1: Anatomy of Hearing and the Auditory Pathway

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Ling 580: Speech Perception and Bias

The Ear

Made up of 3 areas: Outer, Middle, Inner

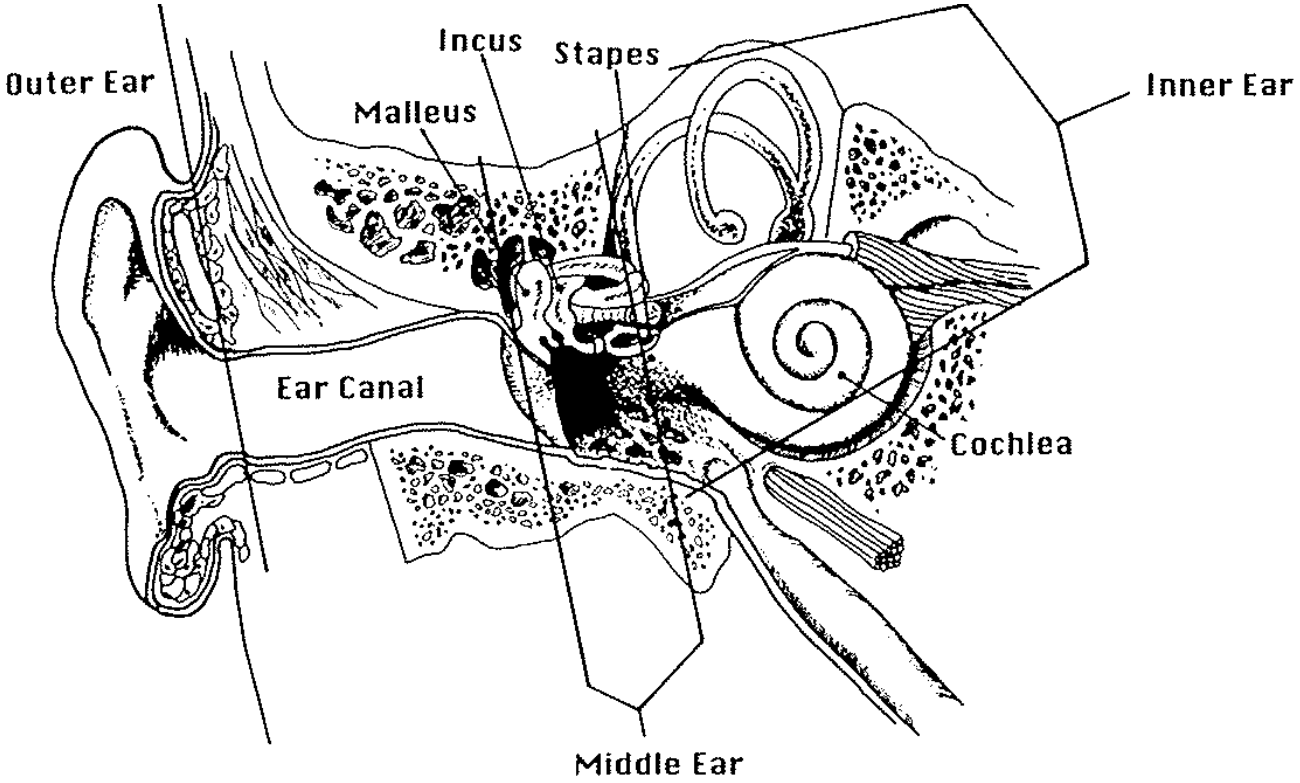
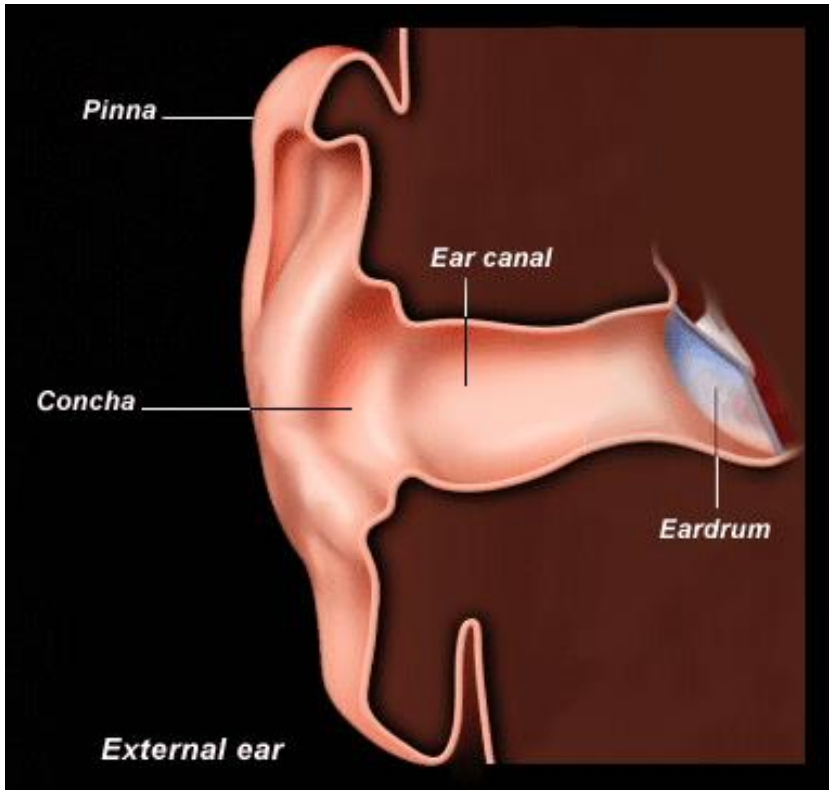


Figure 4.1 Sketch of the outer, middle, and inner ear. (From Berlin, 1994.)

From: Stevens (1998)

The Ear

Outer Ear: Pinna, concha, ear canal



From: http://www.neuroreille.com/promenade/english/

The Ear

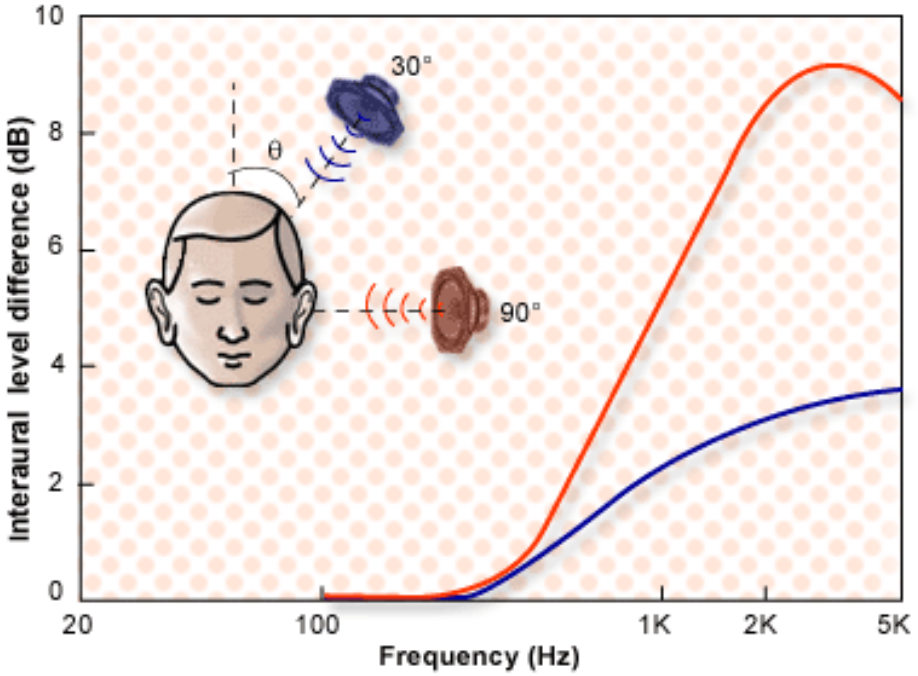
Outer ear – Pinnae and head orientation

- together with head orientation act as attenuators/amplifiers aiding in directional hearing – sounds coming from in front are amplified, from behind are attenuated (higher frequencies more attenuated than lower frequencies because of the impedance of the flesh)
- the soundwaves entering the each ear are at different phases and attenuations (determined by the orientation of the head to the sound) also aiding in directional hearing

The Ear

Outer ear – concha and ear canal

– The *Pinnea*, *Concha,* and *Ear Canal* act to amplify certain frequencies based on head orientation



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The Ear

Outer ear – concha and ear canal

- The *Concha* and *Ear Canal* together act as a resonator that amplifies higher frequencies based on the standing waves in the length of the structure: single tube resonator (2n-1c/4L)

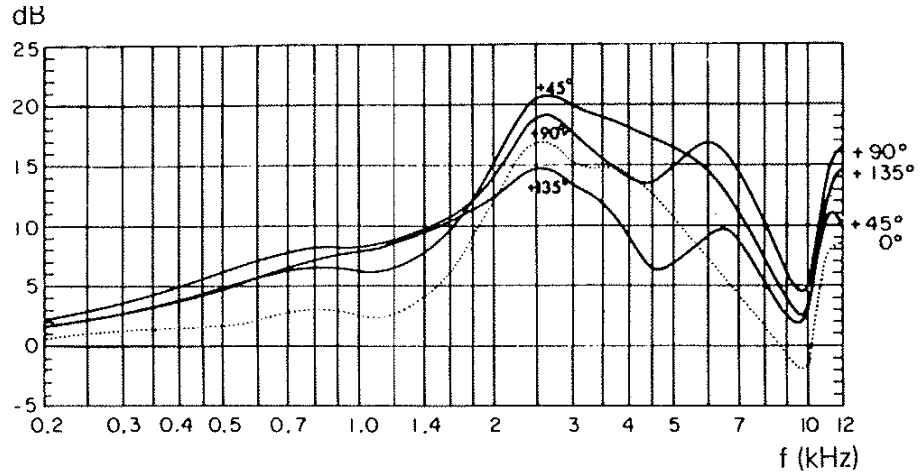


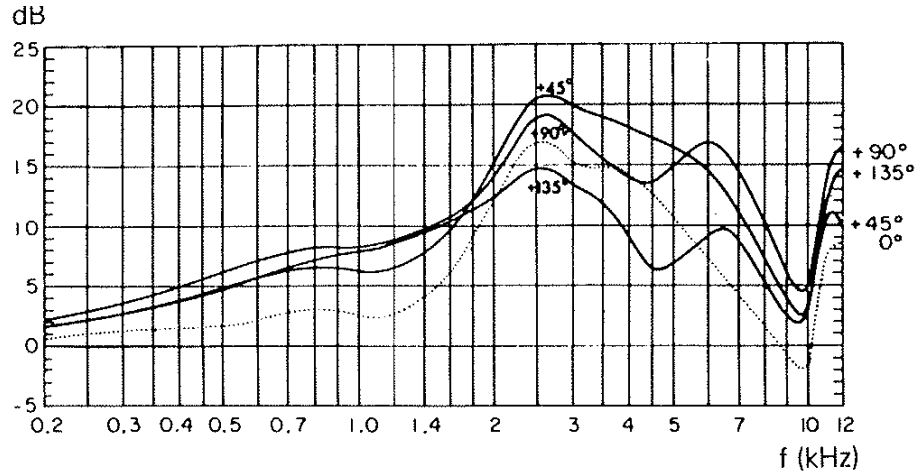
Figure 4.2 Ratio of the sound pressure at the tympanic membrane to the sound pressure that would exist (in the absence of the subject) at the point located at the center of the head, as a function of frequency for several values of azimuth of the source in the horizontal plane. Zero degrees azimuth is straight ahead, and 90 degrees azimuth is in line with the ears. (From Shaw 1974.)

From: Stevens (1998)

The Ear

Outer ear – concha and ear canal

- The *Concha* and *Ear Canal* together act as a resonator that amplifies higher frequencies based on the standing waves in the length of the structure with the first main peak around 3 kHz



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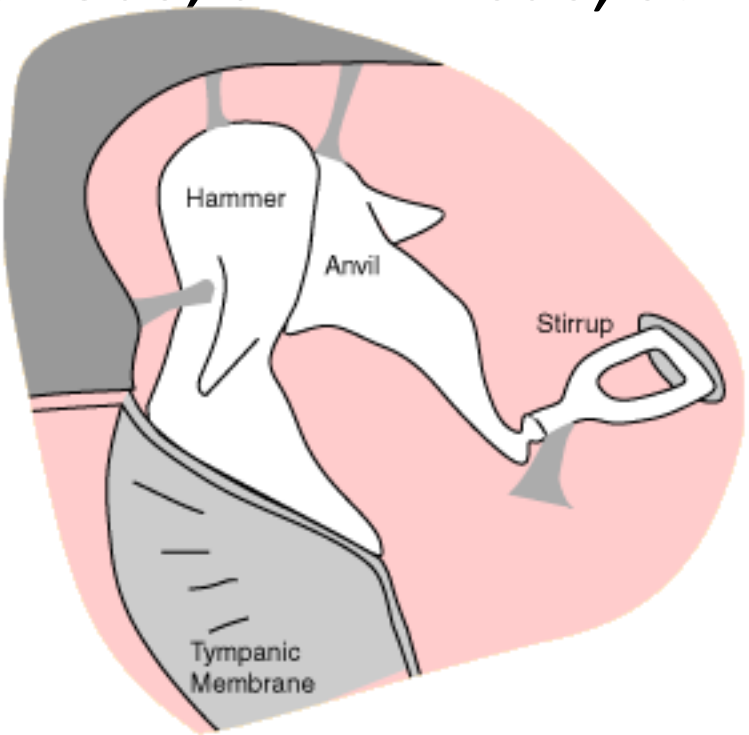
From: Stevens (1998)

The Ear

Middle ear – Ossicles

(hammer-malleus, anvil-incus, stirrup-stapes)



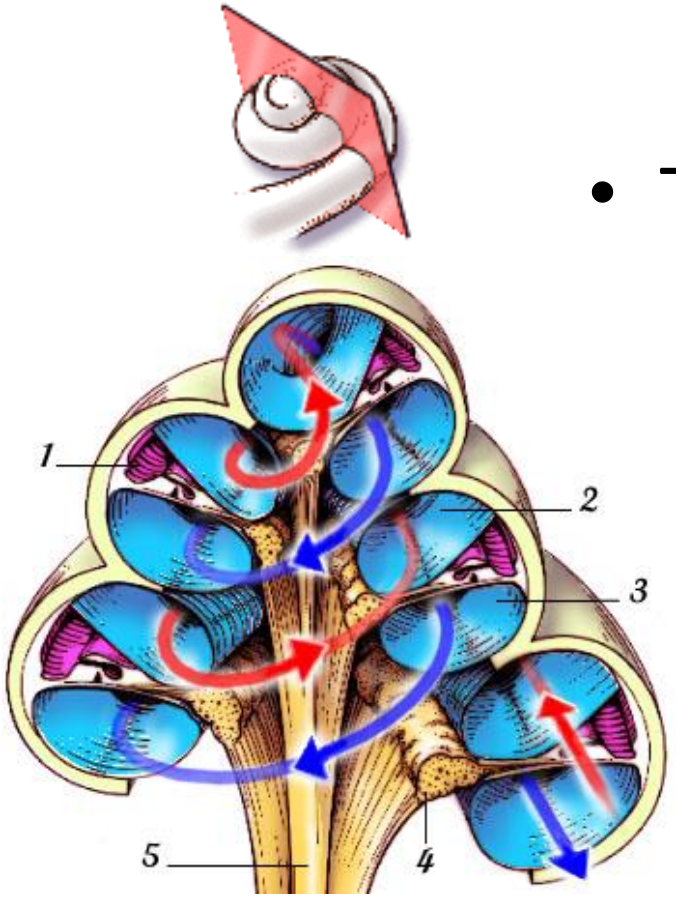
http://hydrogen.physik.uni-wuppertal.de/hyperphysics/hyperphysics/hbase/sound/oss.html

The Ear

Middle ear – Ossicles, Ligaments, Muscles

- Acts to overcome air to fluid (inner ear) impedance
  - Bone chain acts as a lever that can amplify by a factor of 3
- Ossicular reflex (attenuation of transfer function):
  - In response to loud sounds the *tensor tympani* stiffens the eardrum
  - It also shifts the stapes back from the oval window reducing amplification
  - Ineffective against impulse noise, sharp onsets
  - Ineffective above 1-2 kHz
- Stapes movement displaces the *oval window* setting up waves in the fluid-filled *cochlea*.
- Transfer function non-linear across frequencies…

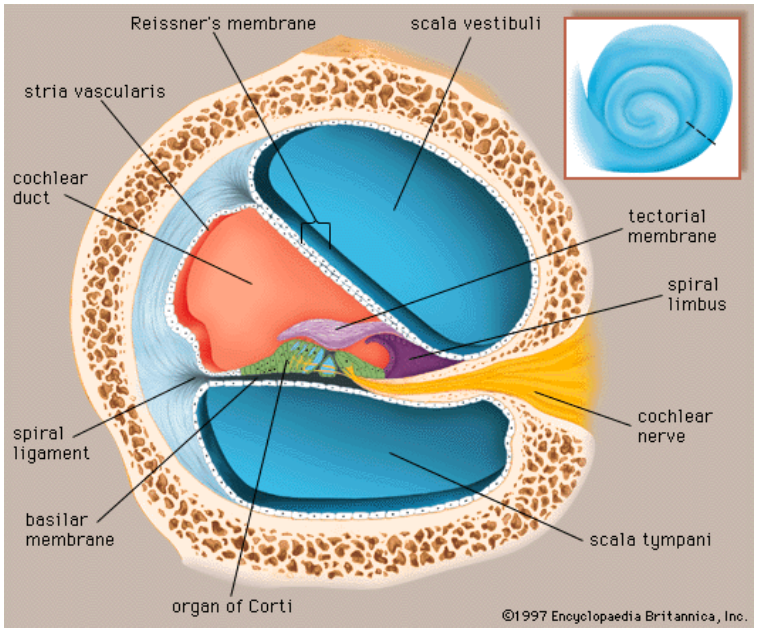
The Ear



- The inner ear: Cochlea
  - Movement at the oval window sets up a traveling pressure pressure wave up the *scala vestibuli* (2) and down the *scala tympani* (with pressure being relieved at the round window).
  - The wave's main peak depends on the frequency of the sound

From: Encyclopedia Britannica 1997

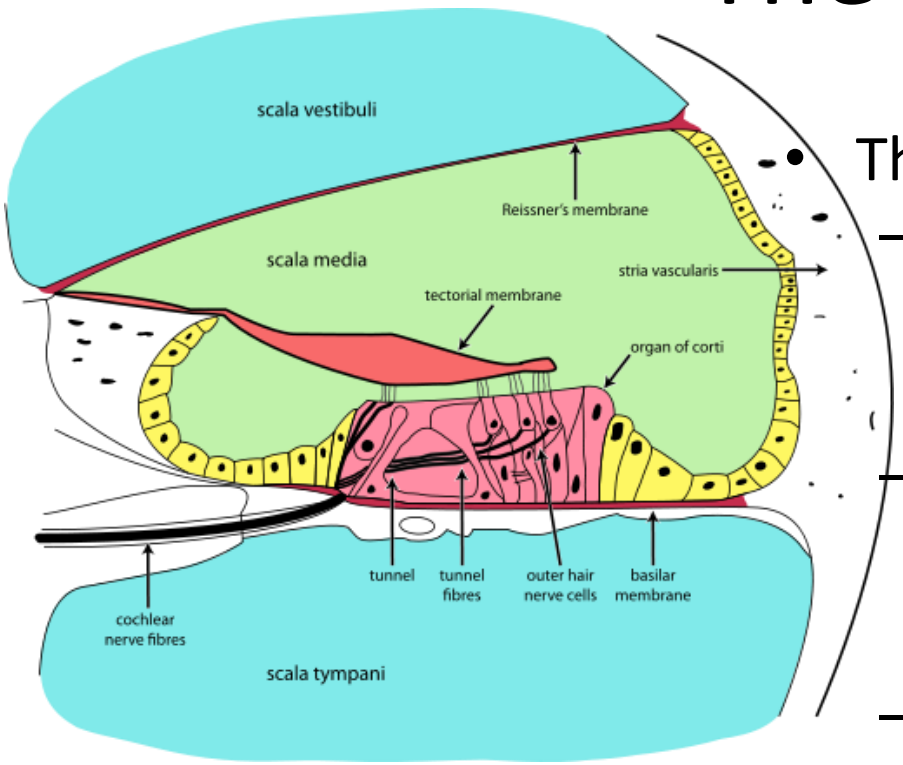
The Ear



From: Encyclopedia Britannica 1997

- The inner ear: Cochlea
  - Vibrations in the endolymph in the *cochlear duct* (*scala media*) displace the *basilar membrane*.
  - Hair cells in the *organ of Corti* (riding upon the basilar membrane) are displaced as they rub against the tectorial membrane (which is fixed)

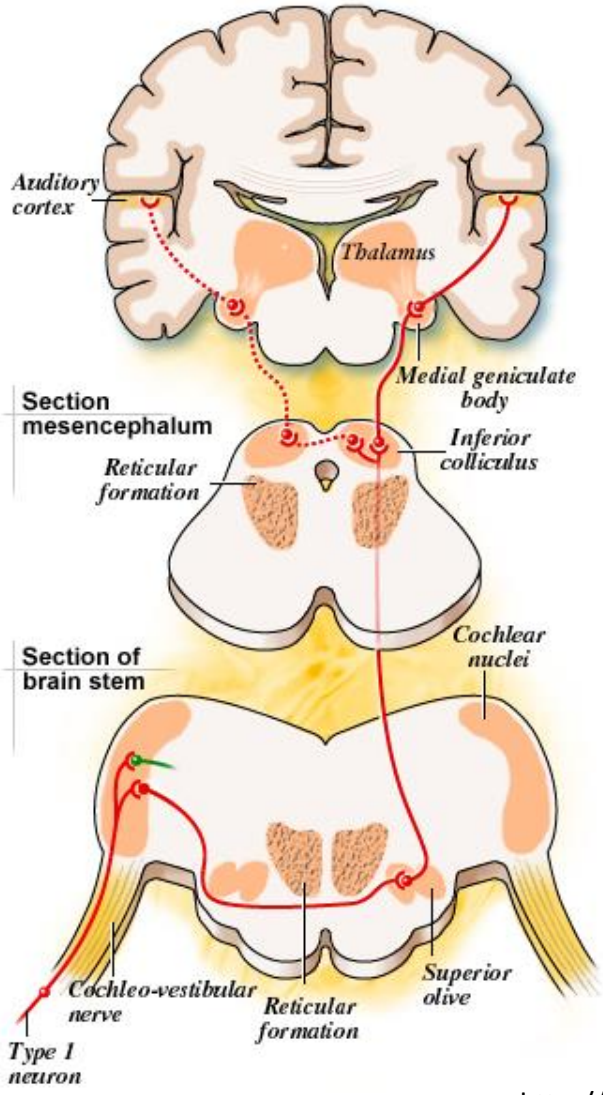
The Ear



From: Wikipedia
http://en.wikipedia.org/wiki/Cochlea

- The inner ear: Cochlea
  - Outer hair cells amplify vibrations at their specific frequency helping to amplify quiet sounds at their frequency
  - Inner hair cells' cilia are displaced by a shearing action between the basilar and techtorial membranes
  - Cilia displacement results in neurotransmitter release
  - Auditory Nerve Fibers (ANF) respond to the neurotransmitters and send signals up the auditory pathway to the auditory cortex

Auditory Pathway



The final neuron of the primary auditory pathway links the thalamus to the auditory cortex, where the message, already largely decoded during its passage through the previous neurons in the pathway, is recognized, memorized and perhaps integrated into a voluntary response.

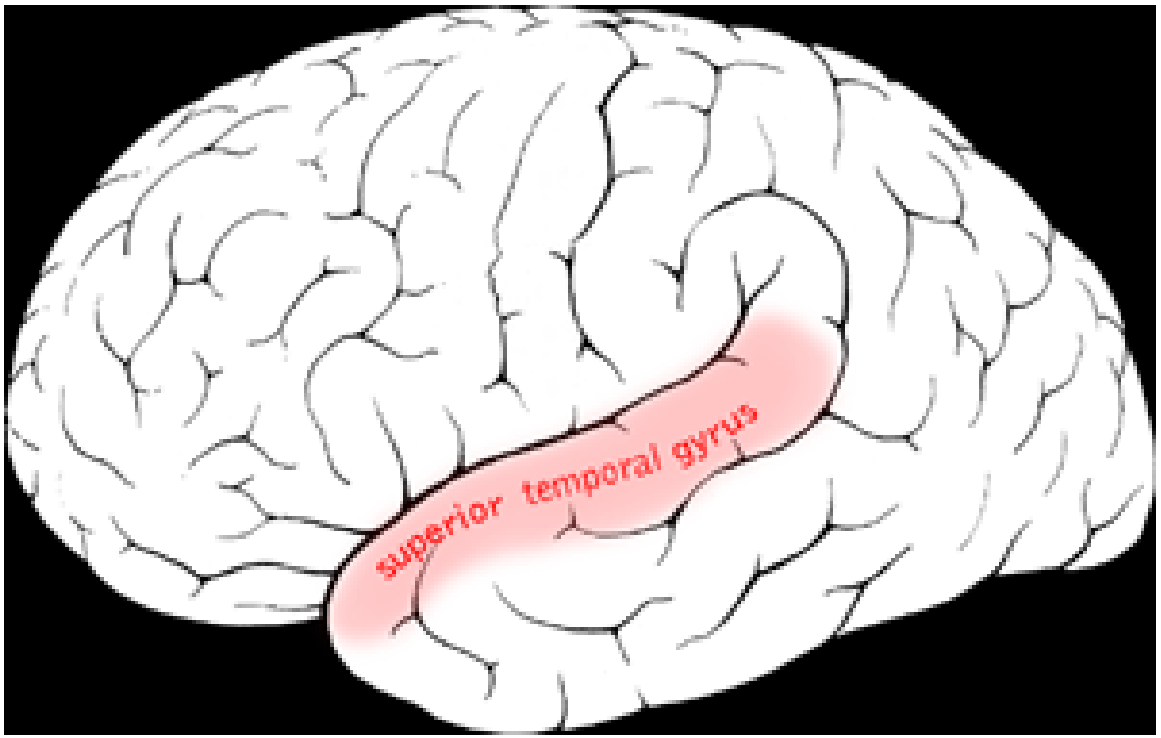
A final relay, before the cortex, occurs in the thalamus (median geniculate body) it's here that an important integration occurs: preparation of a motor response (eg vocal response).

Leaving this relay, a third neuron carries the message up to the level of the superior colliculus. These two relays play an essential role in the localization of sound.
The second major relay in the brain stem is in the superior olivary complex: the majority of the auditory fibers synapse there having already crossed the midline.

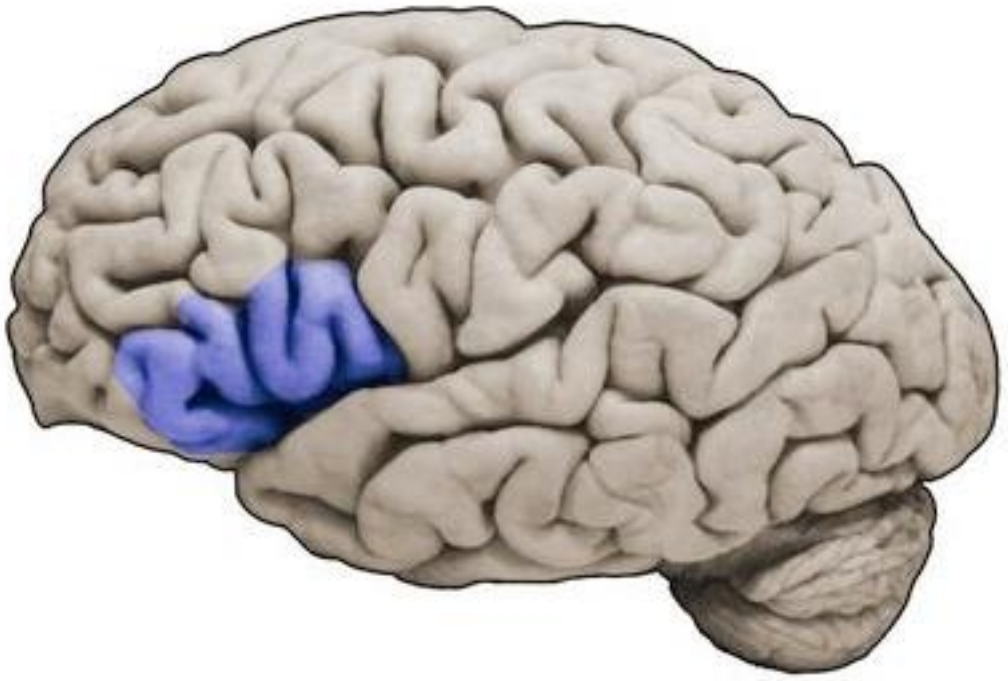
The first relay of the primary auditory pathway occurs in the cochlear nuclei in the brain stem, which receive Type I spiral ganglion axons (auditory nerve); at this level an important decoding of the basic signal occurs: duration, intensity and frequency.

http://www.neuroreille.com/promenade/english

Superior Temporal Gyrus



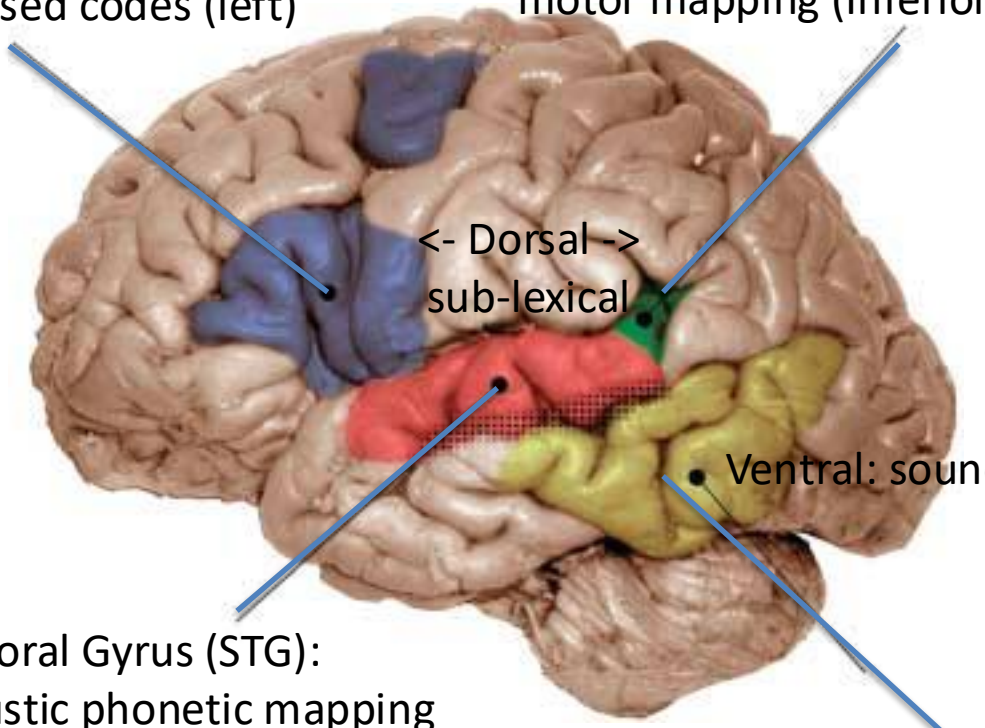
Inferior Frontal Gyrus: Broca's Area



Areas involved in speech processing

Inferior Frontal Gyrus (IFG):
articulatory-based codes (left)

Sylvan Parieto-Temporal area (SPT):
Sensori-motor transformation, auditory-motor mapping (Inferior Perietal) (left)



Superior Temporal Gyrus (STG):
(bilateral) acoustic phonetic mapping
(uniform across task)

Middle Temporal Gyrus (MTG)/Middle Temporal Gyrus (MTG):
Sound-meaning interface — lexical activation (left)

Hickok & Poeppel: Model of Cortical Network

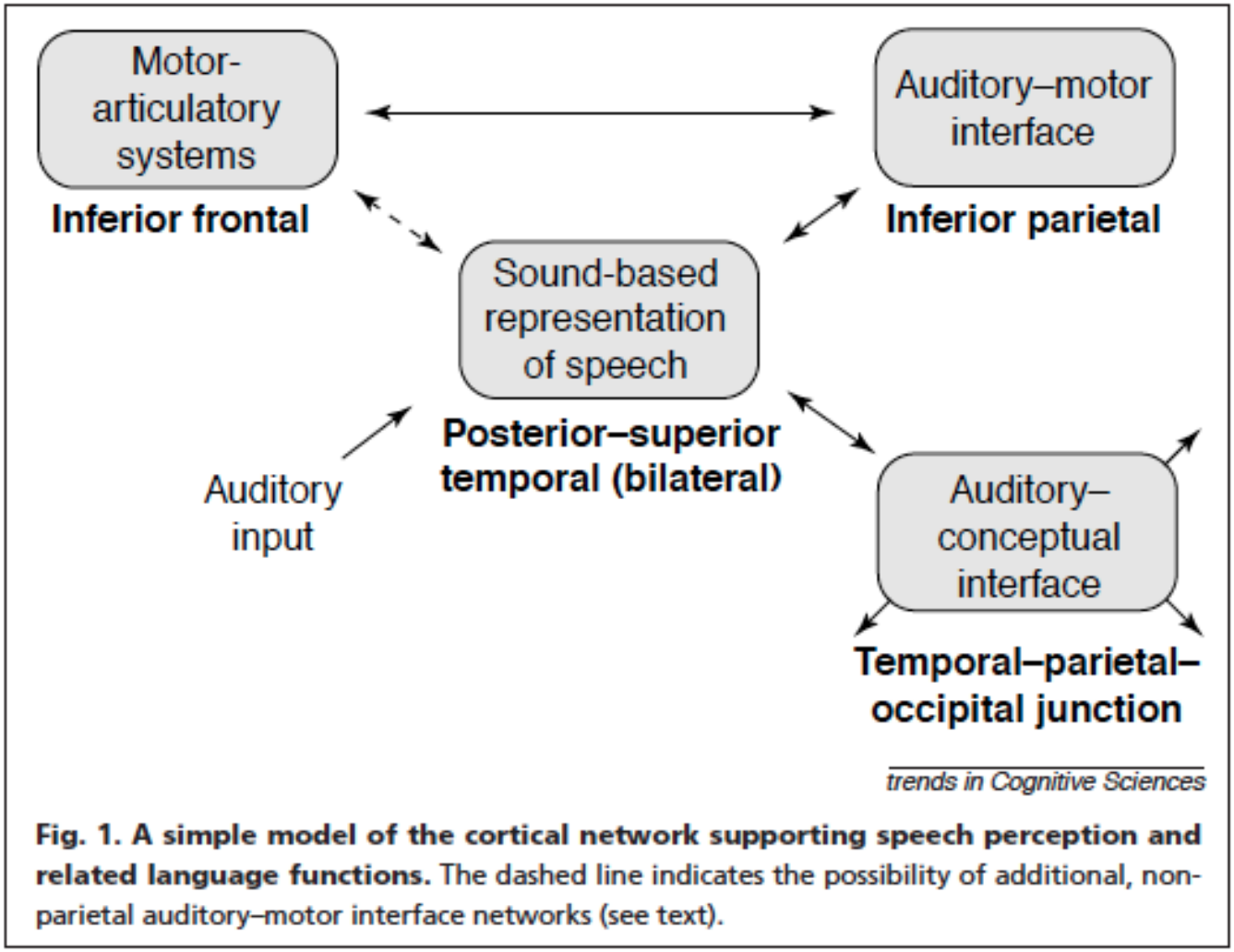


Fig. 1. A simple model of the cortical network supporting speech perception and related language functions. The dashed line indicates the possibility of additional, non-parietal auditory–motor interface networks (see text).

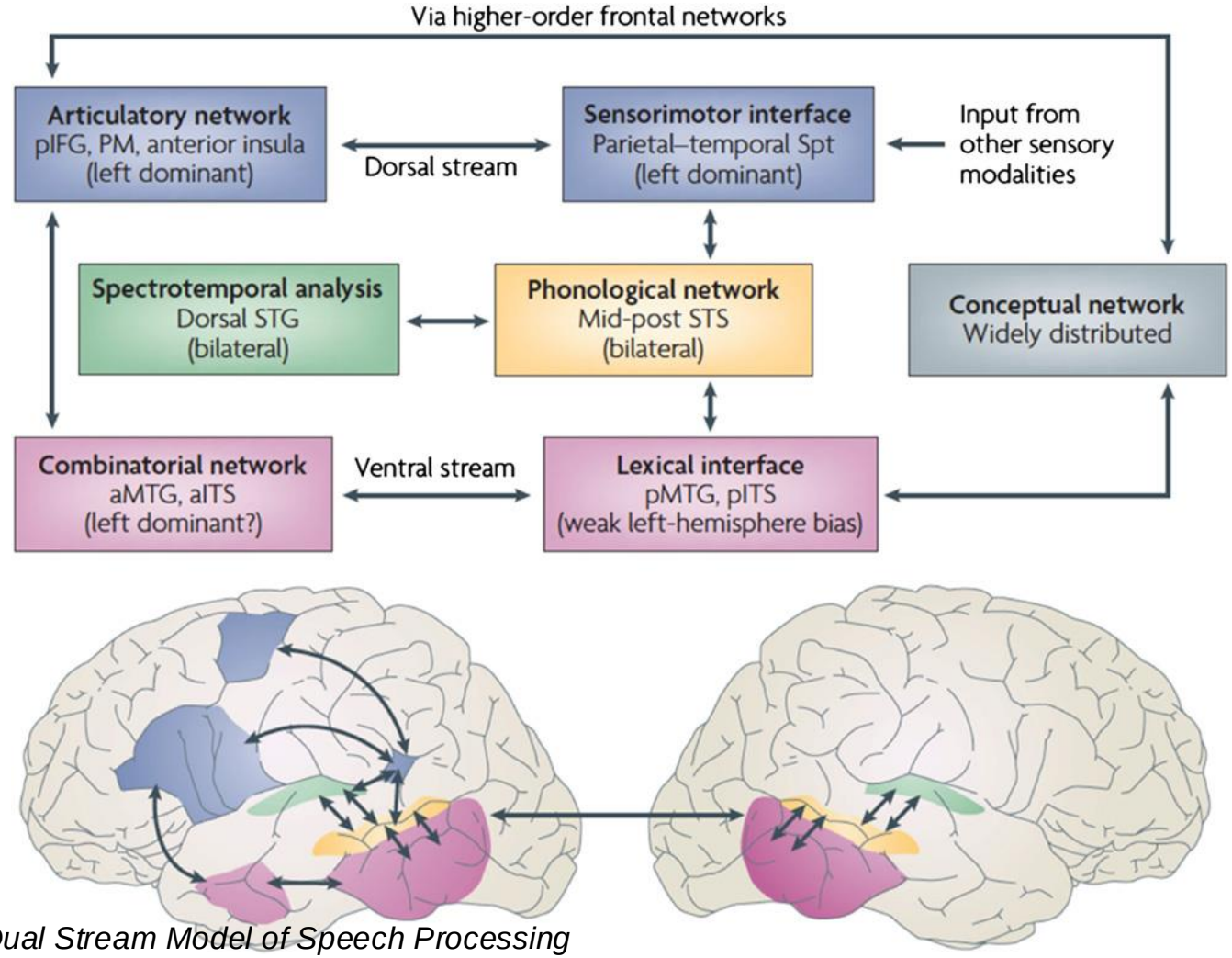


Figure 3. Dual Stream Model of Speech Processing

The dual stream model (Hickok and Poeppel, 2000, 2004, 2007) holds that early stages of speech processing occurs bilaterally in auditory regions on the dorsal STG (spectrotemporal analysis; green) and STS (phonological access/representation; yellow) and then diverges into two broad streams: a temporal lobe ventral stream supports speech comprehension (lexical access and combinatorial processes; pink) whereas a strongly left dominant dorsal stream supports sensorymotor integration and involves structures at the parietal-temporal junction (Spt) and frontal lobe. The conceptual-semantic network (gray box) is assumed to be widely distributed throughout cortex. IFG, inferior frontal gyrus; ITS, inferior temporal sulcus; MTG, middle temporal gyrus; PM, premotor; Spt, Sylvian parietaltemporal; STG, superior temporal gyrus; STS, superior temporal sulcus. Reprinted with permission from (Hickok and Poeppel, 2007).