COGS 17 section A02

audition

section resources repo

reminders

- congrats on completing midterm I! (get excited for midterm II <3)
- homework 4 due wednesday 11:59 PM

sound waves basics

frequency

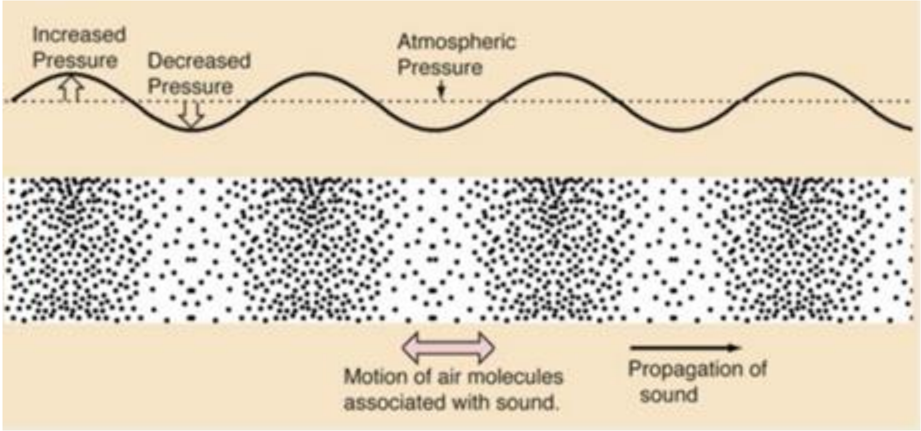
- number of cycles of sound pressure /second
- measured in Hertz (Hz)
- perceptual dimension: pitch

amplitude

- level of sound pressure
- measured in decibels (dB)
- perceptual dimension: loudness

phase

- place in cycle of condensation and rarefaction of sound pressure



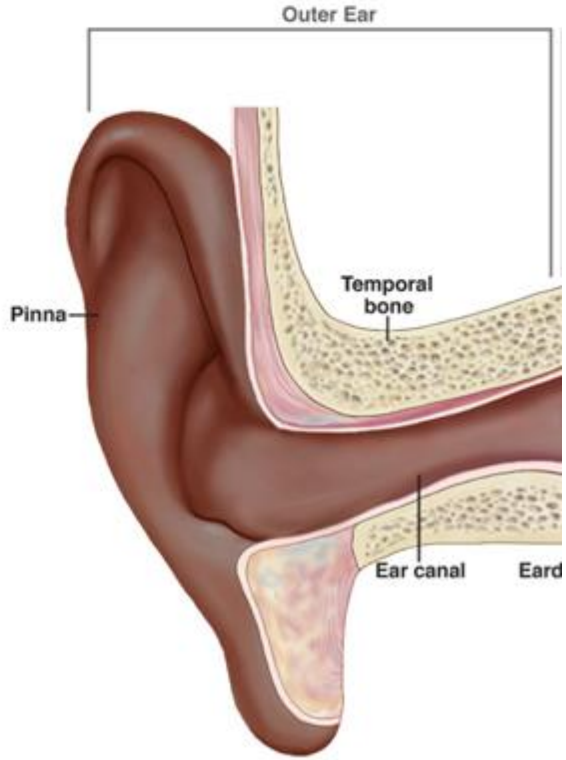
auditory system anatomy – outer year

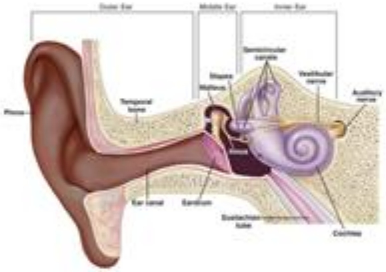
pinna

- individually shaped
- sound localization

auditory canal

- air channel funnels sound to eardrum





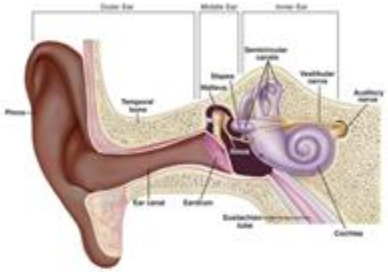
auditory system anatomy – middle ear

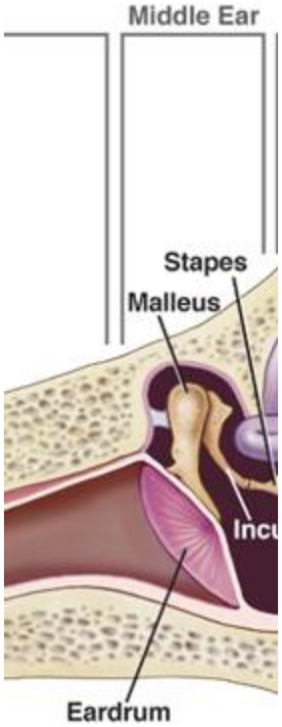
tympanic membrane (eardrum)

- convert air pressure from auditory canal into kinetic energy

ossicles = malleus + incus + stapes

- tiny bones form lever system
- convert large vibrations from eardrum to high-force vibration on oval window
  - amplification to bridge **impedance mismatch** between air (outer) and fluid (inner)





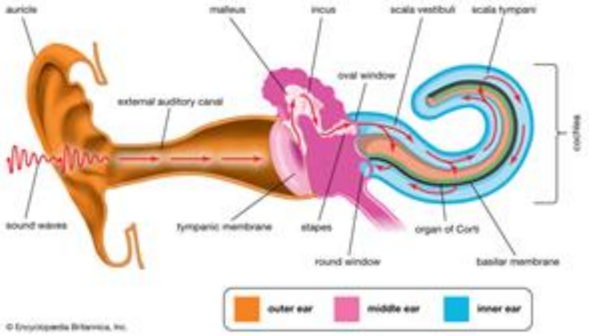
auditory system anatomy – inner ear

oval window

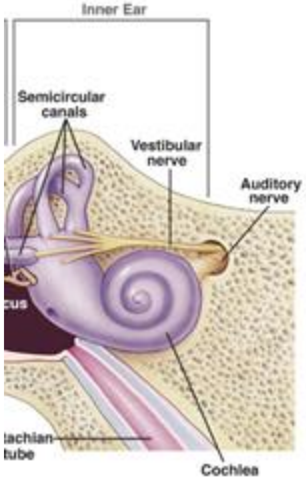
- receives vibration by stapes
- entrance point to cochlea

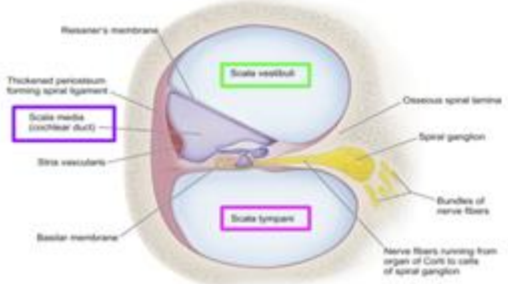
cochlea

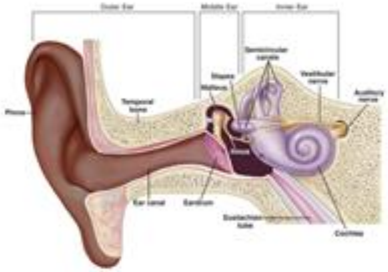
- snailed shaped
- 3 fluid-filled chambers
    - scala vestibuli (top)
    - scala media (middle, transduction site)
    - scala tympani (bottom)



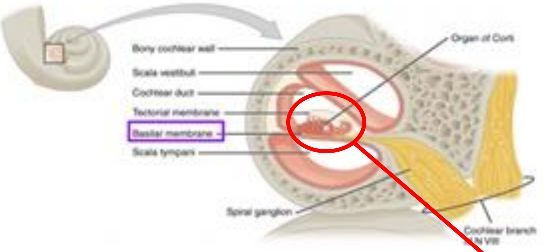
fluid motion pathway



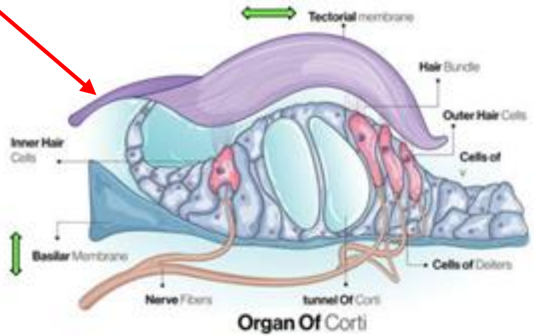


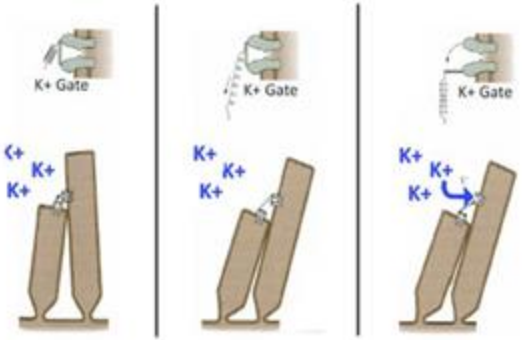


organ of corti



- in the scala media
  - **basilar membrane**: floor
  - **tectorial membrane:** ceiling
  - **hair cells** (auditory receptors) embedded between membranes
- chambers filled with **endolymph (**K+ -rich fluid)
- as membrane vibrates…
  - basilar membrane (↑↓), tectorial membrane (⇆) → bends cilia on hair cells
    - toward longest
      - K+ channels open → K+ influx (depolarization) → Ca^{2+} enters → release glutamate (NT)
    - toward shortest
      - K+ channels close → K+ efflux → Ca^{2+} exists → repolarization
- hair cells fire **graded** potentials (not AP!!)
  - NT release depend on magnitude and frequency of cilia bending
  - signals relay to spiral ganglion (auditory nerve fibers) that fire AP

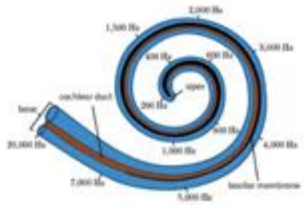


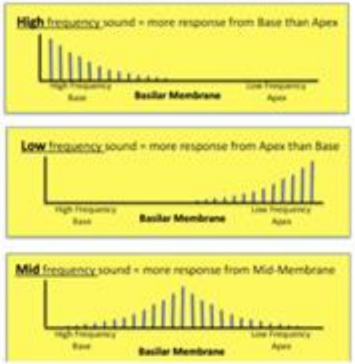


encoding frequency – place coding

different locations on basilar membrane respond to different frequencies

- base
  - near oval window
  - narrow and stiff
  - high frequencies
- apex
  - far end
  - wide and floppy
  - low frequencies
- greater membrane displacement → greater cilia bending → more NT release → greater probability of spiral ganglion firing
- produce place of maximum activation with surrounding lesser activity → sound encoded by pattern across multiple fibers = across-fiber coding





encoding frequency – temporal (rate) coding

while different ”places” of the basilar membrane resonate more than others (different amplitude), the whole membrane is also vibrating at the rate of input (same frequency)

- ie. entire membrane moves at the **same rate** though **amplitude (membrane displacement)** varies by place

spiral ganglion fibers fire in sync with membrane vibration → action potential reflects input frequency timing

BUT

a single neuron’s firing has a limit

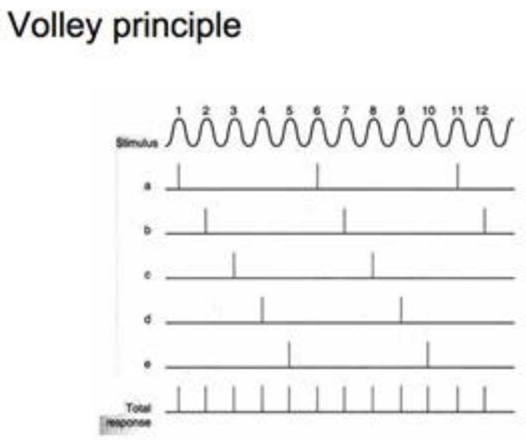
- maxes out at ~1 k /sec (1000 Hz) due to refractory period
- can’t individually encode high frequencies

encoding frequency – temporal (rate) coding

SOLUTION to encoding frequencies > 1 kHz

volley principle (a type of across-fiber coding)

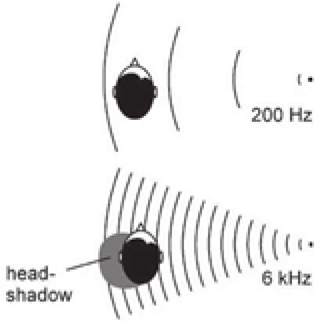
- groups of spiral ganglia share load – take turns firing
  - spiral ganglia are phase-locked to fire AP at particular peaks
    - respond at different peaks on soundwave
      - eg. group A fires at first peak, group B fires at next peak while A is in refractory period…
  - taken altogether creates "volley" of AP to capture entire stimulus frequency
- coordinated group activity not individual firing



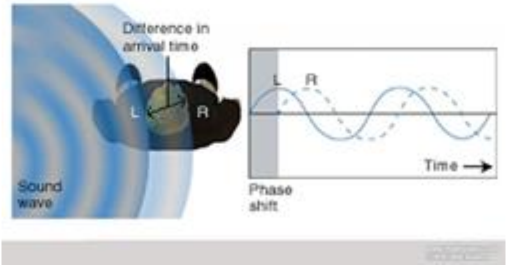
localization

depends on disparity between left and right ear inputs

1. intensity (amplitude) differences
    a. **head shadow**: head absorbs some sound energy
        i. sound louder at the ear closer to the source
        ii. most effective for high frequencies

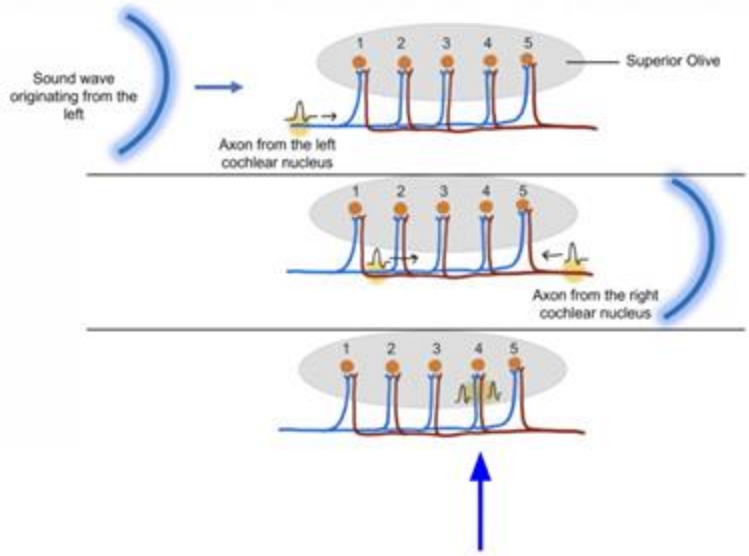


2. phase differences
    a. brain detects differences in wave phase (peak vs trough) between ears
    b. direction of sound source
    c. effective for low frequencies



localization

3. timing differences (interaural time differences ITD)
   a. detected by ITD detectors in superior olive (in medulla)
   b. when sound arrives
      i. onset cells in cochlear nucleus fire
      ii. signal travels through axonal delay lines to an array in the superior olive
         1. only fires when inputs from both ears converge
         2. position in array encodes which ear hears sound first
   c. that said…
      i. sound comes in from right → signal meets in left
      ii. simultaneous arrival (equidistant) → signal meets in center



auditory pathway

begins with hair cells in cochlea

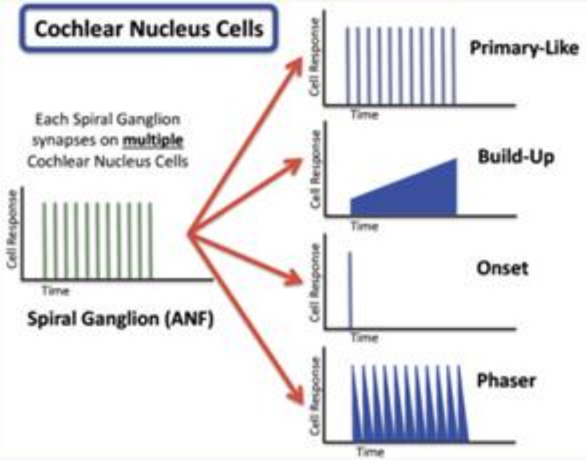
- inner hair cells
  - divergent: 1 IHC : 8 spiral ganglion
  - encodes frequency with high redundancy → detailed
- outer hair cells
  - convergent: 20 OHC : 1 spiral ganglion
  - amplification

spiral ganglia axons form auditory nerve fibers

- feed into cochlear nucleus (medulla)
- each auditory nerve connects to ipsilateral side
  - monaural – left ear → left nucleus

each spiral ganglion synapses to multiple cell types

- primary-like: preserves firing patterns → tonotopic map
- build-up: create continuously increasing graded response → encodes amplitude
- onset: race to superior olive to determine which ear the sound came to first → rapid adapting for localization



auditory pathway

superior olive: **first binaural site**

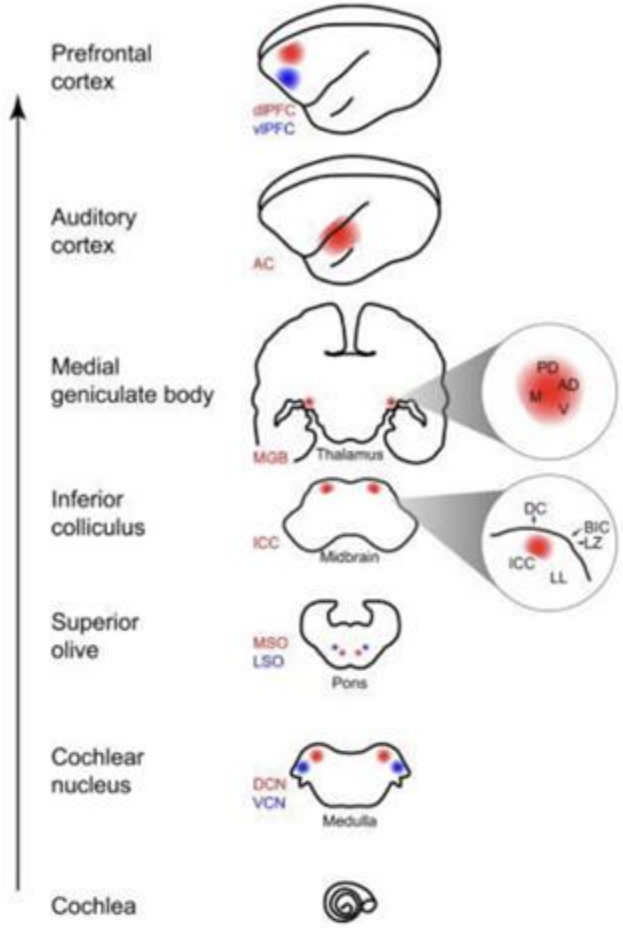
- localize sound by integrating input from both ears
- inputs from both ipsilateral and contralateral cochlear nuclei

inferior colliculus

- in tectum
- receive most from ipsilateral superior olive
- integrates auditory + visual info (via superior colliculus)
  - orienting eyes to sound source

medial geniculate nucleus (MGN)

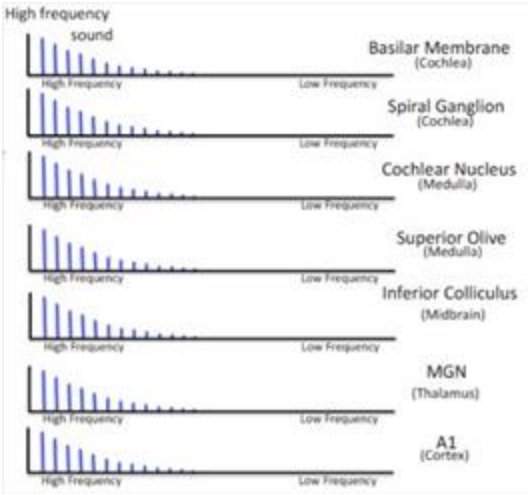
- in thalamus
- preserves tonotopic map – adjacent neurons tuned to adjacent frequencies

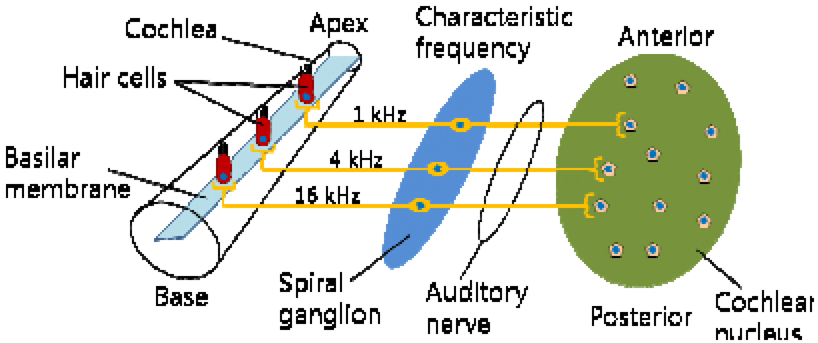


tonotopic map

preserves distribution of activity across the basilar membrane

- at each point along the way, primary-like cells re-represent the same pattern to preserve the topological map originally started in the basilar membrane





auditory pathway

A1: primary auditory cortex

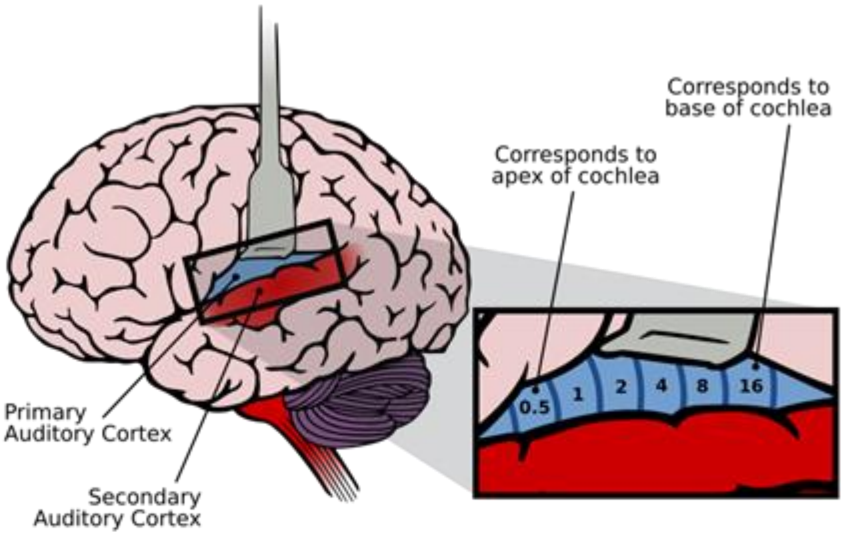
- medial temporal cortex
- preserves tonotopic and amplitude maps
  - high → low frequency: posterior → anterior
  - high → low amplitude: medial → lateral
- neurons respond best to single frequency (pure tones)

A2: secondary auditory cortex

- complex, meaningful sounds
- neurons respond best to changing frequency (complex sounds)

higher auditory cortex

- integrating sound with cognition and perception
  - wernicke’s area (left hemisphere, speech comprehension)



kahoot

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