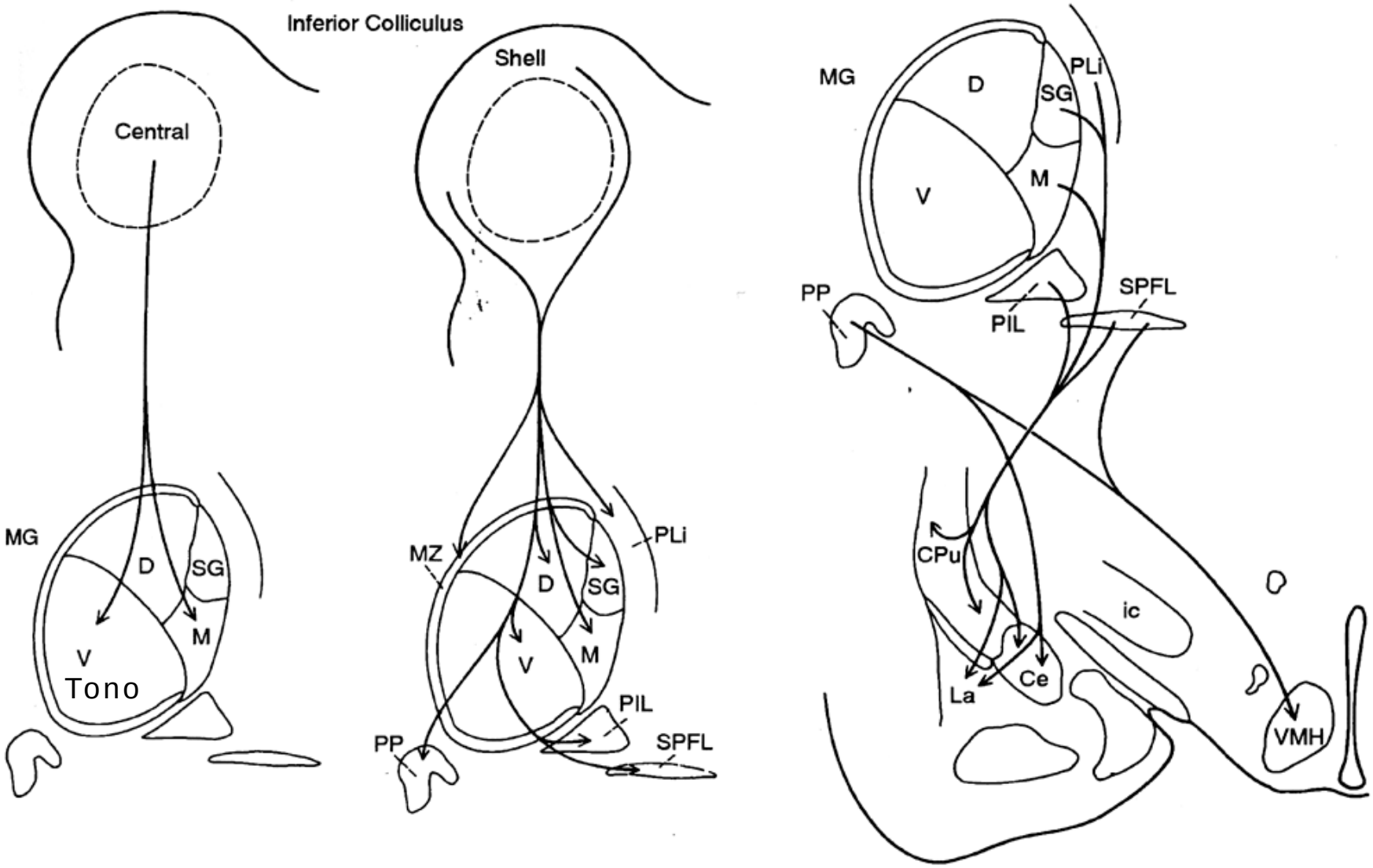
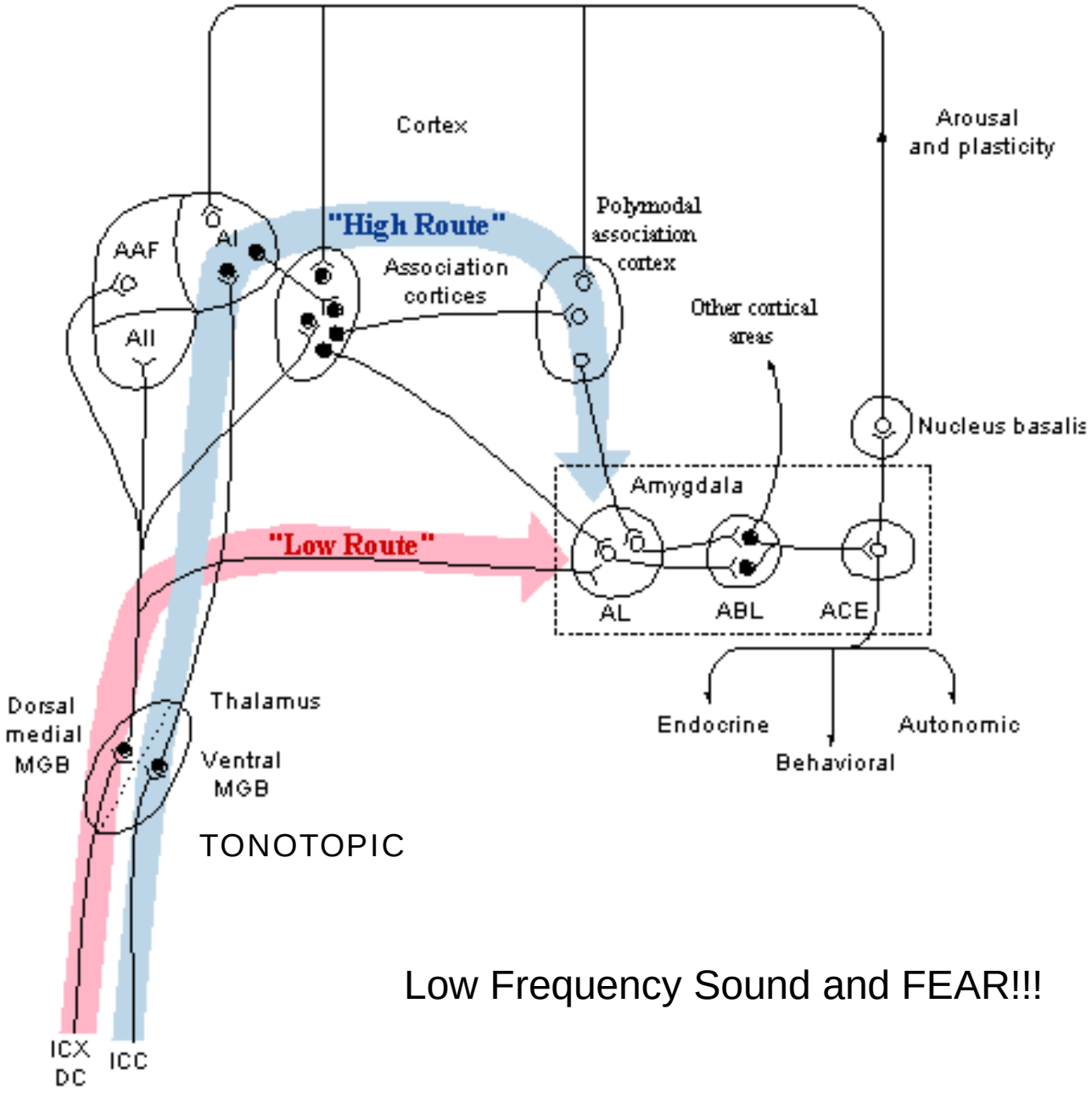
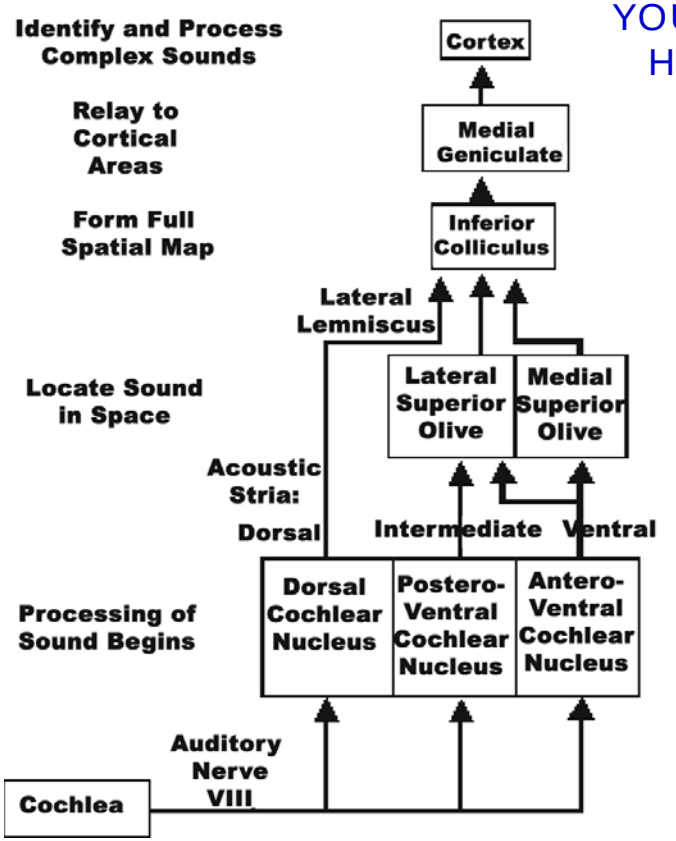


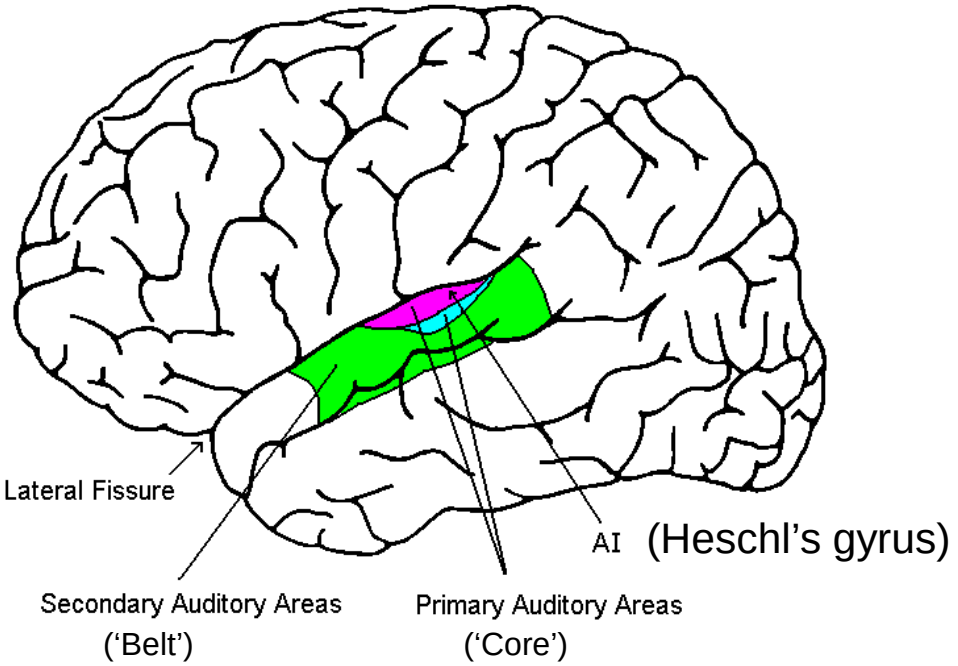
Figure 4 Diagram of the input to the MG complex from the shell and central core of the inferior colliculus (on the left) and of outputs from the "intralaminar-like" nuclei medial to MG at that end in the caudal part of CPu and in the amygdala. Note that the central core of the inferior colliculus projects primarily to MGV, whereas the shell projects to all parts of the MG complex. Slightly modified from Figs. 19 and 20 of LeDoux *et al.* (1985).

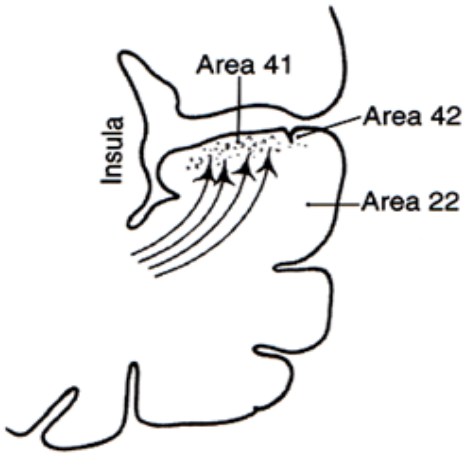


Low Frequency Sound and FEAR!!!

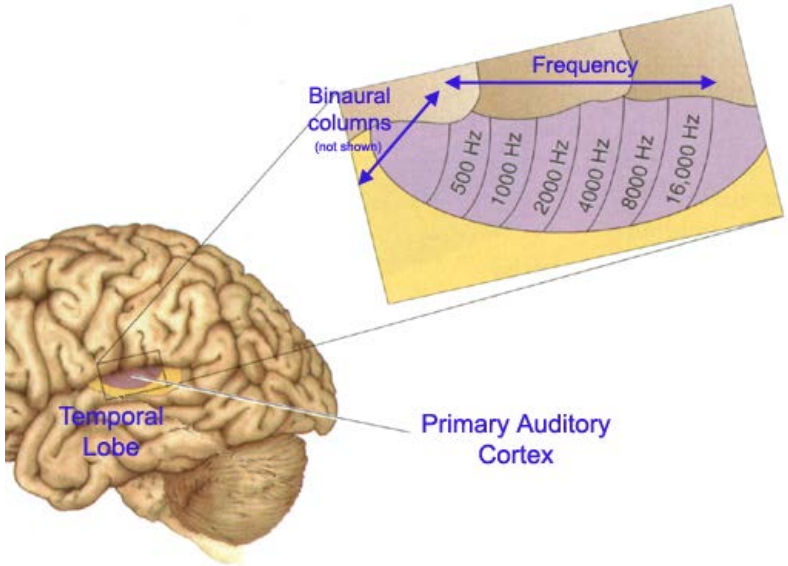

Identify and Process Complex Sounds
Cortex
Relay to Cortical Areas
Medial Geniculate
Form Full Spatial Map
Inferior Colliculus
Lateral Lemniscus
Locate Sound in Space
Lateral Superior Olive
Medial Superior Olive
Acoustic Stria:
Dorsal
Intermediate
Ventral
Processing of Sound Begins
Dorsal Cochlear Nucleus
Postero-Ventral Cochlear Nucleus
Antero-Ventral Cochlear Nucleus
Auditory Nerve VIII
Cochlea

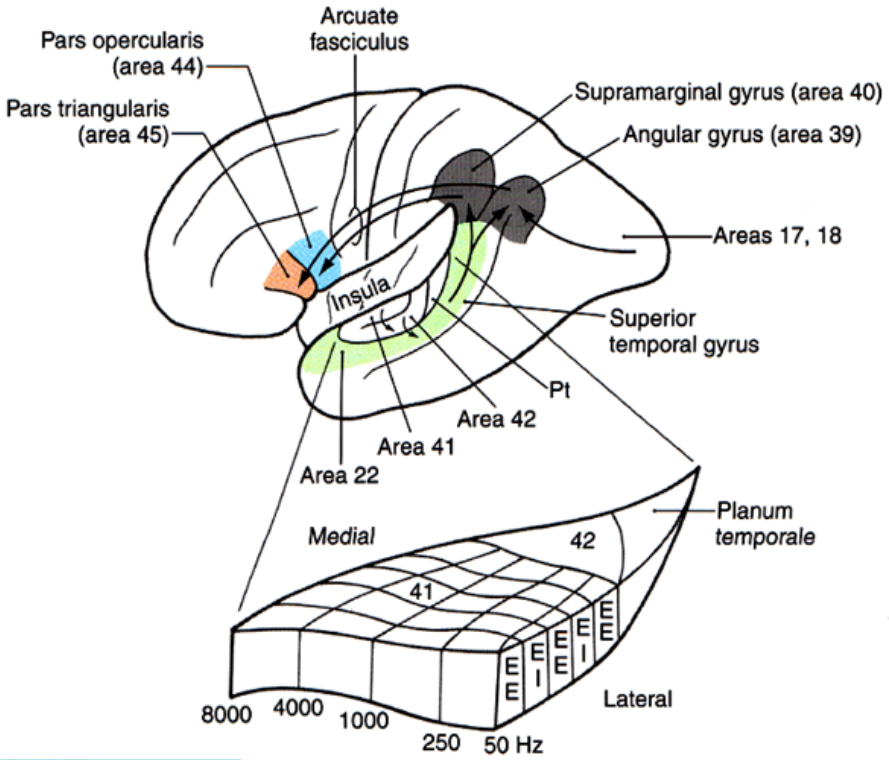
YOU ARE HERE

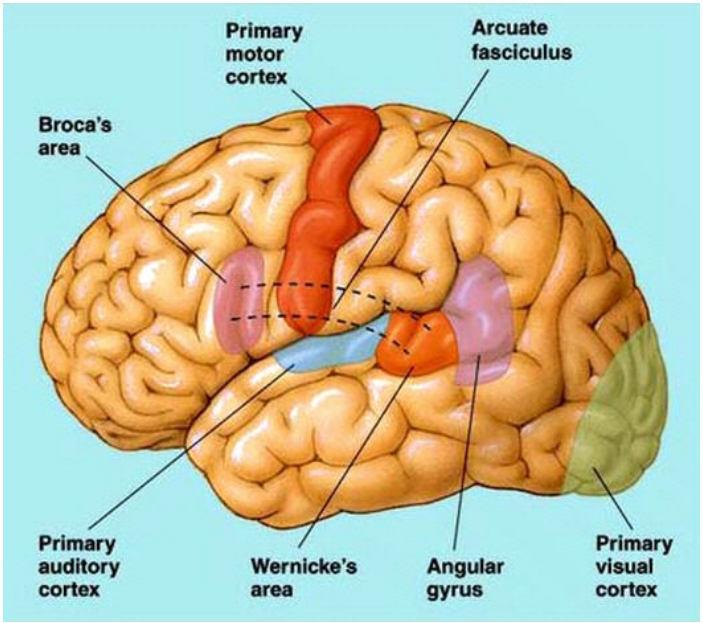

Lateral Fissure
AI (Heschl's gyrus)
Secondary Auditory Areas
('Belt')
Primary Auditory Areas
('Core')


Area 41
Area 42
Insula
Area 22

Tonotopic Map Has Columnar Organization







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