Nina Kazanina
Experimental Psychology
University of Bristol

PSYC 10009: INTRODUCTION TO BIOLOGICAL PSYCHOLOGY

Lecture 6. Audition.

Overview

- What's a sound?
- What's inside the ear?
- How the sound is 'passed into' the brain
- How are sound frequency and intensity encoded?
- Impaired auditory perception

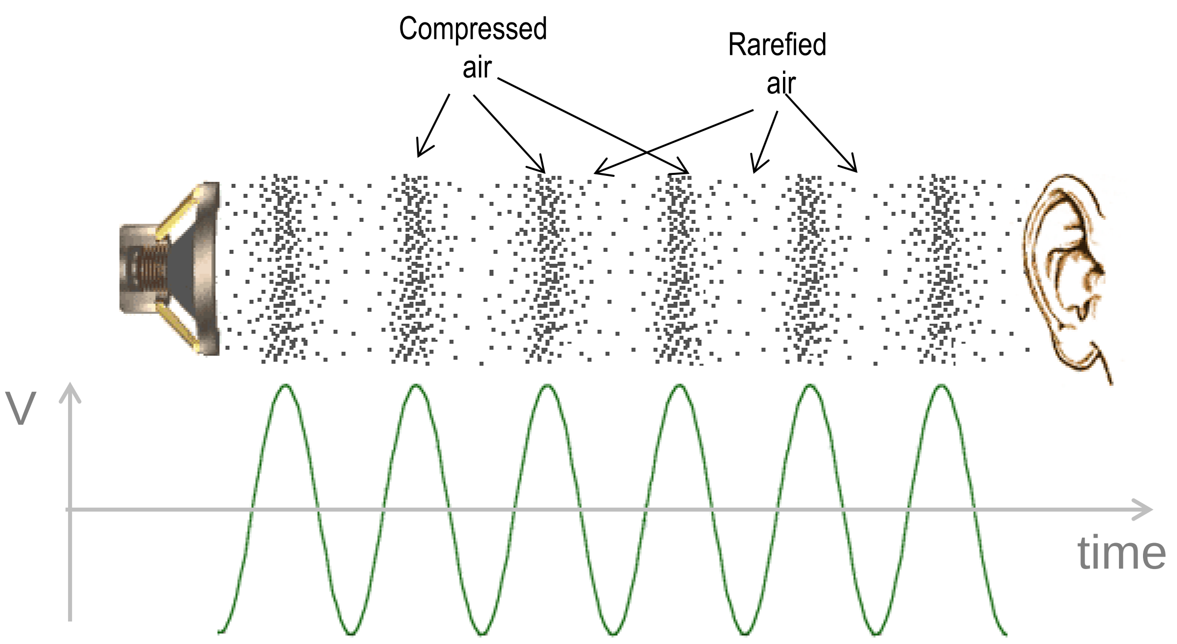
Auditory perception

- The auditory domain is the primary domain for two sensory experiences that are considered to be most uniquely human
  - speech
  - music

- An example of how sensory information is ‘translated’ by the brain into a perceptual representation of our surrounding environment

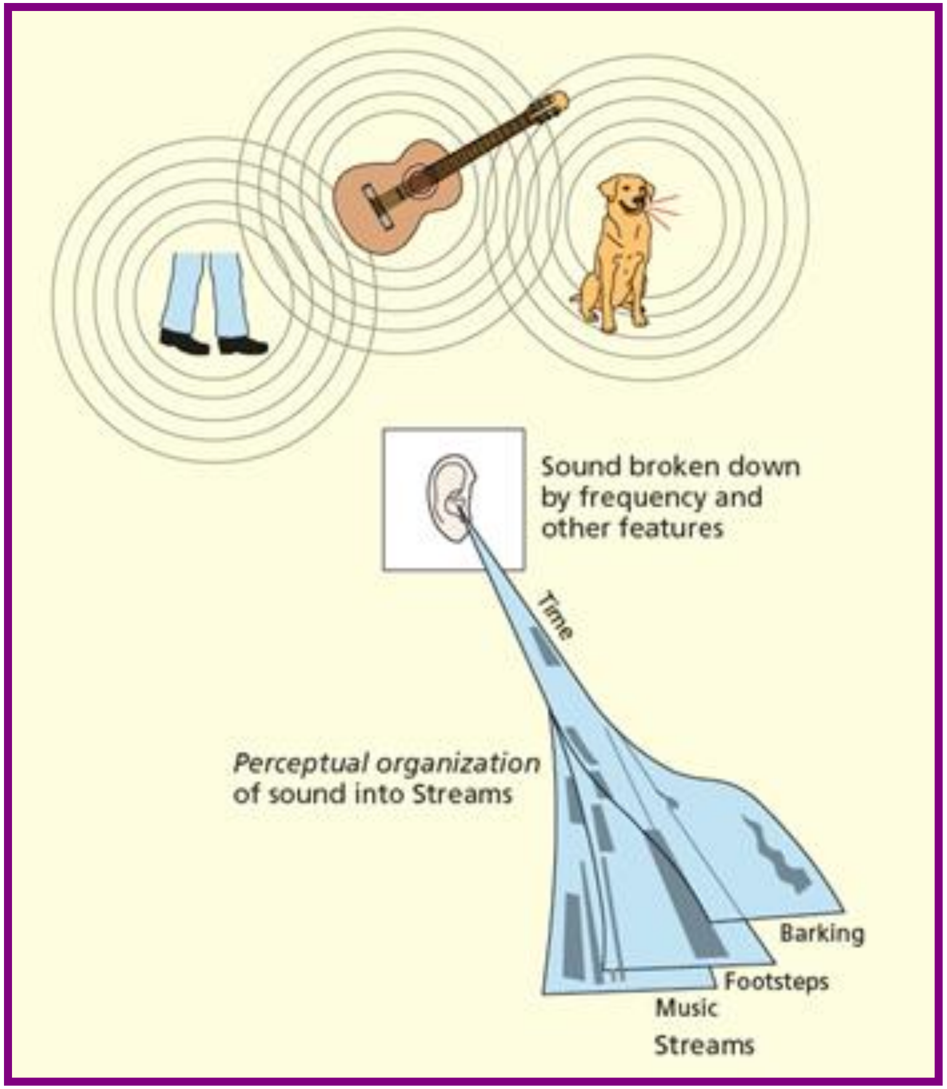
Sounds

- Sound – periodic compressions of air, water or another medium
  - An object (e.g. a tree) vibrates the air and sets up sound waves that hit the ear

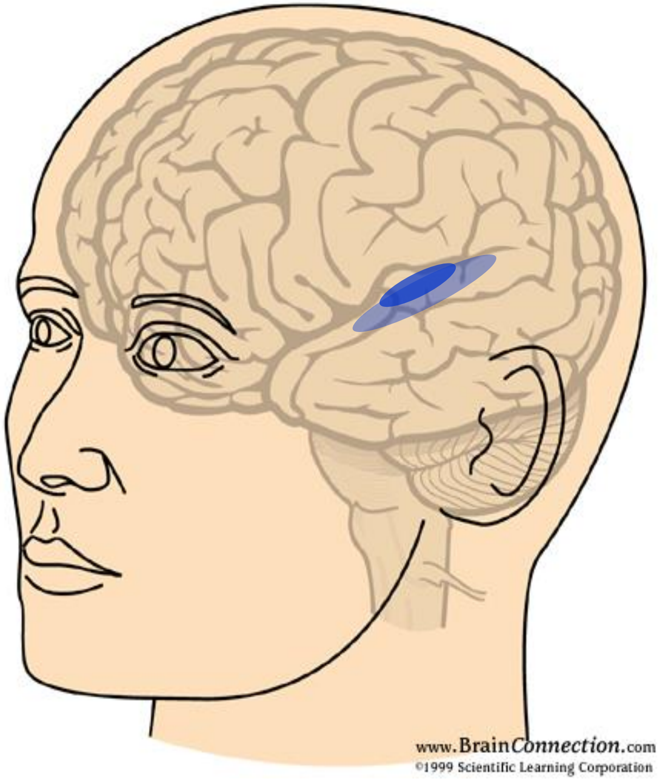


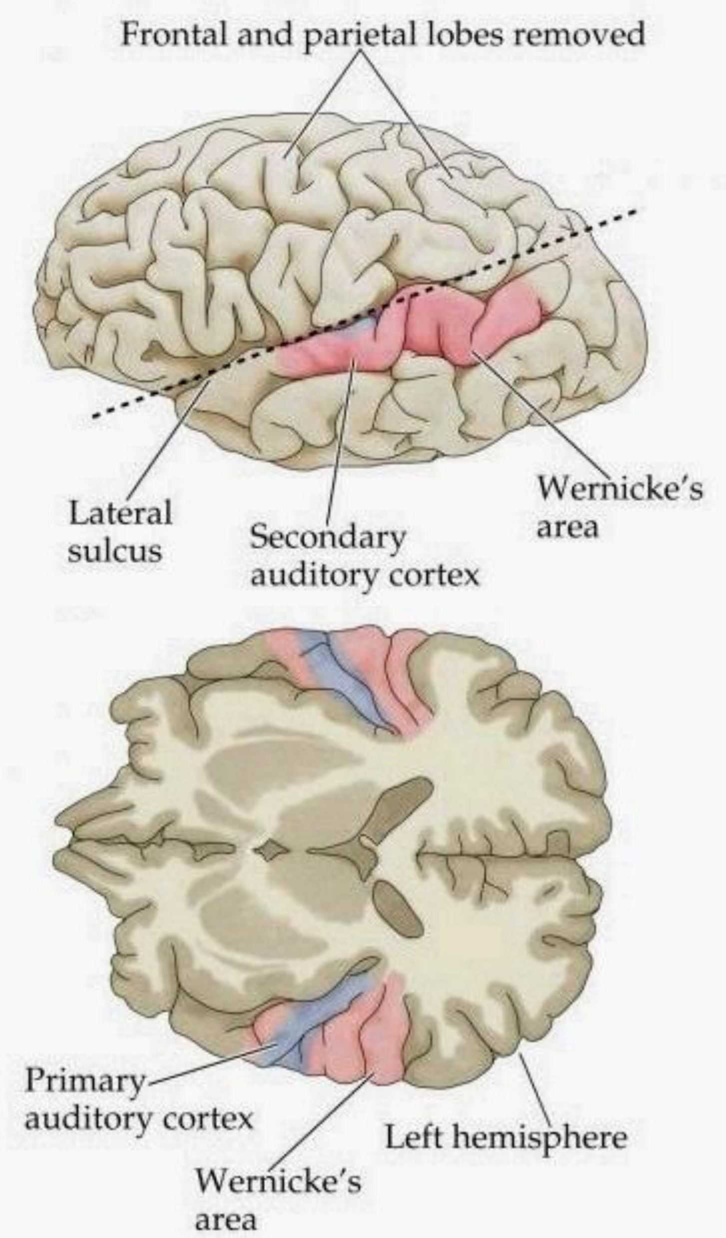
Hearing is more than detection of sounds

- Hearing involves constructing a model of the world:
  - What objects do the sounds correspond to?
  - Where are they?
  - What do they mean?
- In noisy environment, many sounds overlap in time
  - The brain needs to use incoming sensory input and prior knowledge about sounds (melodies, pitches of familiar voices) to segregate them

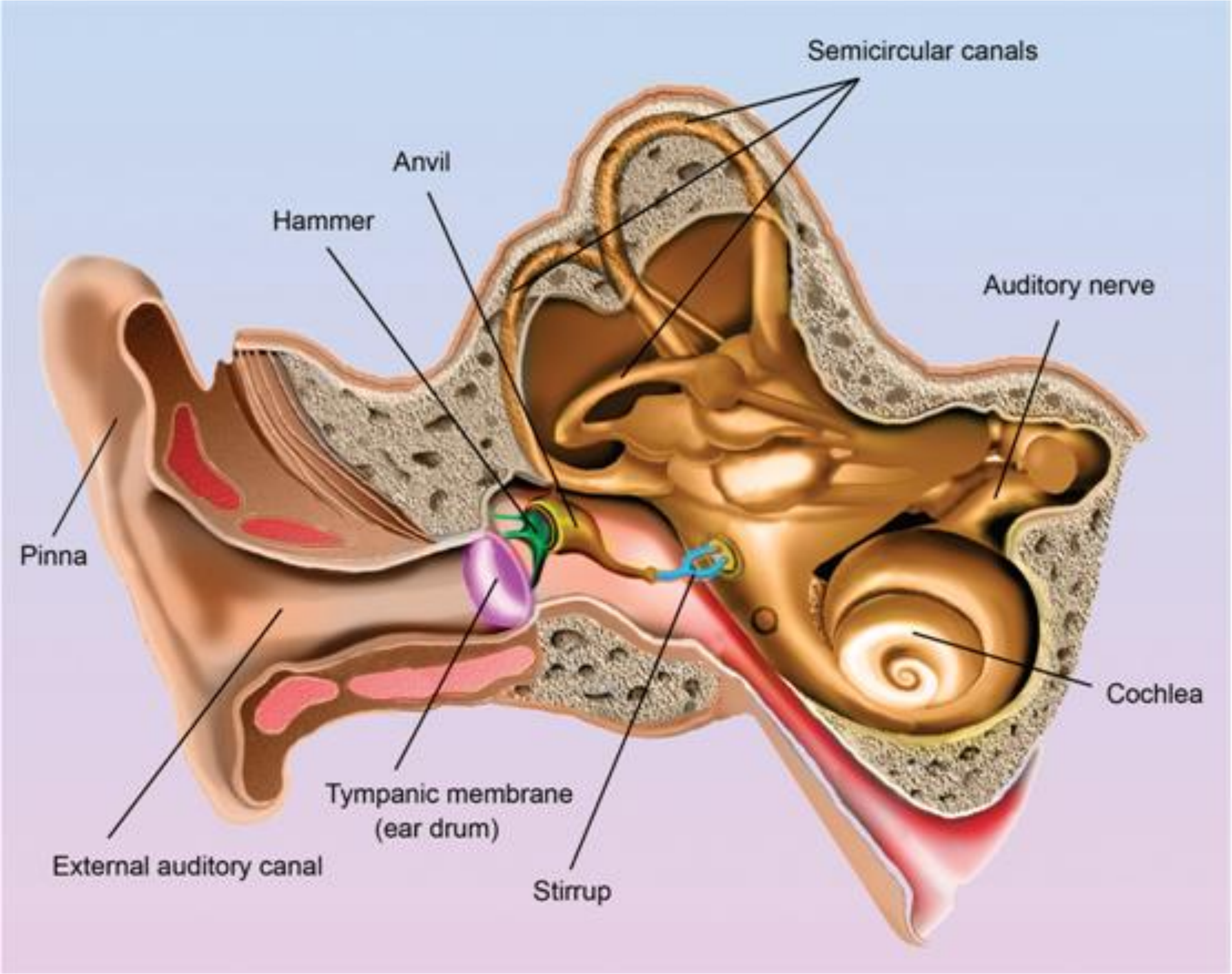


Auditory cortex





The outer, middle and inner ear



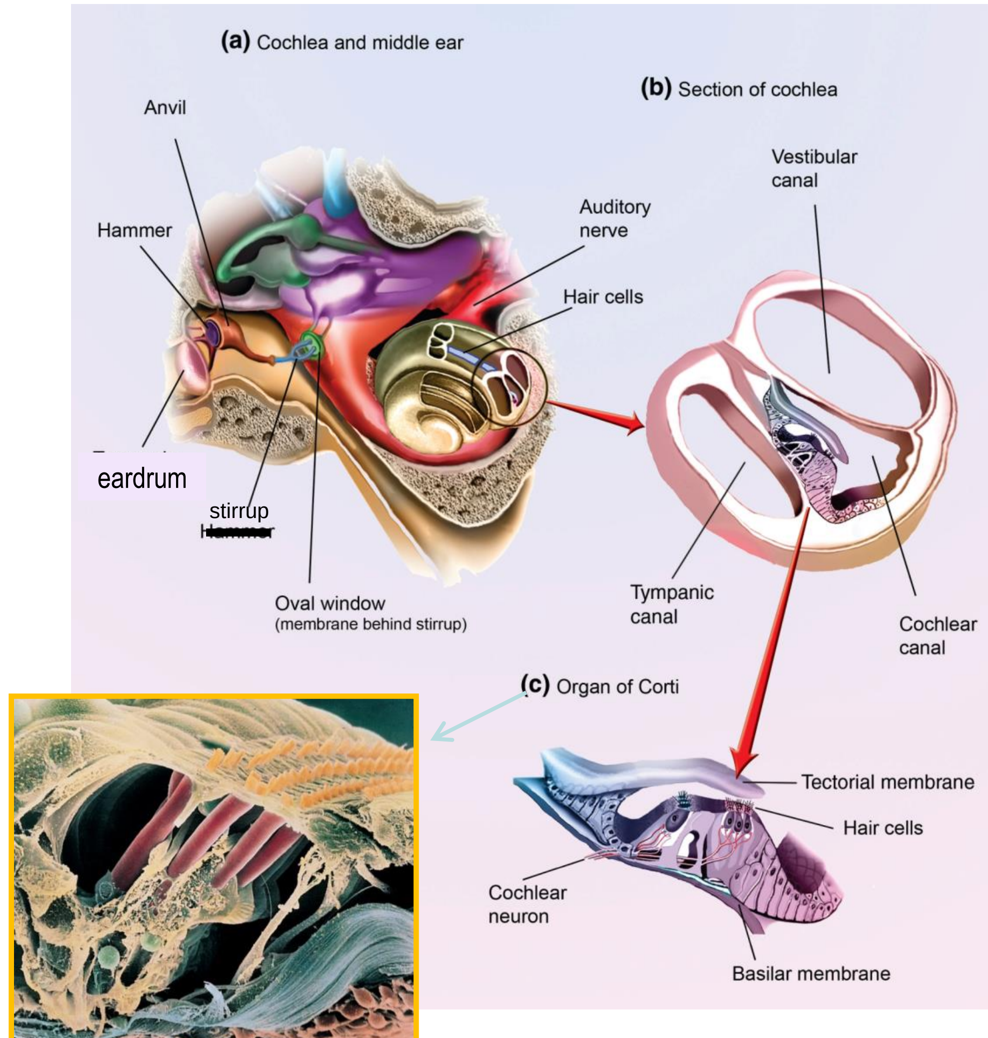
The outer and middle ear

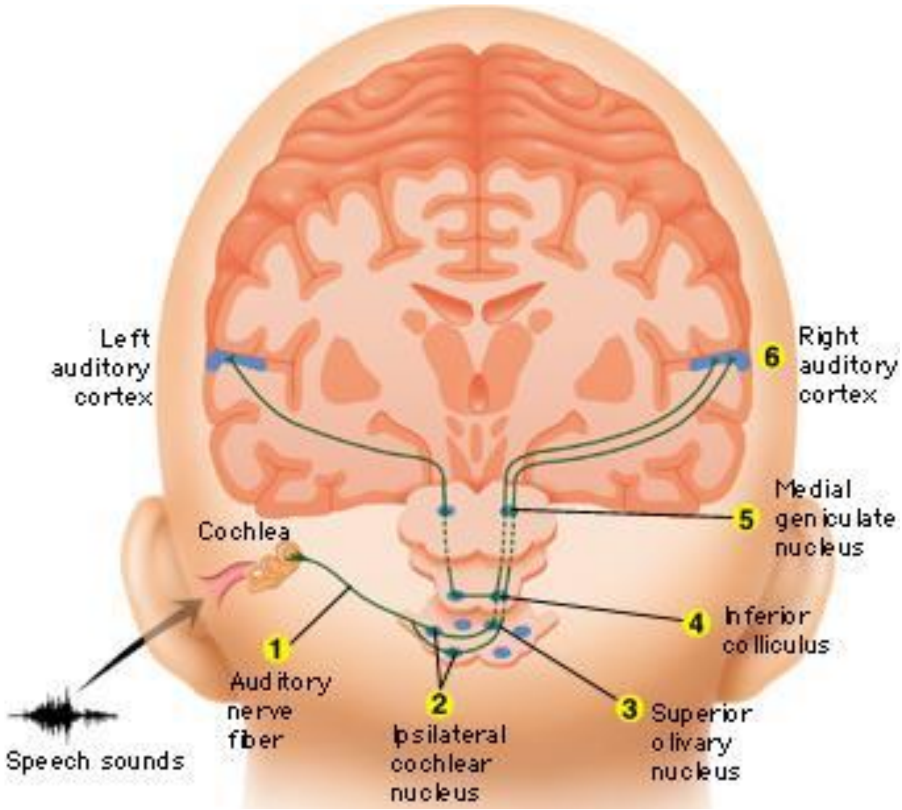
- The **outer ear** (= **pinna**)
  - captures the sound and amplifies it by funneling it into the smaller auditory canal
- The **middle ear**
  - the **eardrum** collects the vibrations
    - we can detect sound when the eardrum vibrates as little as the diameter of the hydrogen atom (Wilska 1935)
  - the eardrum transmits the vibration to the **ossicles** (3 small bones: **hammer, anvil & stirrup**) whose lever action transfers the vibration to the cochlea

The inner ear

- The **cochlea** (Latin: ‘snail’) is divided into three fluid-filled canals: vestibular, tympanic & cochlear canal
- The stirrup sends vibrations throughout the cochlea and to the organ of Corti (the sound-analyzing structure)
  - four rows of hair cells embedded in the basilar membrane
  - vibration bends the hair cells, opening potassium and calcium channels; this depolarizes the cells and sets off signals in the neurons
- The hair cells synaptically excite the cells of the auditory nerve (part of the 8th cranial nerve)

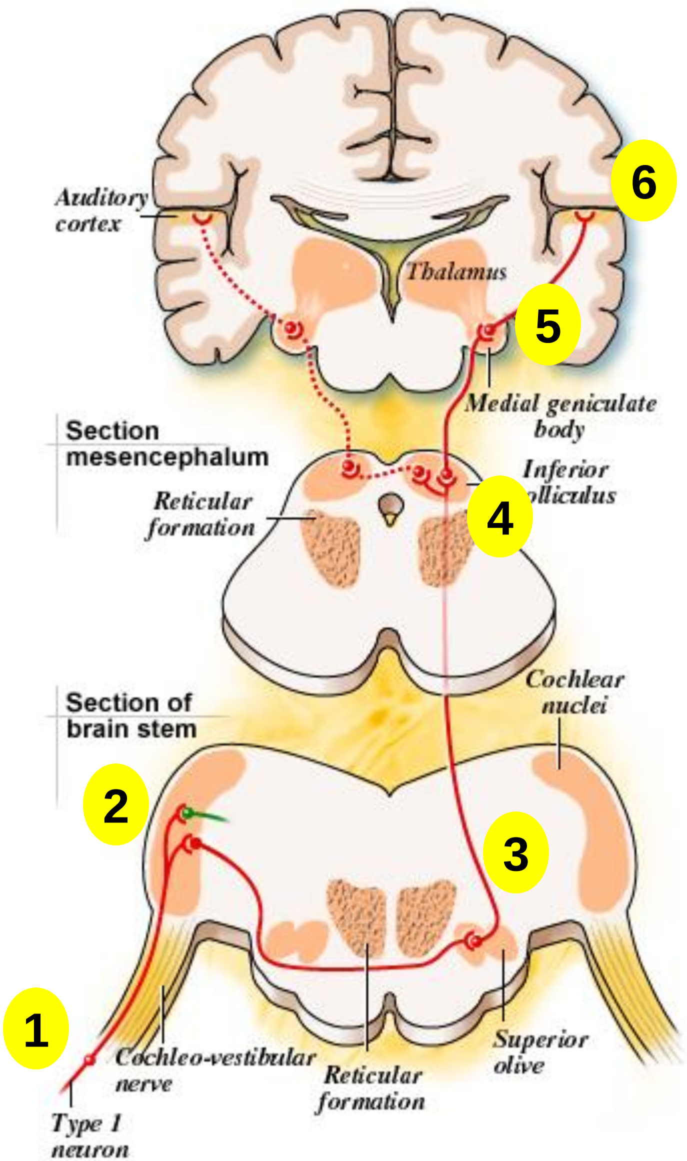
Watch Auditory transduction 2002 video on YouTube





Travel time for the sound (from the eardrum to the auditory cortex: approx 20 ms

Auditory pathway: from cochlea to cortex



6 There is a neuronal projection from the thalamus to the auditory cortex

5 **A final relay**, before the cortex, occurs in the thalamus (medial geniculate body).

4 **The third relay** takes place in the inferior colliculus of the midbrain (mesencephalon)

3 **The second relay** in the brain stem is in the superior olivary nucleus. The majority (but not all!) of the auditory fibres are contralateral

2 **The first relay**: ipsilateral cochlear nuclei in the brain stem, which receive input from the auditory nerve; some decoding of the signal duration, intensity and frequency occurs here

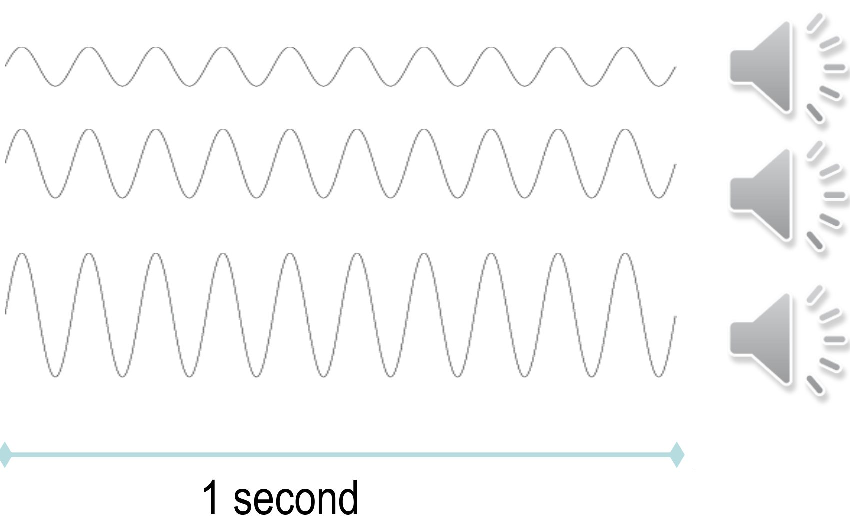
http://www.iurc.montp.inserm.fr/cric/audition/english/ptw/ptw.htm

Sound

- Sound – periodic compressions of air, water or another medium
  - An object (e.g. a tree) vibrates the air and sets up sound waves that hit the ear
- Physical properties of the sound
  - **Frequency**
  - **Intensity**
  - Sound source location (see *For the curious*)
  - Duration

Sound properties: intensity

- Intensity/amplitude: how much air fluctuation (compression/rarefaction) the sound creates, i.e., the energy in the sound
- Sound wave pressure is measured in decibels (dB, a logarithmic scale)
- A perceptual correlate of intensity (NB - no one-to one correspondence!): loudness

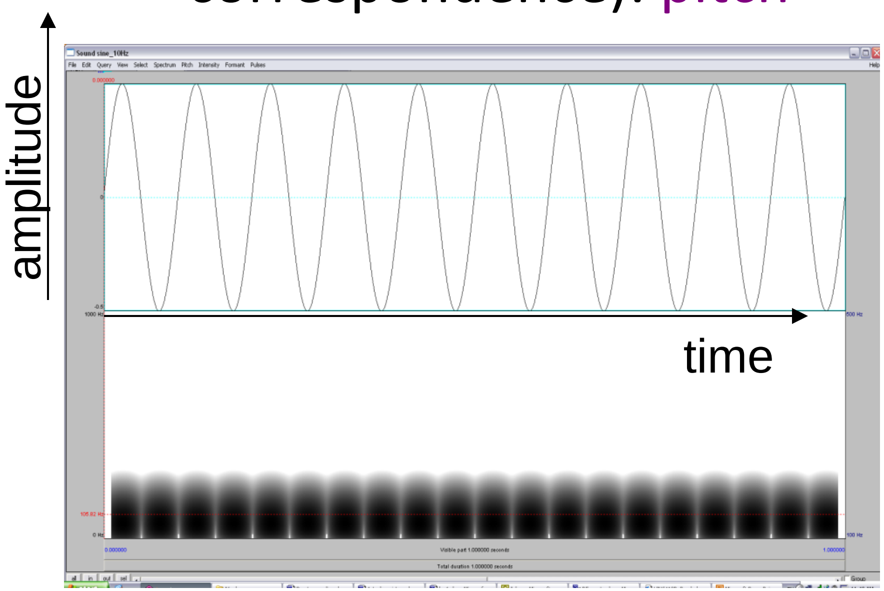


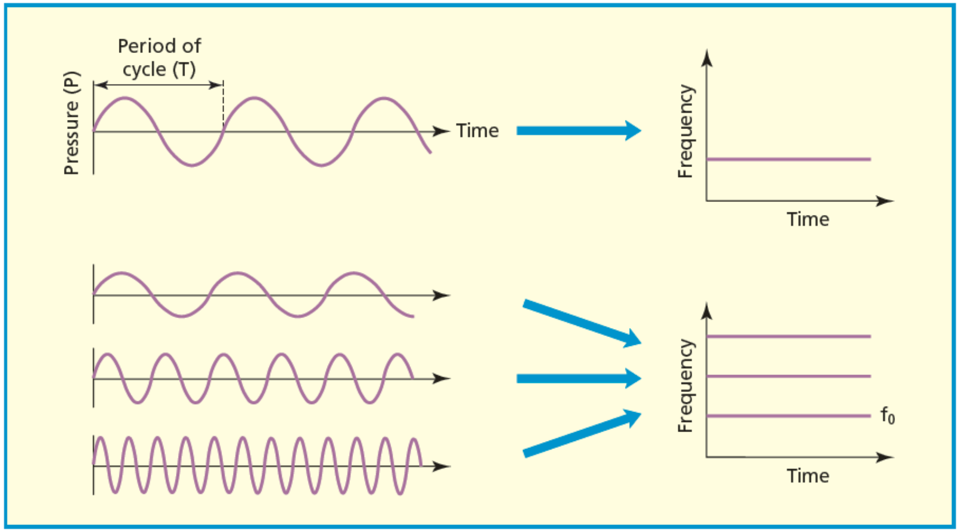
Weakest sound heard	0 dB
Whisper Quiet Library	30 dB
Normal conversation	60-70 dB
Telephone dial tone	80 dB
City Traffic (inside car)	85 dB
Truck Traffic	90 dB
Motorcycle	100 dB
Loud Rock Concert	115 dB
Pain begins	125 dB

Level at which sustained exposure may result in hearing loss

Sound properties: frequency

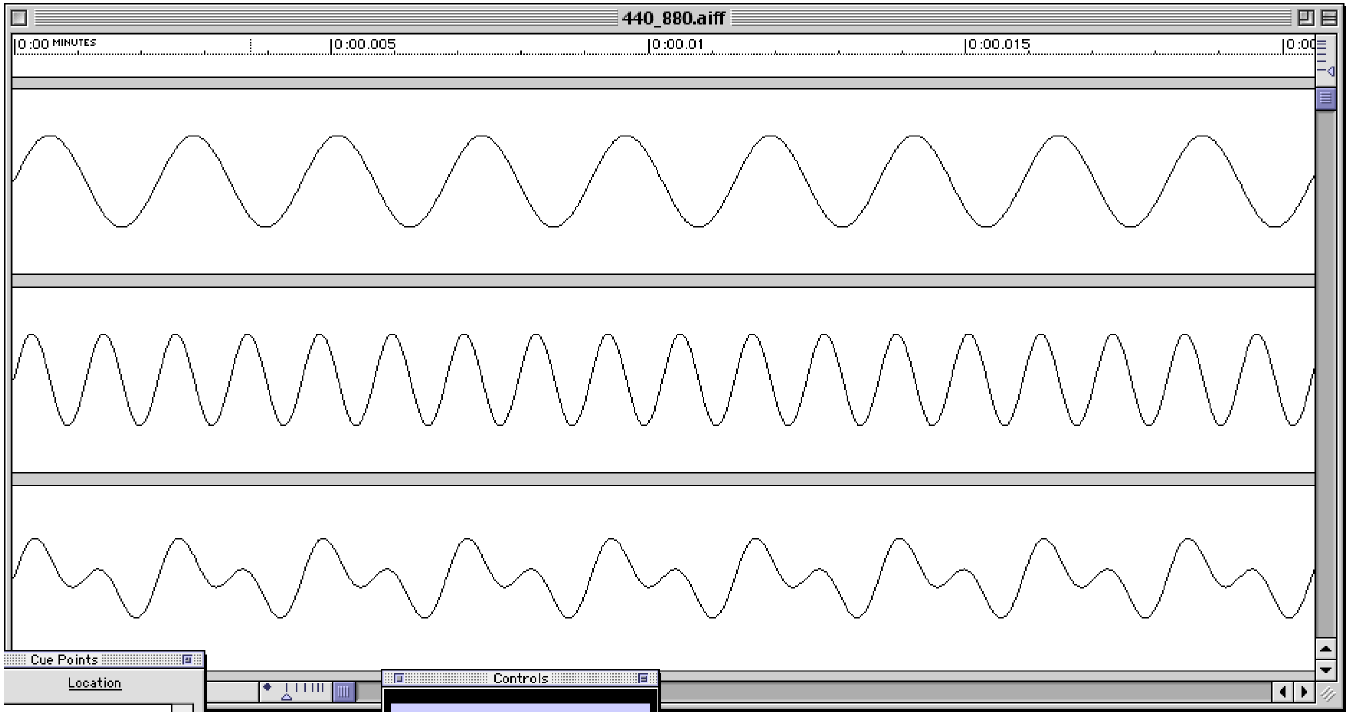
- Frequency – number of air compressions per second that the object creates
  - 100 compressions/cycles per second = 100 Hz
  - 1000 compressions (=1000 Hz = 1kHz)
    Period of each cycle = 1/1000 s = 1 ms
- A perceptual correlate of frequency (NB - no one-to one correspondence): pitch

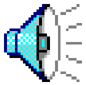




Complex tones (playing 2 notes together)

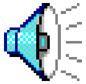
- Most sounds (music, speech or environmental sounds) are combined of many frequencies, i.e. complex tones



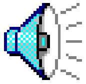


440 Hz

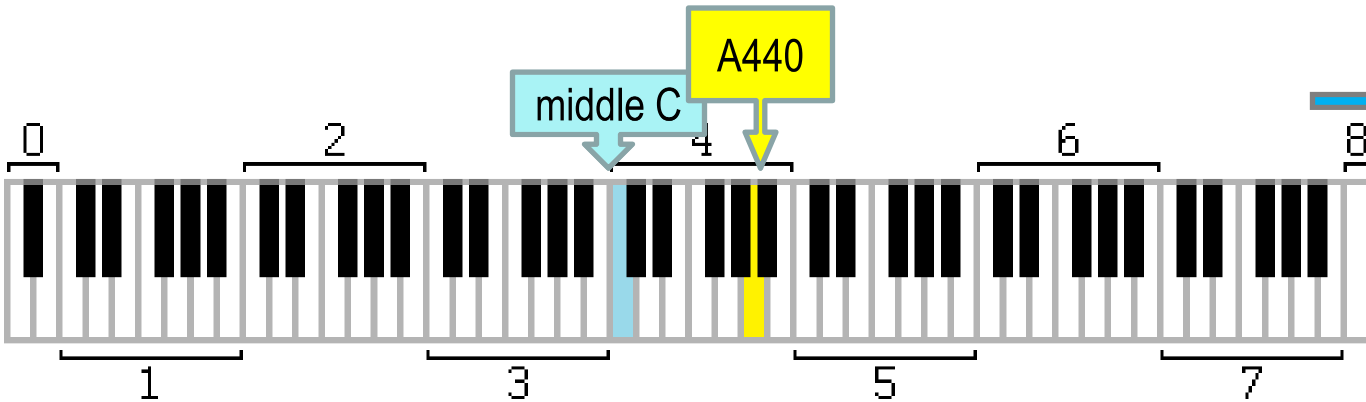
+



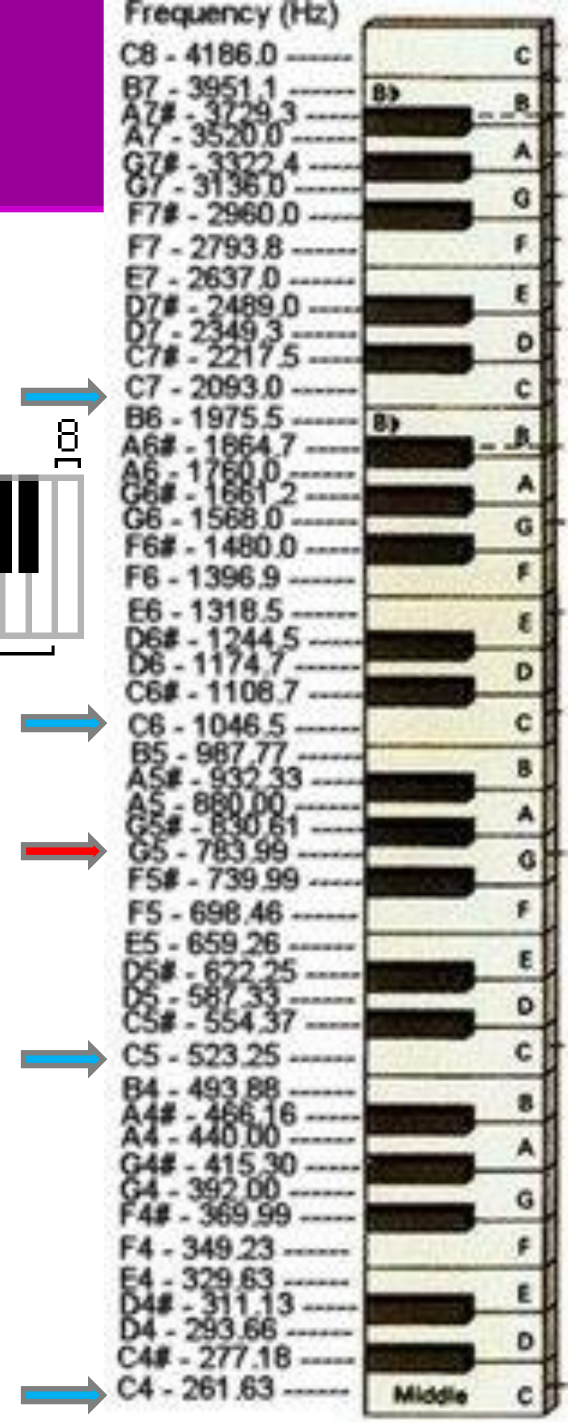
880 Hz



Σ



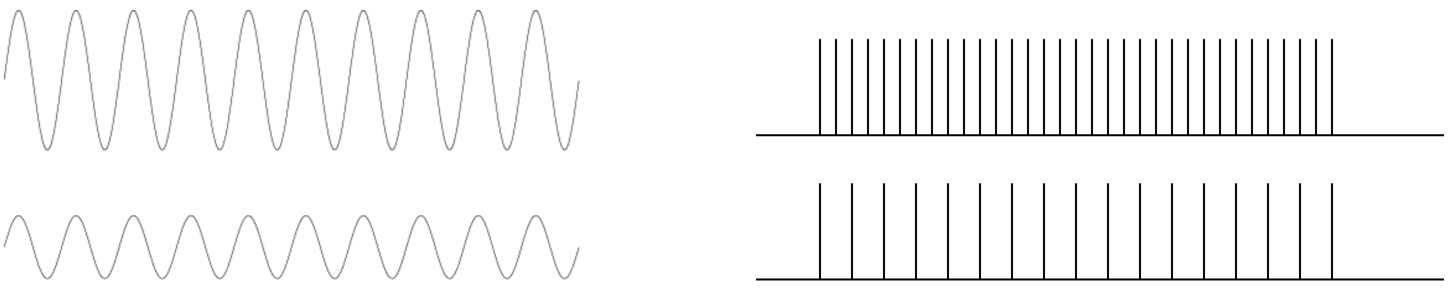
- 88-key piano, with the octaves numbered
  - Piano range: ~27-4200 Hz
  - Normal hearing range: ~15-20000Hz



How is sound intensity encoded by the brain?

- (For all frequencies above 200 Hz)

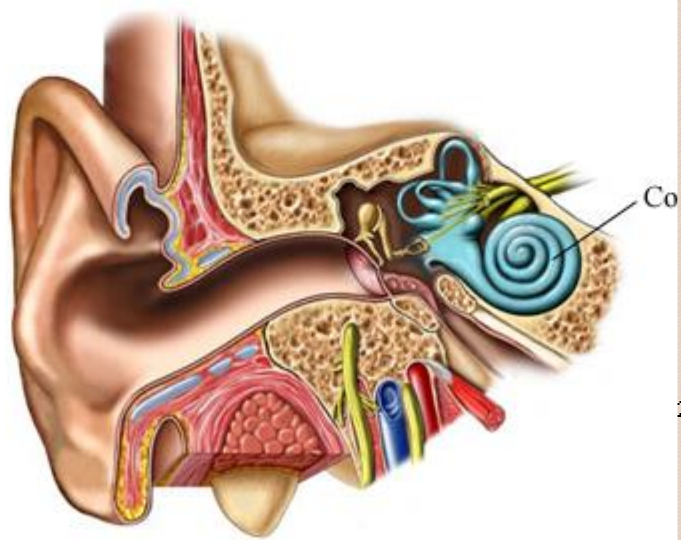
  Sound intensity is encoded via neuron firing rate:

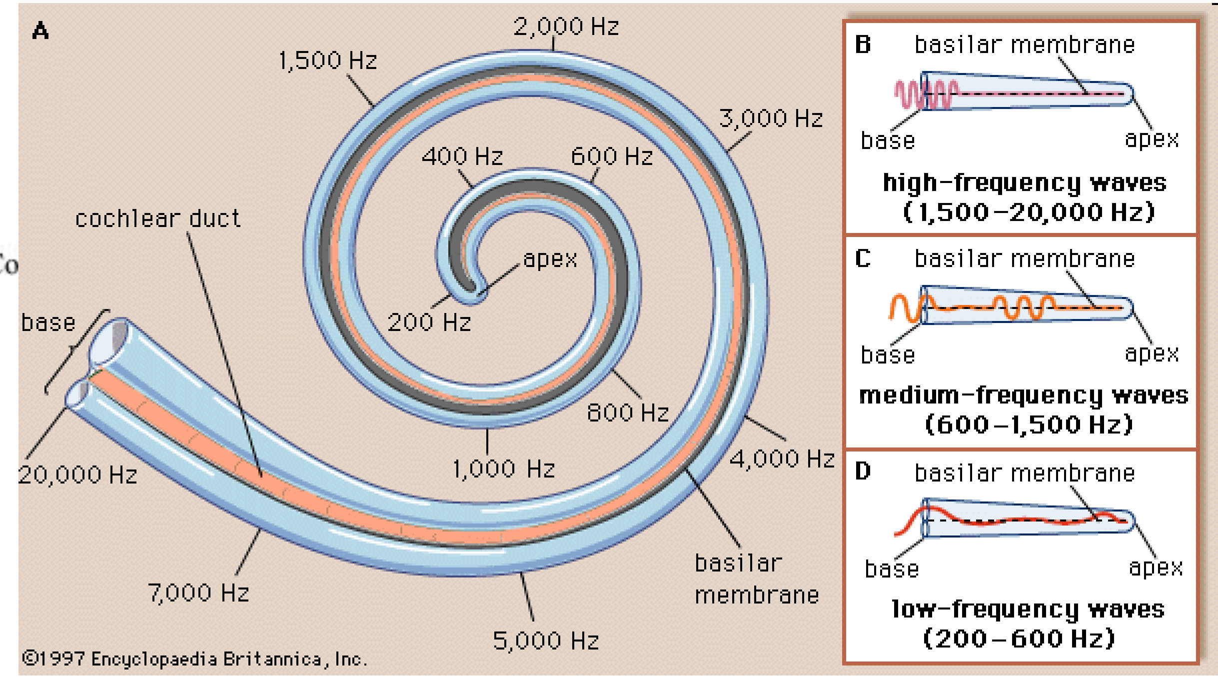


Neurons fire more frequently as sound intensity grows

How is sound frequency encoded by the brain?

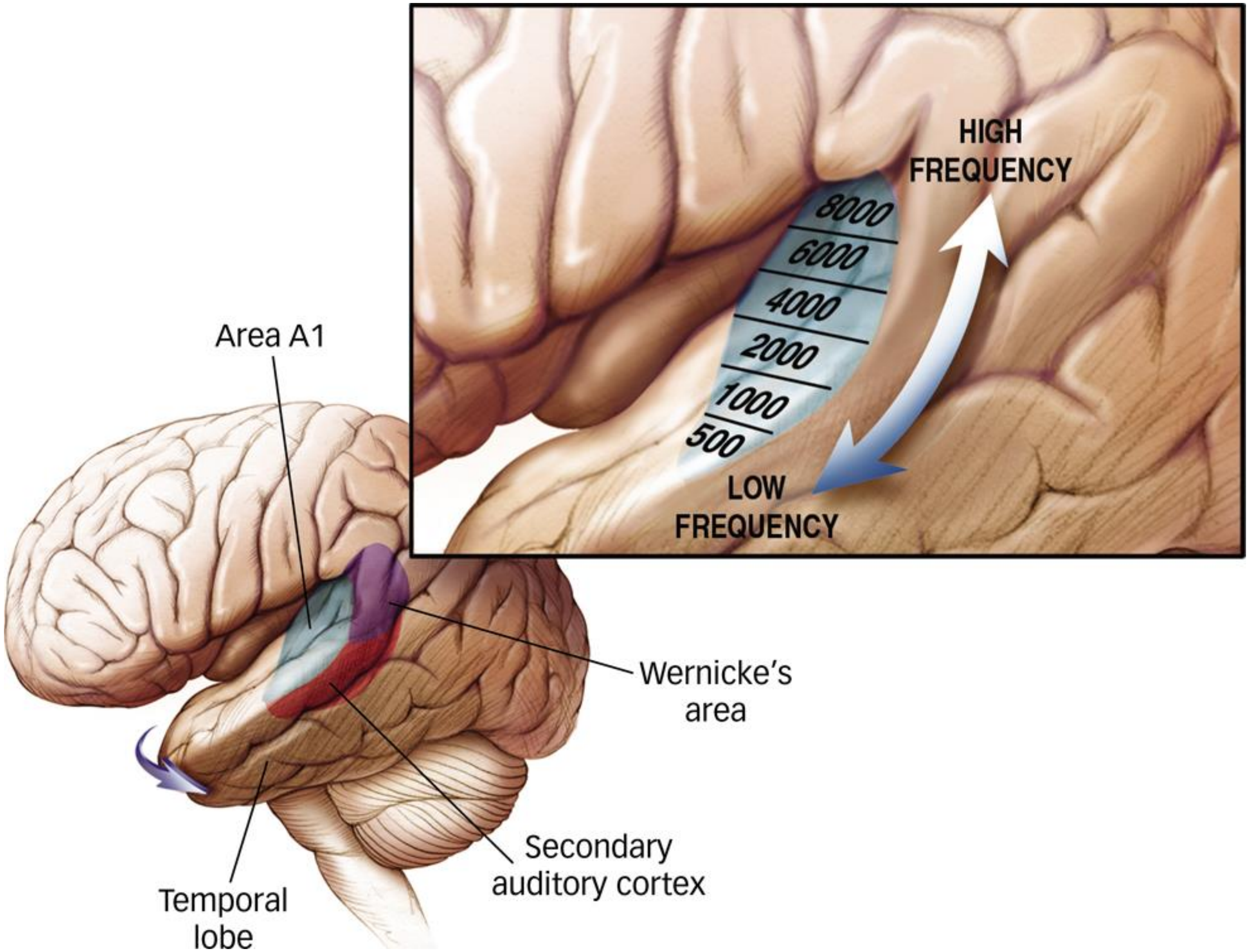
- **The Place code** (discovered by Georg von Békésy)
  - Different places along the cochlea respond to different sound frequencies because of differences in stiffness/elasticity of the cochlear membrane (the outside edge is 100 stiffer then the central end) – ‘tonotopic organisation’
    - Each frequency has its designated path from the cochlea to the brain





How is sound frequency encoded by the brain?

- Tonotopic organisation in the primary auditory cortex

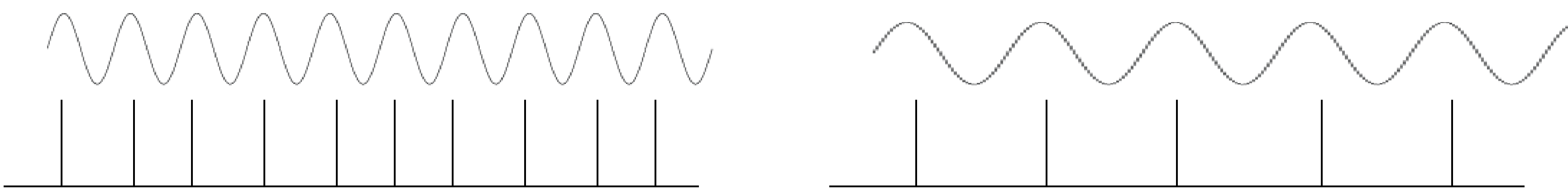


Special case: sounds with frequency <200 Hz

Q: The lowest frequency at the cochlea is around 200 Hz, how are frequencies below 200 Hz encoded?

A: The basilar membrane vibrates in synchrony with a sound, causing auditory nerve axons to produce action potentials with the same frequency (‘**the Temporal code**’)

- E.g., a 100 Hz sound causes 100 action potentials per second in the auditory nerve, a 50 Hz causes 50 APs/sec



- *Intensity:* the brain relies on the number of neurons firing, i.e., the higher stimulus intensity the higher the number of firing neurons

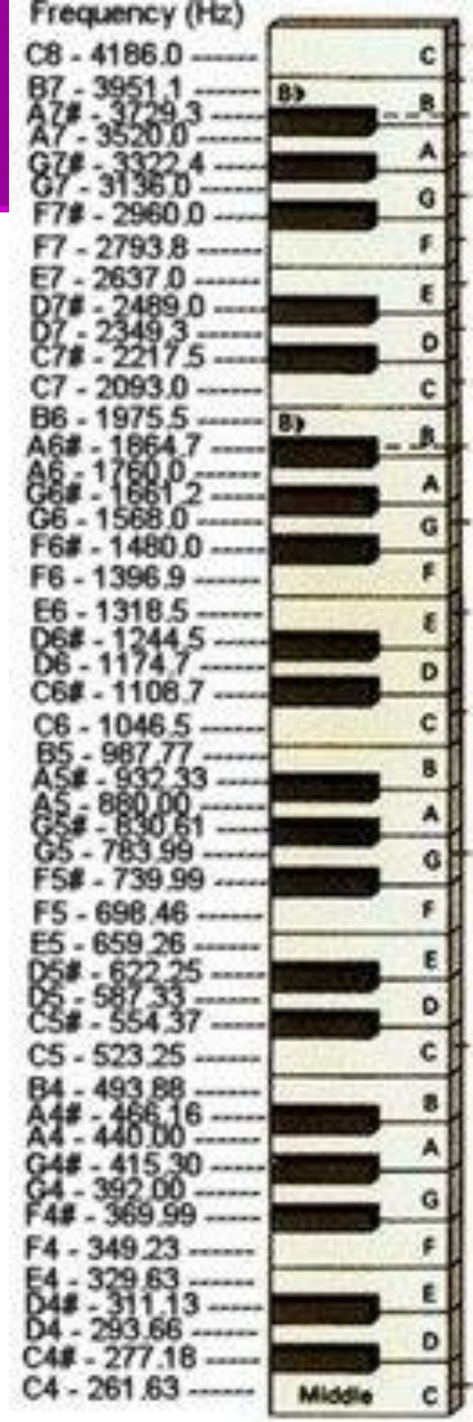
Brain encoding of sounds: summary

- Combination of Temporal & Place codes
  - Sound frequencies from 200 - 20000 Hz range are encoded in accordance with the Place code; their intensity is coded via neuron firing rate
  - Sound frequencies below 200 Hz are encoded in accordance with the Temporal code, i.e., through firing rate of individual neurons; their intensity is encoded via the number of firing neurons

A musical ear

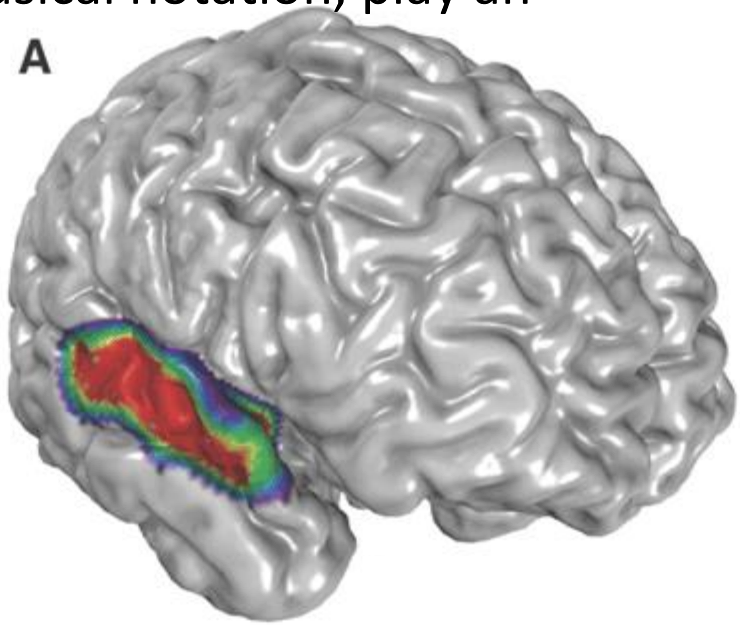
- **Relative pitch**
  - distance of a musical note from a given reference point (e.g. ‘three octaves above middle C’)
  - a musician's ability to identify the intervals between given tones
    - used by singers to correctly sing a melody, following musical notation, by pitching each note in the melody according to its distance from the previous note

- **Absolute pitch (= perfect pitch)**
  - ability to name/reproduce a musical note <u>without</u> an external reference (e.g., ‘middle A’)



Amusia (*aka* ‘musical deafness’)

- Congenital amusia (*aka* ‘tone deafness’, present from birth, ~4% of population) or acquired amusia as a result of brain damage (e.g., a lesion)
- Symptoms
  - inability to recognize familiar melodies, read musical notation, inability to detect wrong or out-of tune notes [receptive]
  - the loss of ability to sing, write musical notation, play an instrument [expressive]



Hearing deficits

- Conductive hearing loss
  - Results from damage to the eardrum or ossicles in the middle ear → failure to reansmit sound waves to the (intact) cochlea
  - Corrected by medication, surgery or by sound amplification from hearing aids, or by using bone conduction
- Sensorineural hearing loss ('nerve deafness')
  - Damage to (some part of) the cochlea/hair cells in the inner ear
  - Congenital, result of a disease or repeated exposure to loud noises
  - Corrected by cochlear implants: a surgically implanted electronic device which receives a sound signal via a microphone and conducts is via thin wires to directly stimulate the auditory nerve
  - As of 2009 about 200,000 people worldwide had cochlear implants

Positive brain damage?

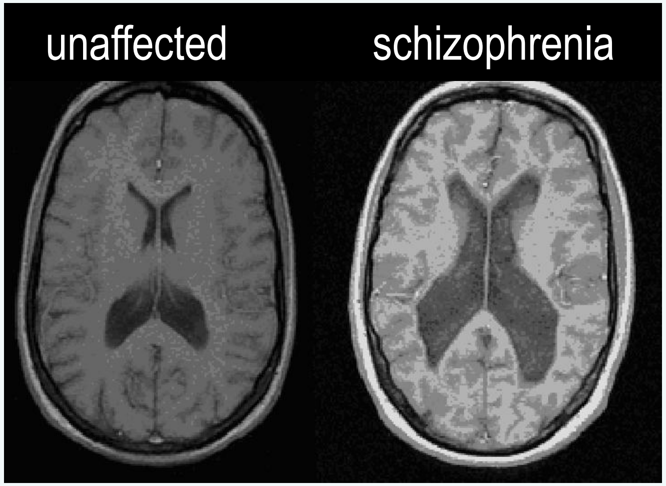
Dmitri Shostakovich (1906 – 1975)

Sound perception in the absence of sounds

- Tinnitus (from Latin *tinnītus* "ringing"): the perception of sound within the human ear in the absence of corresponding external sound
  - Inner ear damage caused by aging, as a side effect of medication, or as a result of noise-induced hearing loss (most common)
  - The persisting sound percept comes from an enlarged sector in the auditory cortex in which neurons are responding in a coordinated way in the absence of sound
  - Two subtypes of tinnitus:
    - persistent ringing is dependent on abnormal patterns of activity that the damaged inner ear is feeding to the brain (cured by surgically severing the auditory nerve)
    - plastic changes in the brain to the extent that it can now sustain itself without ear inputs to generate the continuous ringing noises (not cured by surgically severing the auditory nerve)

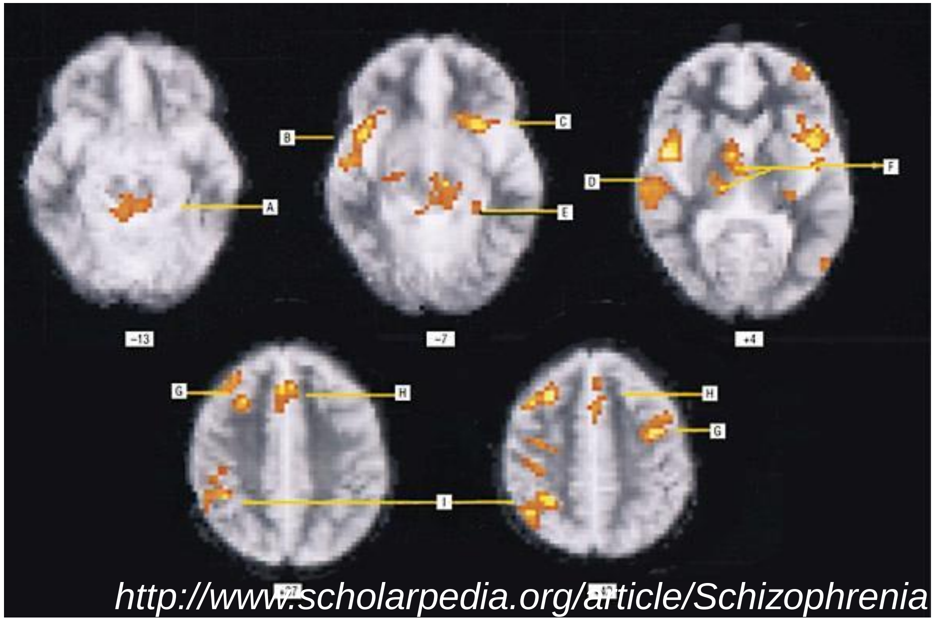
Sound perception in the absence of sounds: schizophrenia

Axial MR image of the brains of the monozygotic twins unaffected and affected with schizophrenia showing ventricular enlargement in the affected twin.



fMRI activations during auditory hallucinations in schizophrenia (Shergill et al, 2000):

- **right inferior colliculus (A)**
- right and left insula (B and C)
- left parahippocampal gyrus (E)
- **right superior temporal gyrus (D)**
- **right thalamus (F)**



http://www.scholarpedia.org/article/Schizophrenia

Summary

- Sounds – periodic compressions of air with physical properties such as intensity, frequency, duration, sound source location
- How the brain encodes sounds
  - Sound frequency is (most often) encoded via the tonotopic organisation of the cochlea and the auditory cortex
  - Sound intensity is (most often) encoded via the neuron firing rate
- Hearing deficits of different nature resulting from damage to different part of the ear/auditory nerve

Selected readings

- SGW, Chapter 4(Sensation and Perception) – pp.150-155
- Kalat, Chapter 7, module 7.1
- Garrett, Chapter 9, p.255-273

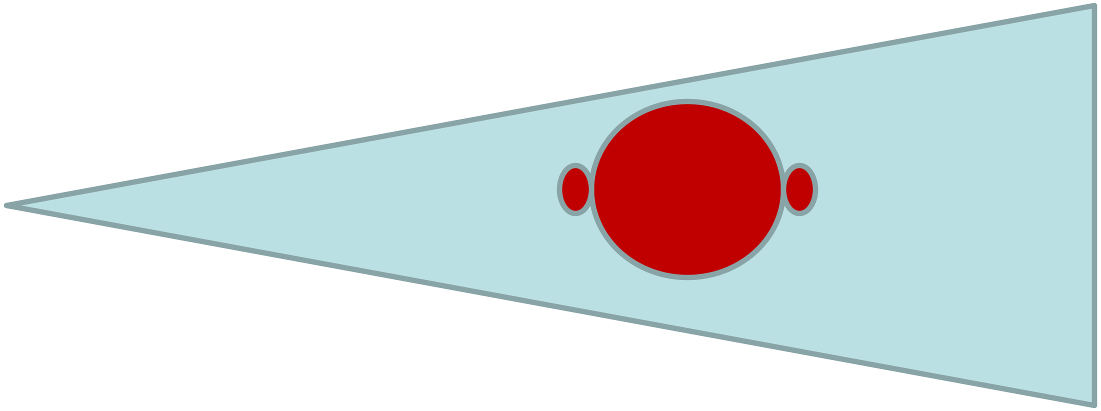
- Auditory Transduction (20002) video:
  - https://www.youtube.com/watch?v=PeTriGTENoc
- An interesting blog entry on tinnitus by Michael Merzenich:
  - http://blog.positscience.com/2010/06/21/tinnitus-a-special-example-of-a-failure-mode-for-your-plastic-brain/

References

- Shergill, S. S., Brammer, M. J., Williams, S. C., Murray, R. M., & McGuire, P. K. (2000). Mapping auditory hallucinations in schizophrenia using functional magnetic resonance imaging. *Archives of general psychiatry*, *57*(11), 1033-1038.

For the curious: Determining sound location

- Listeners can identify where the sound source is: in front/behind, left/right
- Three main *binaural* (involve the use of both ears) cues for sound localization:
  - difference in intensity between the ears
  - difference in time of arrival at two ears
  - phase difference between ears



For the curious

- The beginning of this post explains how sound localisation is computed in the barn owl:

  http://www.talkingbrains.org/2014/10/embodied-or-symbolic-who-cares.html

- A great discussion of the difference between sound intensity (physical property of the sound) and sound loudness (perceptual correlate of intensity)

  http://hyperphysics.phy-astr.gsu.edu/hbase/sound/loud.html