COGS 101A: Sensation and Perception

Virginia R. de Sa

Department of Cognitive Science

UCSD

Lecture 14:

Audition continued

Course Information

- Class web page: http://cogsci.ucsd.edu/ desa/101a/index.html
- Professor: Virginia de Sa
  - I'm usually in Chemistry Research Building (CRB) 214 (also office in CSB 164)
  - Office Hours: Monday 5-6pm
  - email: desa at ucsd
  - Research: Perception and Learning in Humans and Machines

For your Assistance

TAS:

- Jelena Jovanovic OH: Wed 2-3pm CSB 225
- Katherine DeLong OH: Thurs noon-1pm CSB 131

IAS:

- Jennifer Becker OH: Fri 10-11am CSB 114
- Lydia Wood OH: Mon 12-1pm CSB 114

Course Goals

- To appreciate the difficulty of sensory perception
- To learn about sensory perception at several levels of analysis
- To see similarities across the sensory modalities
- To become more attuned to multi-sensory interactions

Grading Information

- 25% each for 2 midterms
- 32% comprehensive final
- 3% each for 6 lab reports - due at the end of the lab
- Bonus for participating in a psych or cogsci experiment AND writing a paragraph description of the study (just a few sentences) Deadline to sign up for experiments on Experimetrix is TOMORROW (Weds before Thanksgiving)
- New lenient midterm policy: If you do better on the final than your worst midterm, we'll downweight that midterm to 10% (and upweight the final); If you do better on the final than your best midterm, we'll downweight that midterm to 15%. There will be no downweighting of the final. We will also drop your lowest lab grade IF you complete all labs

You are responsible for knowing the lecture material and the assigned readings. Read the readings before class and ask questions in class.

Academic Dishonesty

The University policy is linked off the course web page.

You will all have to sign a form before each test

For this class:

- Labs are done in small groups but writeups must be in your own words
- There is no collaboration on midterms and final exam

Midterm 2

Congratulations! Generally grades are very high.

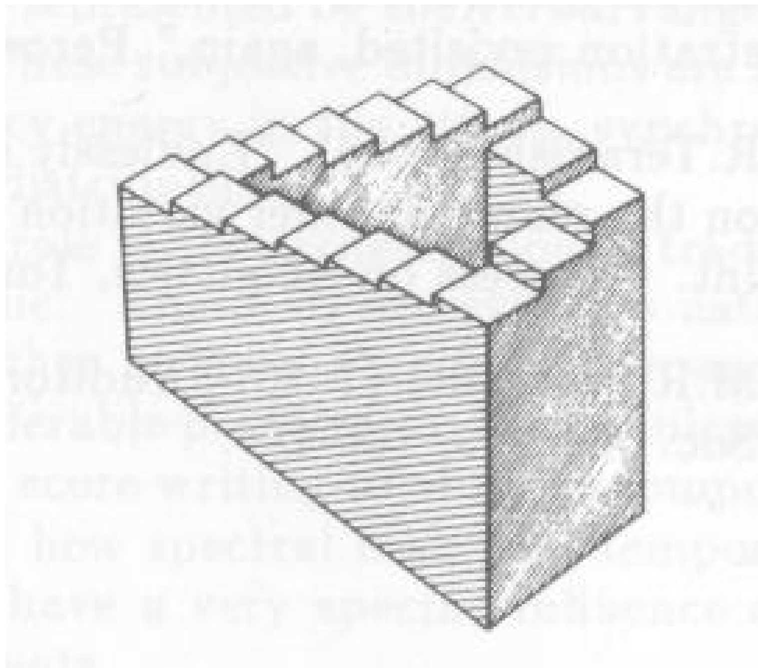
Mean

Median

Low

High

Review of Shepard Tones



http://www.acs.appstate.edu/ kms/classes/psy3203/MusicIllusions/Shepard_Scale.swf

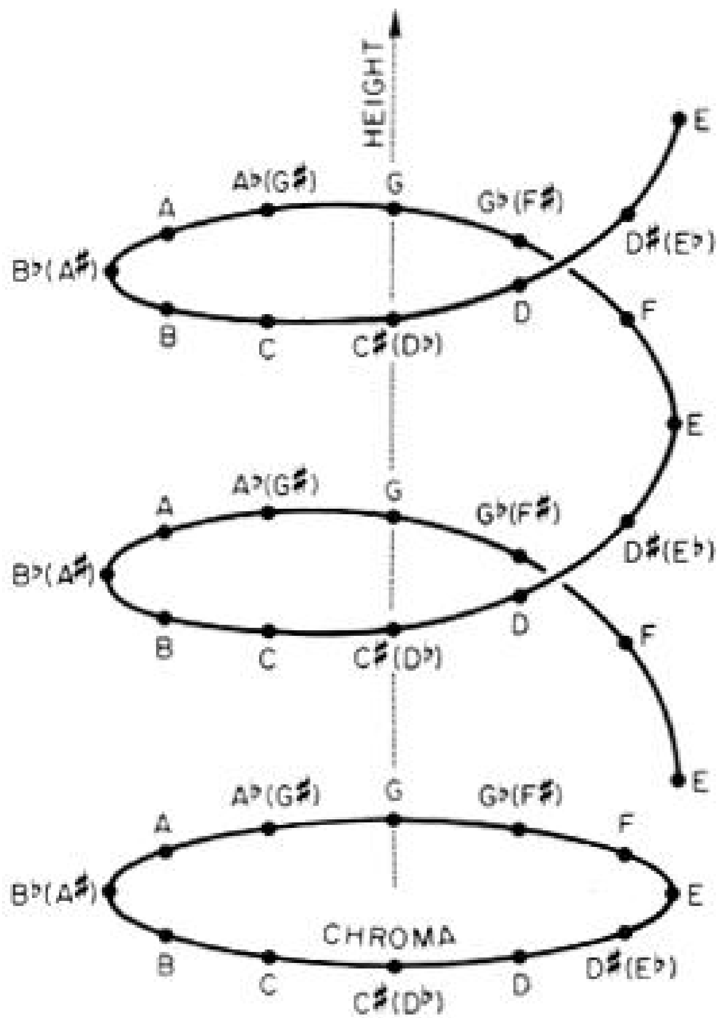
Shepard's Tones demo

http://www.acs.appstate.edu/ kms/classes/psy3203/MusicIllusions/Shepard_Scale.swf

Pitch is perceived frequency.

Tone chroma

tone chroma refers to the letter name we give to a tone.



[after Shepard 1982] from http://ccat.sas.upenn.edu/music/music55/sept16.html

The tritone paradox

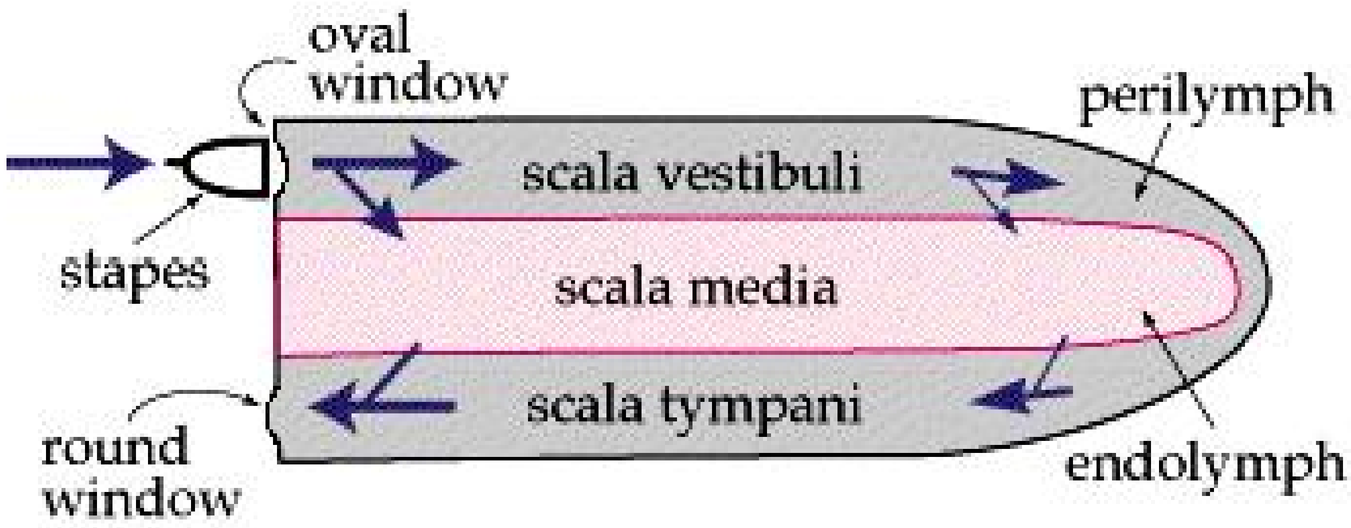
In the Shephard's tones the octave chords keep stepping by one semitone til they wrap around. In the tritone paradox, two octave chords consisting of notes six semitones apart are alternated. Some people find the pitch of the one to be higher and others find the pitch of the other to be higher. Even musicians will disagree. The way you hear it is related to your auditory experience.

Tritone Paradox demo
http://www.cs.ubc.ca/nest/imager/contributions/flinn/Illusions/TT/tt.html

Review of the Cochlea

The cochlea is a snail shaped fluid filled structure.

Through most of its length, it is divided into 3 chambers **scala vestibuli** (top) **scala media** (middle) and **scala tympani** (bottom)



http://thalamus.wustl.edu/course/audvest.html

Pressure waves start at the oval window at base of top chamber and move to apex of cochlea then to bottom chamber and back to base of the bottom chamber (round window)

The Cochlea

The scala media (book uses the term cochlear partition) contains the **Organ of Corti** which contains the **hair cells** which transduce the vibrations.

Basilar membrane is the floor of the Organ of Corti

Tectorial membrane is the ceiling of the Organ of Corti

Hair cells lie between. **Inner hair cells** lie in the basilar membrane and don't reach the tectorial membrane. **Outer hair cells** have their hairs embedded in the tectorial membrane.

The pressure wave in the scala vestibuli and scala tympani sets up vibrations in the scala media. The basilar membrane goes up and down and the Tectorial membrane goes side to side.

great basilar membrane movie http://www.sissa.it/multidisc/cochlea/twlo.htm (Fabio Mammano)

Hair cells

The motion of the basilar membrane and tectorial membrane cause the cilia (hair like structures) on the hair cells to bend and transduce the vibrations to electrical signals.

Motion of the cilia in one direction cause depolarization of the hair cell and in the other direction cause hyperpolarization.

Inner hair cells are responsible for most of the sound coding

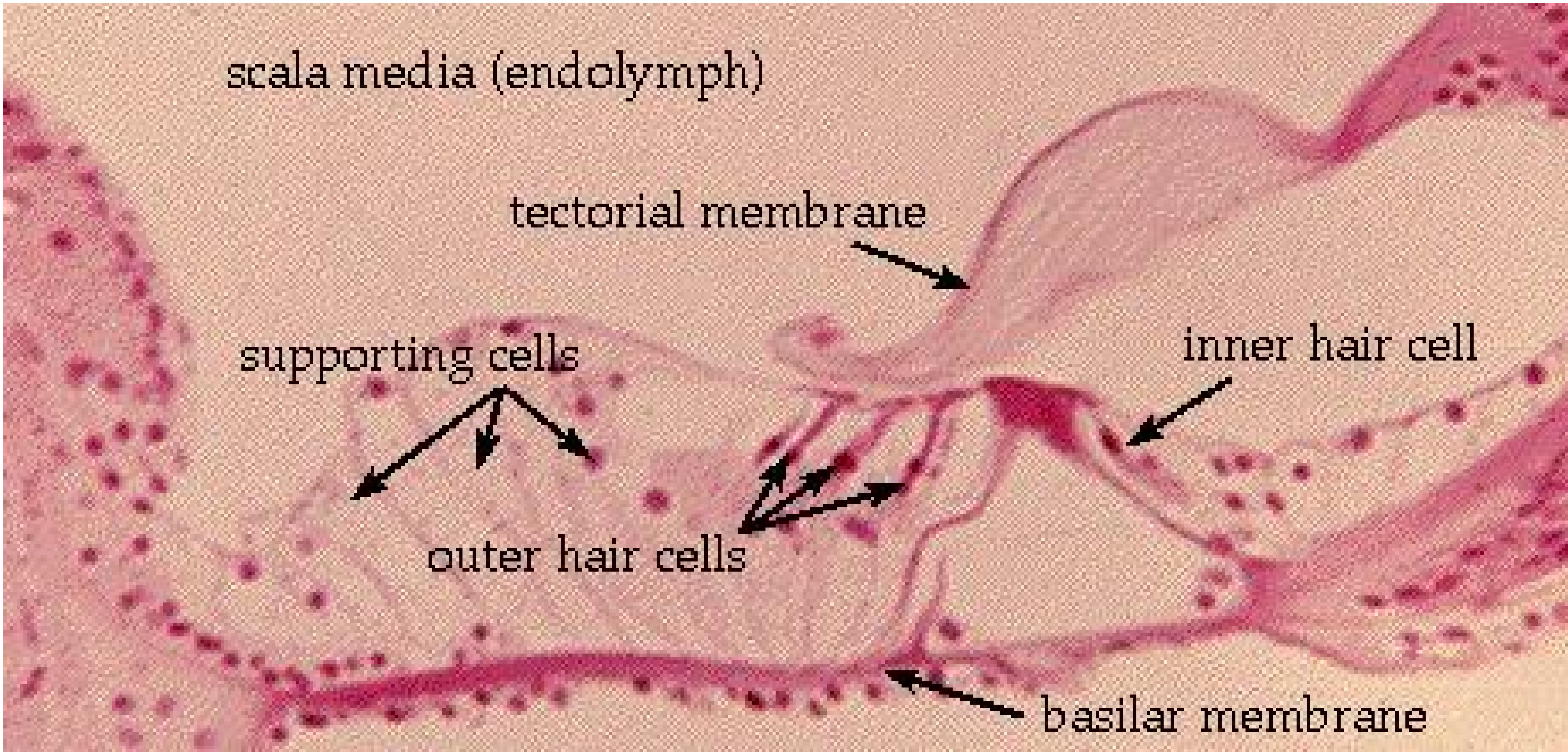
Outer hair cells serve to amplify the motion of the basilar membrane by stretching and shortening as they hyperpolarize and depolarize (respectively)

great movie of outer hair cells shortening
http://www.sissa.it/multidisc/cochlea/transduc.htm (Fabio Mammano)

real outer hair cell movie http://www.sissa.it/multidisc/cochlea/ohc.htm (Fabio Mammano)

new basilar membrane movie http://www.biomedsci.creighton.edu/faculty/he.html

The Organ of Corti



http://thalamus.wustl.edu/course/audvest.html

The Cochlea

The base of the cochlea (near the oval and round windows) is narrow and stiff

The apex of the cochlea is wide and floppy

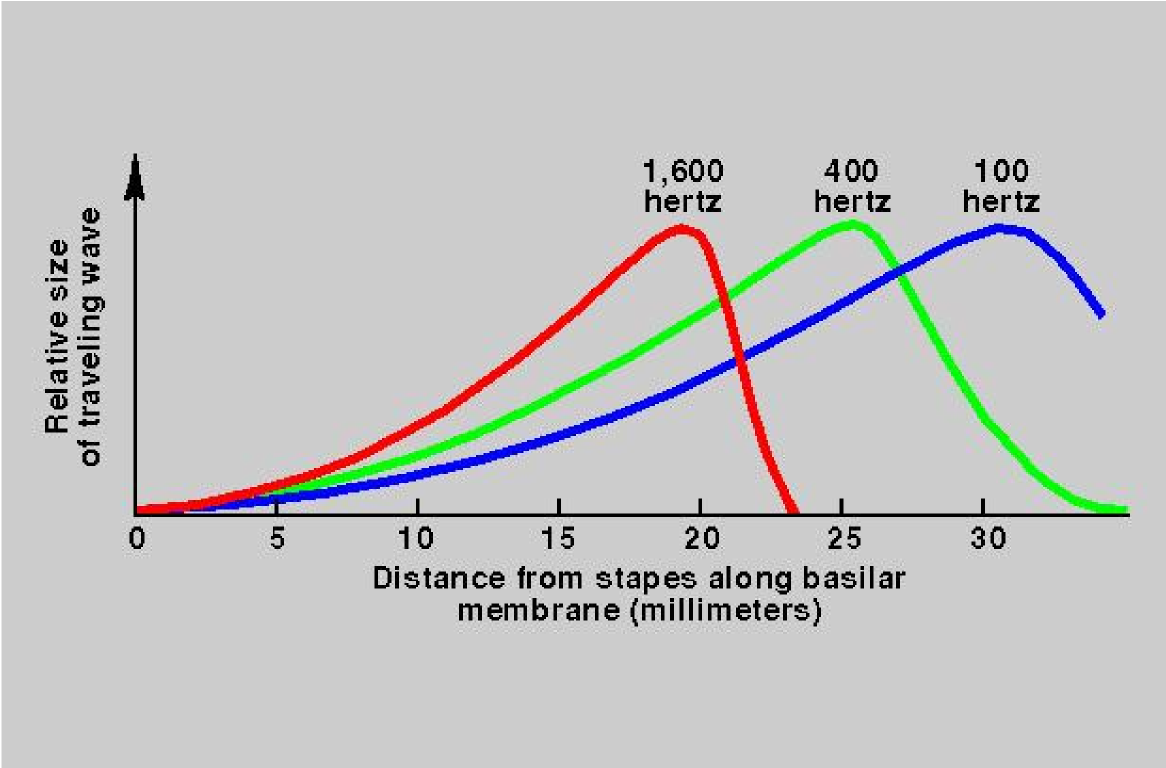
Helmholtz (1863) predicted that fibers at base end would resonate at high frequencies and those at apex at lower frequencies

Georg von Békésy observed basilar membrane vibration in cadavers and modeled the structure physically.

He proposed the **place theory for hearing** : frequency is indicated by the place of maximum firing rate along the cochlea

Place coding for frequency

Sound vibrations cause traveling wave in the Basilar membrane. The **envelope** of the wave will be maximal for different frequencies. The envelope shows the maximum length of travel for the membrane as the wave passes.



http://www.awa.com/norton/struc/chap_05/figures.html

Larger membrane fluctuations result in more hair cell displacement and more neurotransmitter (NT) release

Physiological evidence for Place coding

We can measure hair cell (and auditory nerve fiber) **tuning curves** (plot of dBSPL to elicit a small response vs Frequency). The frequency of greatest sensitivity is called the **characteristic frequency** (draw example on board)

Characteristic frequencies change smoothly across the cochlea

Population coding

Note that with loud sounds, all of the basilar membrane vibrates (but the part most sensitive to the heard frequency moves most).

At very low sounds only the most sensitive part to that frequency moves.

The code for frequency must involve comparing relative firing rates (population code)

More complex sounds

More complex sounds consist of many frequency components – Many parts of the basilar membrane will be very excited. The cochlea performs a “fourier” analysis breaking the sound into its frequency components.

Limitations to Place Code

- We can discriminate more finely than tuning curves suggest
- We can discriminate at high amplitudes (where many places might be maxed out)
- We can discriminate frequencies that would be off the Basilar membrane (too low)

Place coding AND temporal coding for frequency

Place coding for frequency Different frequencies are coded maximally at different places along the basilar membrane

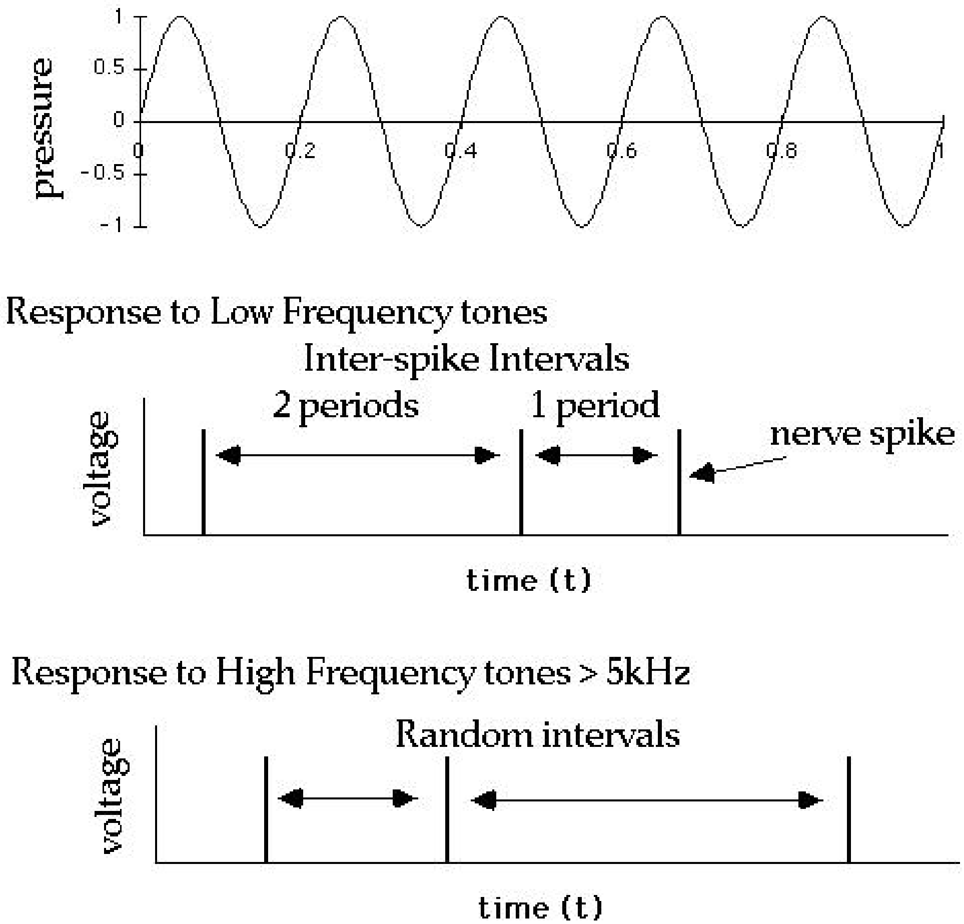
The base of the cochlea (near the oval and round windows) is narrow and stiff and codes for high frequencies

The apex of the cochlea codes for low frequencies

In addition to place coding, there is ...

Temporal coding for frequency The auditory nerve fibers tend to phase lock to the sound (for frequencies below about 4000Hz). This is because for a 1000Hz sound, the basilar membrane moves up and down 1000 times per second (at 2000Hz it moves up and down 2000 times per second).

Temporal coding for frequency



Psychophysical evidence of frequency code

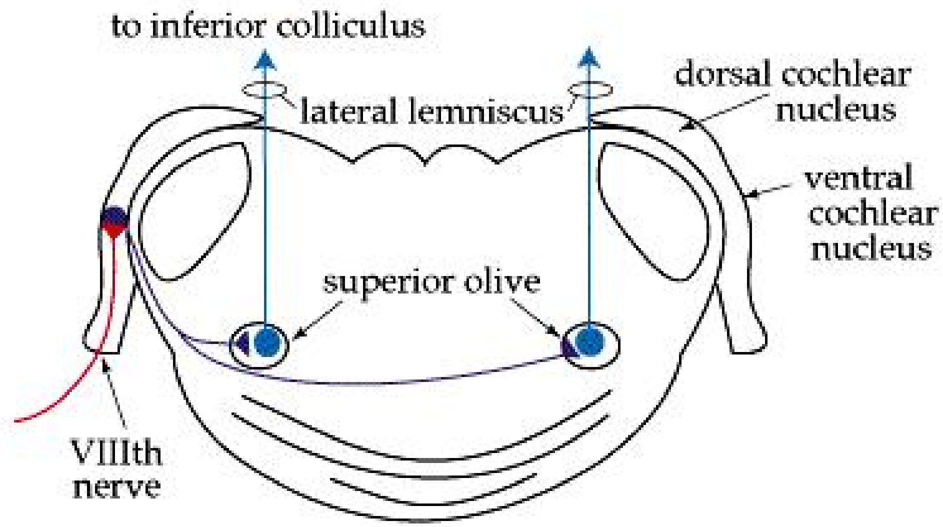
Play "white noise" (all frequencies) in bursts at a rate of 1000/second. People hear this with a pitch of 1000Hz.

NOTE: Each neuron does not have to fire at every peak. In particular at rates above 1000Hz, it can't. But as long as it has a greater tendency to fire at the peak, the population code will follow the frequency nicely.

Auditory pathway after the cochlea

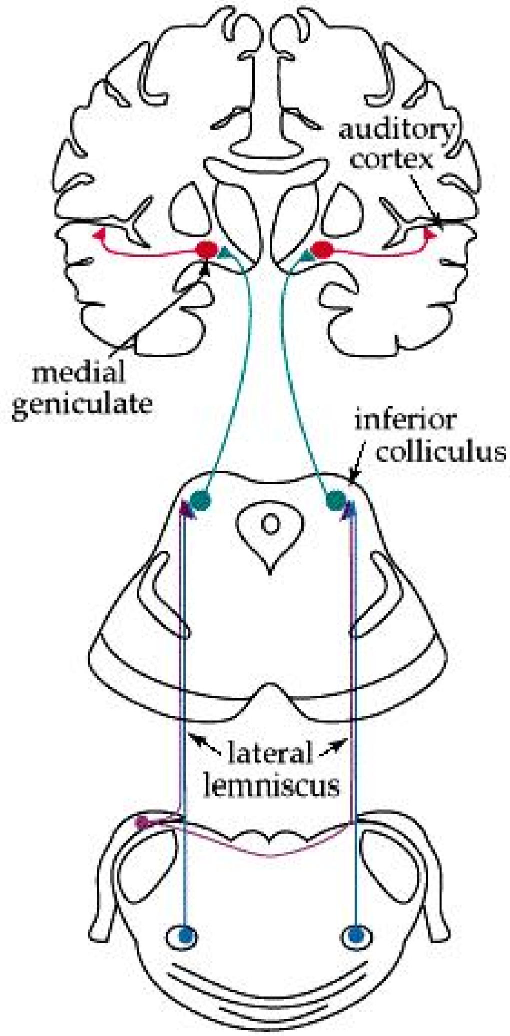
The auditory nerve collects information from the hair cells and transmits it to the **cochlear nucleus** and then the superior olivary nucleus and then the **inferior colliculus** and the medial geniculate nucleus (MGN) of the thalamus (remember lateral geniculate nucleus for vision).

The MGN projects to the **primary auditory cortex (A1)**



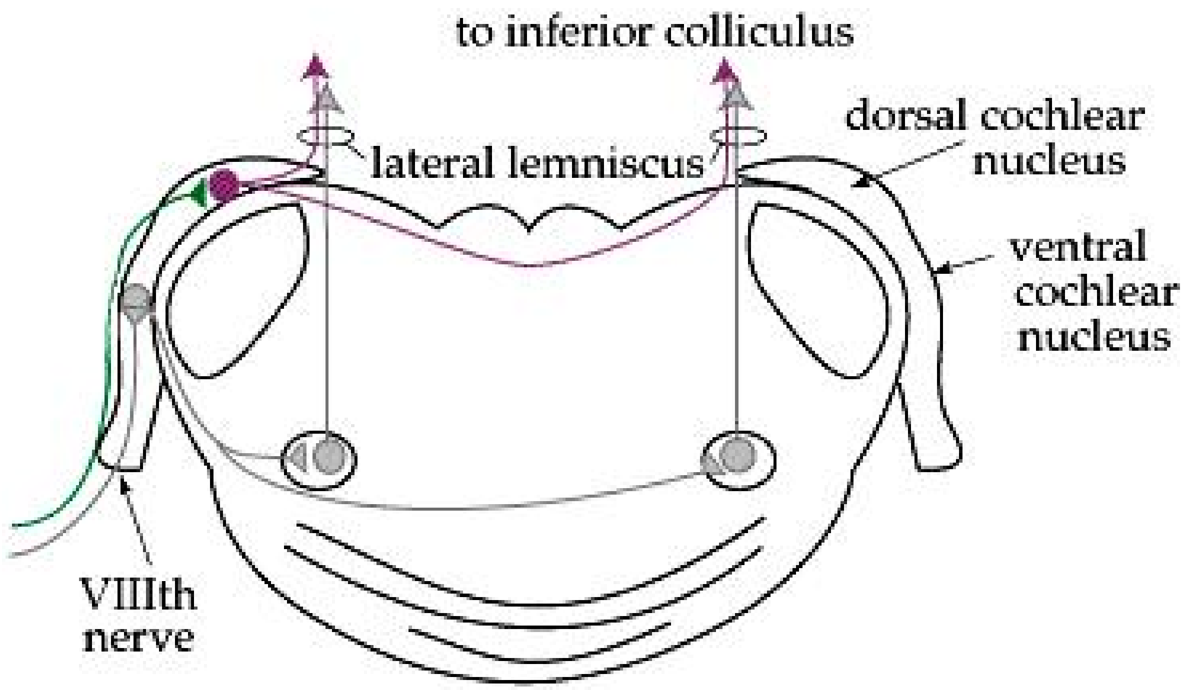
http://thalamus.wustl.edu/course/audvest.html

The auditory pathway



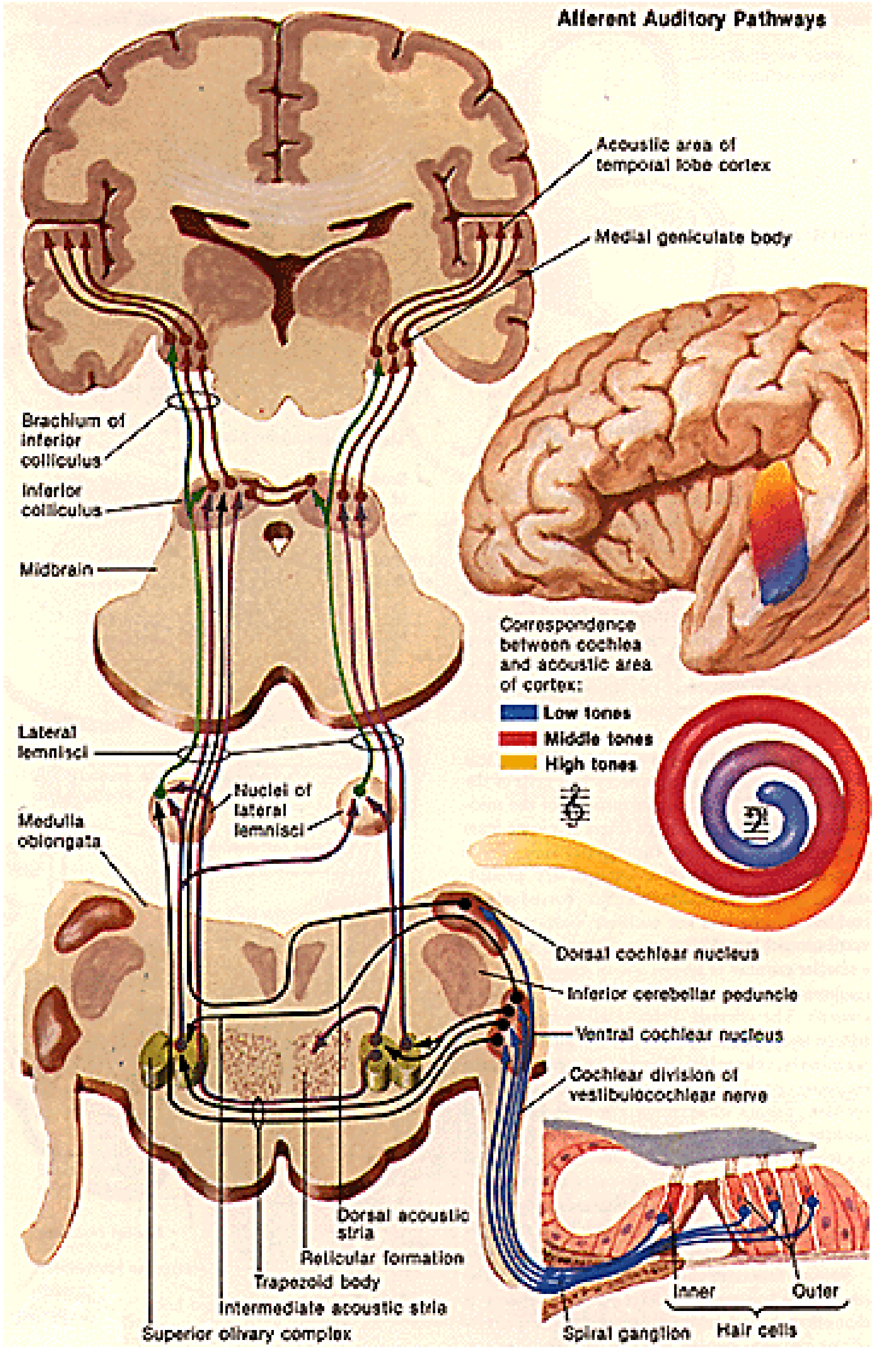
http://thalamus.wustl.edu/course/audvest.html

The auditory pathway is actually more complicated (but you won't be tested on this picture



http://thalamus.wustl.edu/course/audvest.html

The auditory pathway is actually more complicated (but you won't be tested on this picture)



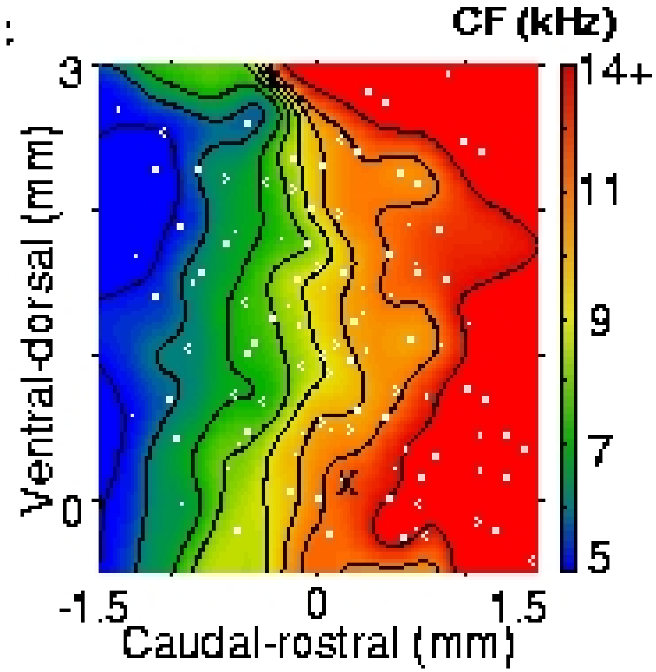
http://www-ece.rice.edu/ dhj/pathway.html

Auditory Pathway

- Inner hair cell
- auditory nerve fiber
- cochlear nucleus - different types of cochlear nucleus cells (onset cells, build-up cells, primary-like cells, phaser cells)
- superior olivary nucleus - first binaural site - important for sound localization
- inferior colliculus [(SON-IC-MG) for these three stages]
- medial geniculate nucleus - thalamic relay nucleus for auditory system
- A1 - some cells respond best to pure tones, others respond best to more complex sounds (rise or fall of frequency)
- A2 - somewhat more complex preferences than A1
- other auditory areas (including Wernicke's area for speech)

A1 has a tonotopic map

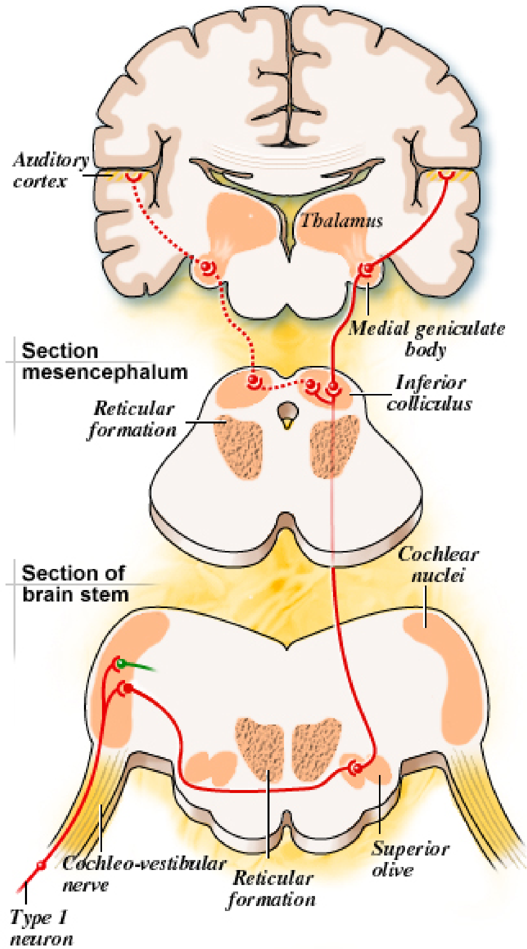
(as do all the other auditory areas we have mentioned)



Read et. al, 2001

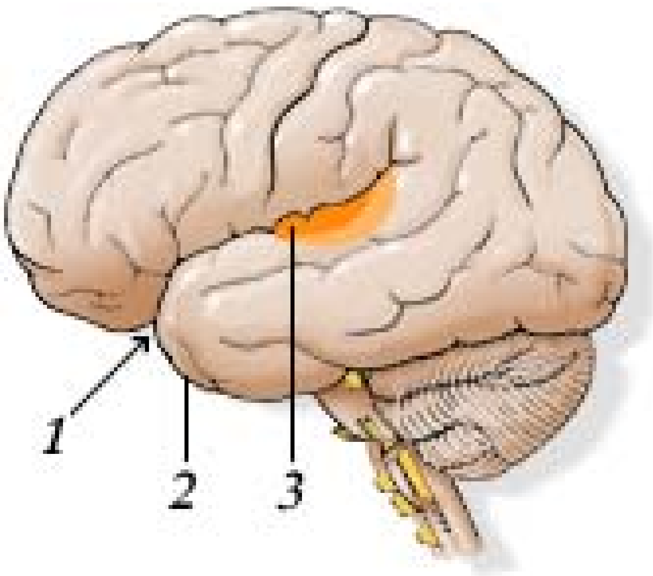
from Heather Read

Primary Auditory Pathway



Drawing by S. Blatrix from EDU website "Promenade around the cochlea" (www.cochlea.org) by R. Pujol et al., University Montpellier 1 and INSERM. Not to be reproduced without author permission (see the original website).

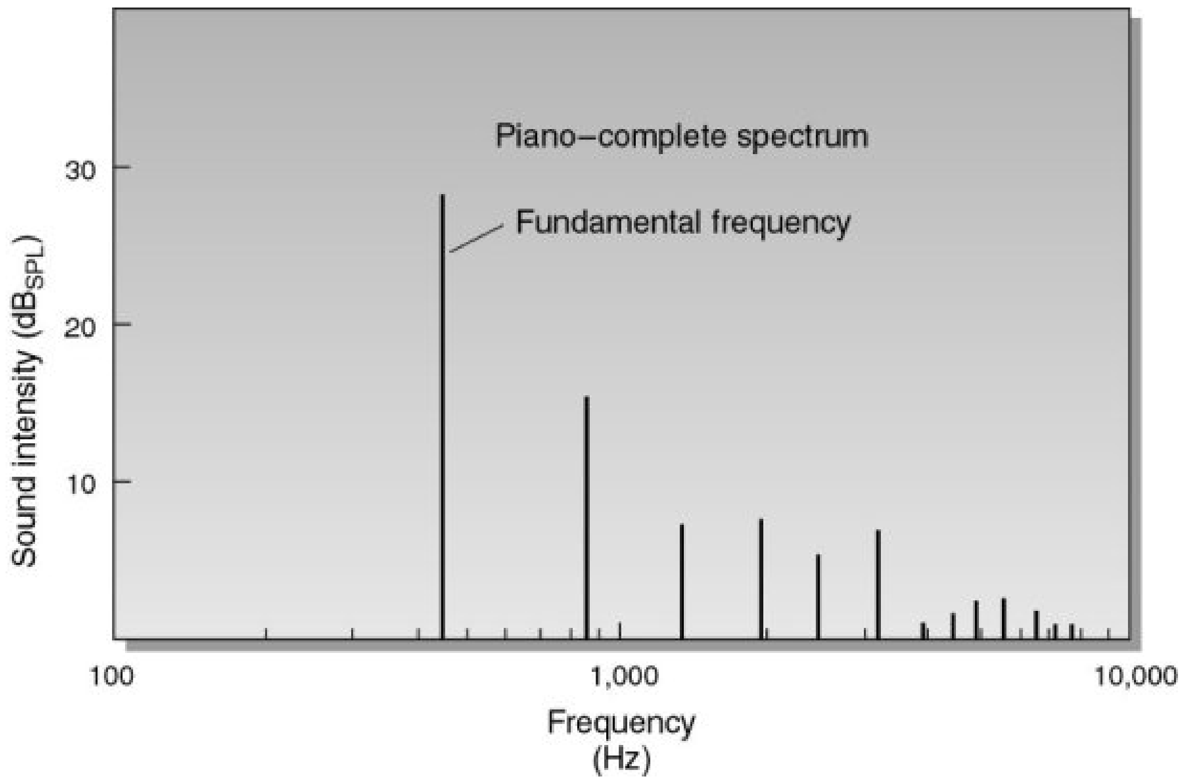
Auditory Cortex



Drawing by S. Blatrix from EDU website "Promenade around the cochlea" (www.cochlea.org) by R. Pujol et al., University Montpellier 1 and INSERM. Not to be reproduced without author permission (see the original website).

Pitch Perception

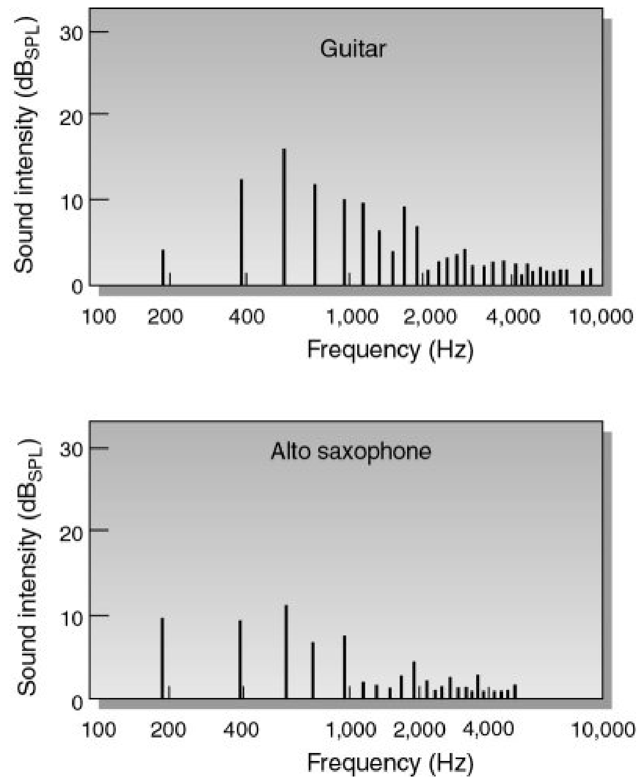
Musical instruments do not play pure tones



http://www.acs.appstate.edu/ kms/classes/psy3203/Music/PianoHarmonics.jpg

Pitch Perception

Musical instruments do not play pure tones



http://www.acs.appstate.edu/ kms/classes/psy3203/Music/harmonics2.jpg

Pitch Perception

A 1000 note played on the piano, has the same pitch as a 1000Hz note played on a guitar.

A simple model for pitch perception is that you pay attention only to the fundamental frequency

This however can be shown to be overly simplified

The Missing Fundamental Effect

If you remove the fundamental frequency (but keep all the other harmonics the same), the pitch sounds the same! Pitch perceived this way is called **periodicity pitch** because you are using the period between harmonics as a cue to pitch.

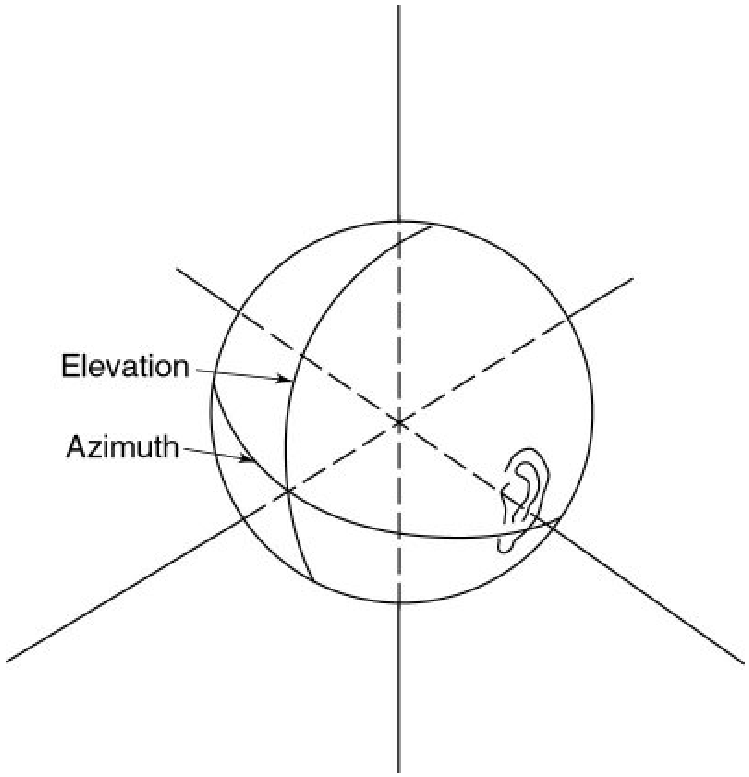
missing fundamental demo

Pitch perception is thought to be computed cortically

Sound localization

Tutis Vilis' notes on sound localization

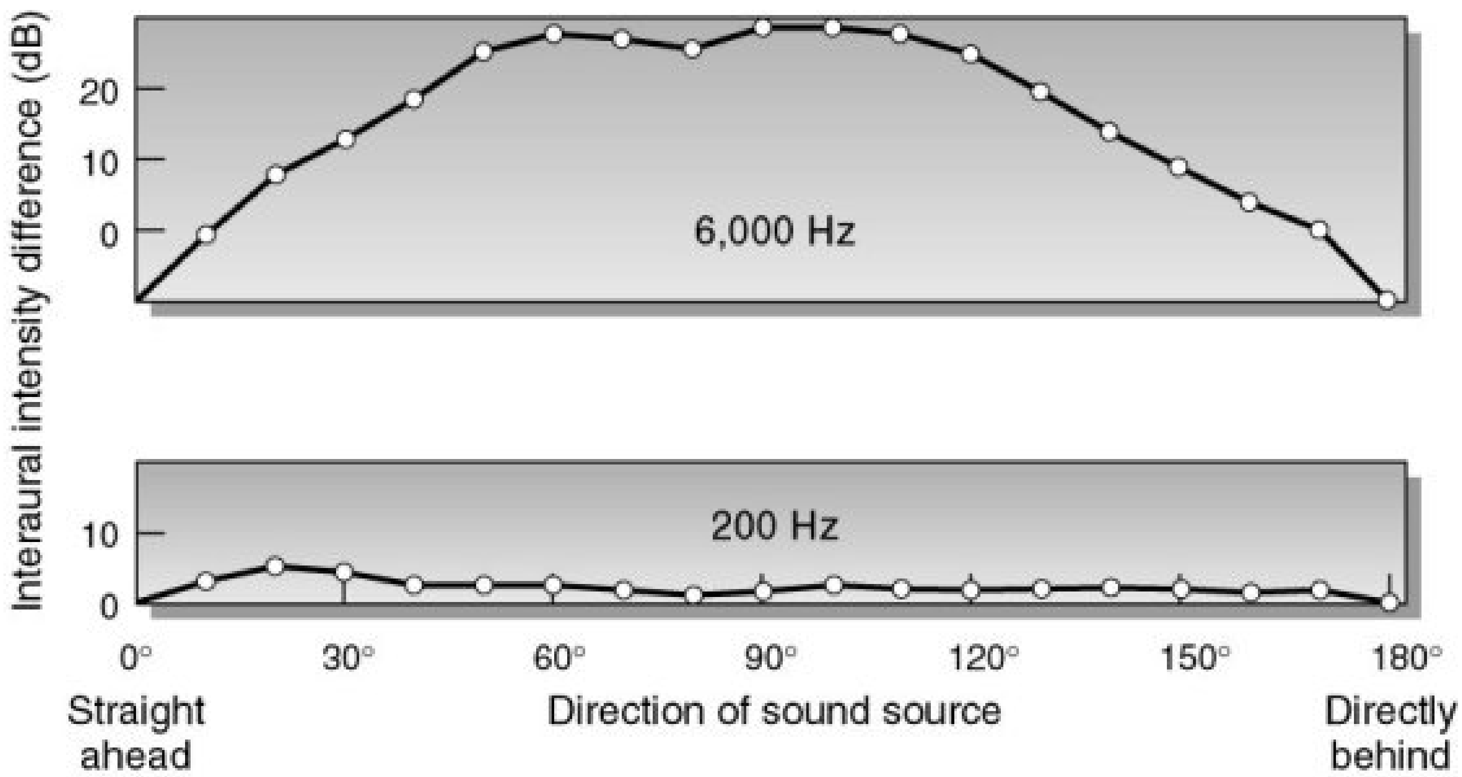
Azimuth and **elevation**



http://www.acs.appstate.edu/ kms/classes/psy3203/SoundLocalize/directions.jpg

Interaural intensity difference (IID) of Interaural level difference (ILD)

caused by shadow of the head



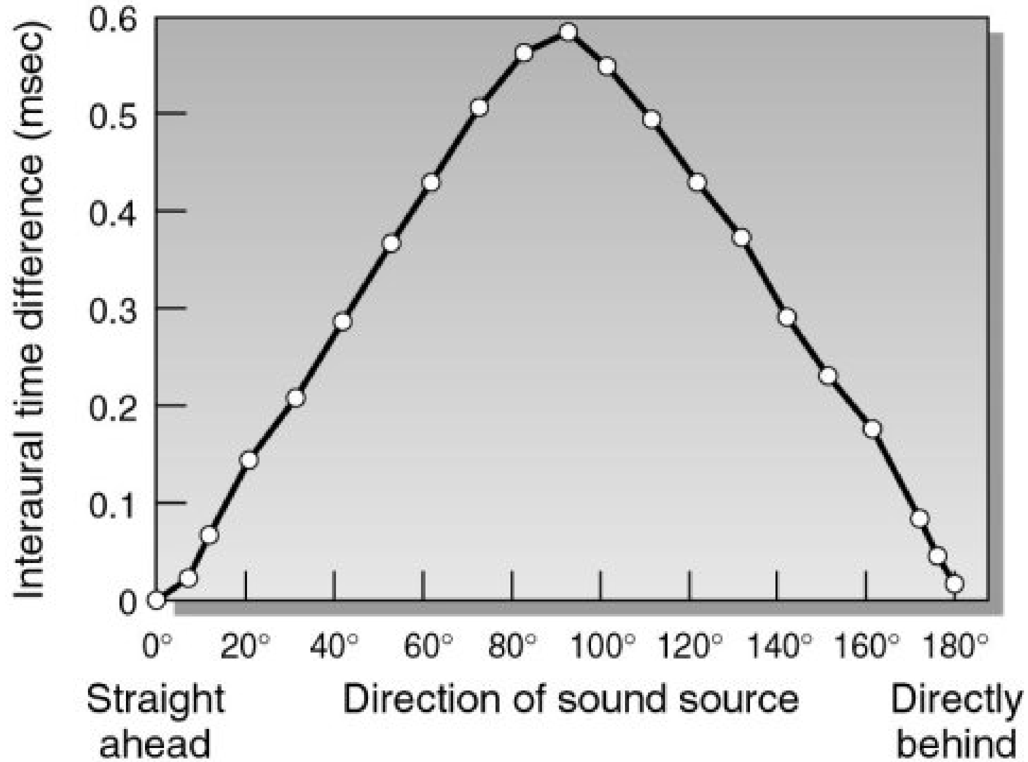
http://www.acs.appstate.edu/ kms/classes/psy3203/SoundLocalize/intensity.jpg

IID

works best for high frequencies (most shadowed by the head) (just like low frequencies get through your neighbors wall better, they get around/through the head better)

Interaural Time Difference (ITD)

Detects phase differences between signals to the two ears (best for low frequencies as high frequencies are too ambiguous)



http://www.acs.appstate.edu/ kms/classes/psy3203/SoundLocalize/time.jpg

Next Class

Audition continued