Acoustics of Speech and Hearing

Week 2-8

Hearing 1: Perception of Intensity

Hearing Lectures

1. Loudness
   - of sinusoids mainly
   - (see Web tutorial for more)
2. Pitch
   - of sinusoids mainly
   - (see Web tutorial for more)
3. Timbre
   - of complex sounds

Loudness Overview

- Subjective/objective
- Sinusoids through outer/middle ear
- Sensitivity to sinusoids as a function of frequency
- Thresholds of audibility - Audiograms
- A scale of "loudness"

Subjective/Objective (recap)

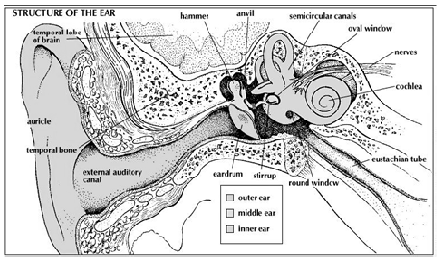
- Objective: Intensity
  - Size of physical pressure variations
  - Wm^{-2}, Pa, dB SPL = 20 log(pressure/20μPa)
- Subjective: Loudness
  - Perceived quantity of sound
  - Sensation limited to range of intensities
    - from about 0dB SPL to 140dB SPL
  - Sensation limited to range of (spectral) frequencies
    - from about 20Hz to 20,000Hz

Facts about Loudness

- Loudness logarithmically related to pressure
  - equal loudness steps like 1-2-4-8-16 Pa
  - rather than 1-2-3-4-5 Pa
- Smallest perceivable change in loudness is about 1dB (i.e. about 12% in pressure)

  10 5 2 1 0.5
- So about 100 perceivably different loudness levels
  - between Threshold of Audibility and Threshold of Pain

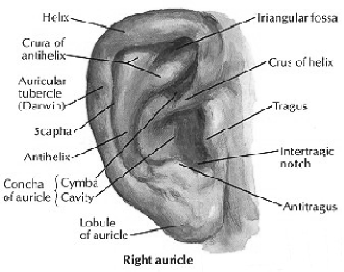
Sinusoids through ear



Sound ➔ Pinna ➔ Ear canal ➔ Middle Ear ➔ Cochlea

← Chain of Systems ! →

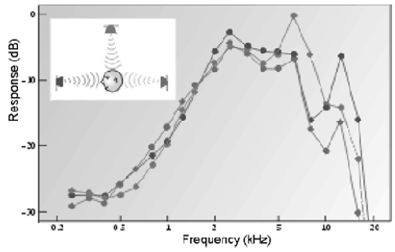
Head and Pinna



- Main function of pinna (auricle) is to funnel sounds into ear canal
- But head itself acts as a sound baffle – forcing sounds to be refracted, changing timbre

Head and Pinna

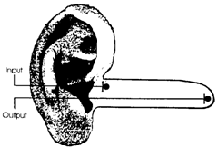
- Frequency response of head and pinna alone shows gain in centre frequencies

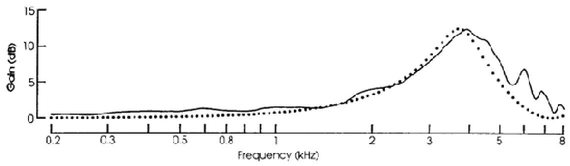


Frequency response varies slightly depending on direction – helps locate sounds front-back

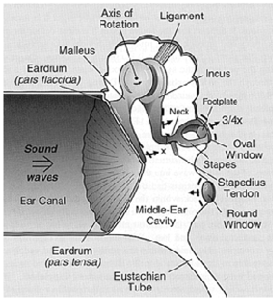
Auditory Canal

- aka External Auditory Meatus
- Acts as tube resonator with resonance at ~4000Hz





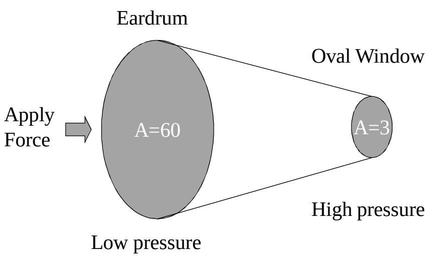
Middle Ear Anatomy



- Ear drum (*Tympanic membrane*)
- Middle ear bones (*Ossicular chain*)
  - Hammer (*Malleus*)
  - Anvil (*Incus*)
  - Stirrup (*Stapes*)
- Oval window into cochlea

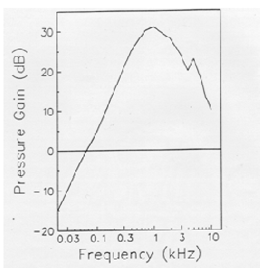
Impedance Matching

- Middle ear increases force exerted by sound by decreasing area over which it is applied



Larger force ensures vibrations pass efficiently into cochlear fluid

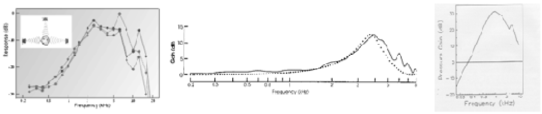
Middle Ear Frequency Response



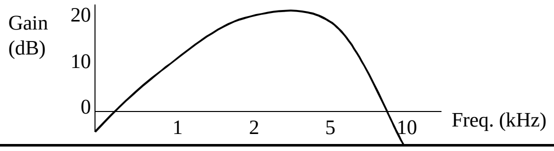
- Middle ear frequency response shows significant gain in the 300-3000Hz region

Overall frequency response

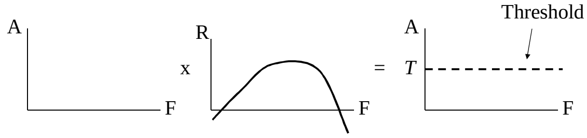
- Combine head+pinna+canal+middle ear



- Overall

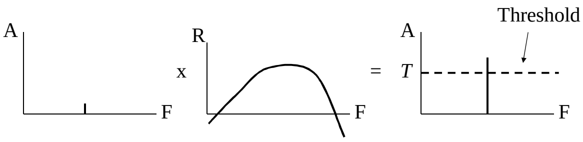


Detection of sinusoids in cochlea



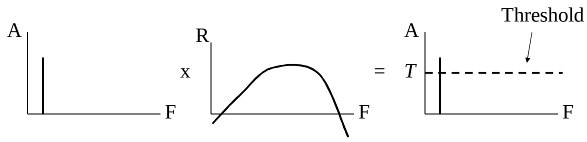
- How big a sinusoid do we have to put into our system for it to be detectable above some threshold?

Detection of sinusoids in cochlea



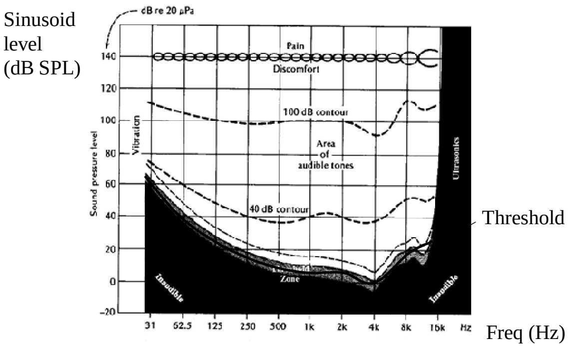
- A mid frequency sinusoid can be quite small because the outer and middle ears amplify the sound

Detection of sinusoids in cochlea

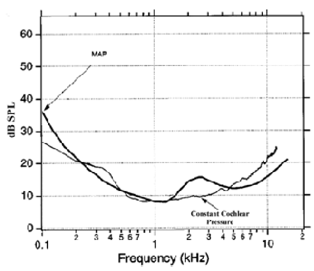


- A low frequency (or high frequency) sinusoid needs to be larger because the outer and middle ears do not amplify those frequencies so much

Threshold of audibility (of sinusoids)



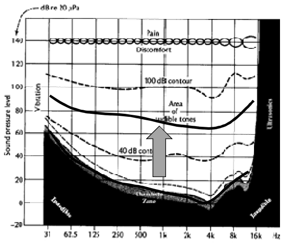
Audibility of Sinusoids



Sinusoids at threshold generate roughly equal pressure in cochlea

- Most of the change in sensitivity to sinusoids of different frequency can be explained by the response of the outer and middle ears.

Measuring hearing loss



Poorer hearing leads to higher thresholds

- Someone with a hearing loss would have higher thresholds
- So we're interested in **differences** to normal thresholds

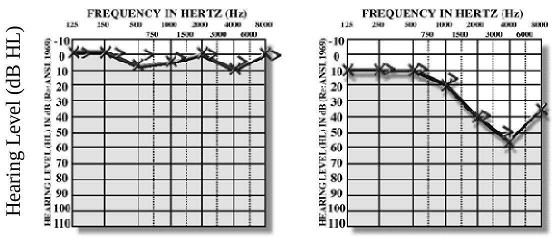
Audiogram

- Plot differences in an individual's thresholds (for sinusoids) compared to "normal"
  - ISO/ANSI standard normal hearing
- dB HL = threshold in dB SPL – normal threshold in dB SPL
- Remember that normal thresholds in dB SPL are different at different frequencies

Frequency	125	250	500	1000	2000	4000	8000
dB SPL	30	19	12	9	9	9	10

Example Audiograms

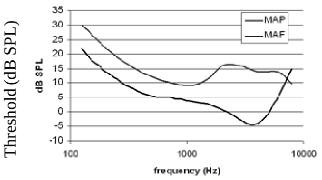
Normal Hearing — Hearing Loss



dB HL = actual threshold (dB SPL) – normal threshold (dB SPL)

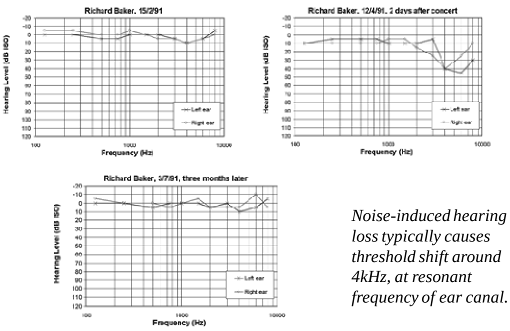
Headphones & Speakers

- You have to be careful when measuring thresholds as to how the equipment is calibrated
- Headphones are typically calibrated to deliver a certain dB SPL level at the ear drum (called MAP calibration)
- Speakers are typically calibrated to deliver a certain dB SPL level at the listener's head (called MAF calibration)



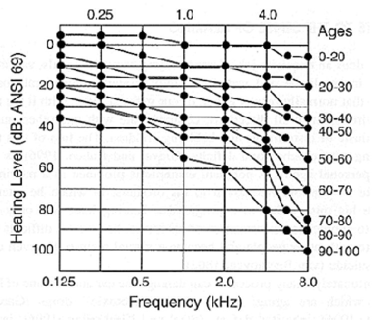
MAP measured thresholds are higher because the listener does not benefit from gain caused by head, pinna and canal.

Temporary Threshold Shift

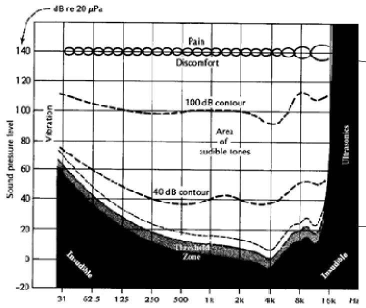


Noise-induced hearing loss typically causes threshold shift around 4kHz, at resonant frequency of ear canal.

Presbycusis (effect of old age!)



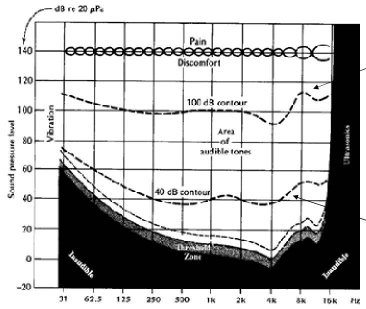
Equal loudness contours



Contour of tones that are all uncomfortably loud

Contour of tones that are all barely audible

Equal loudness contours

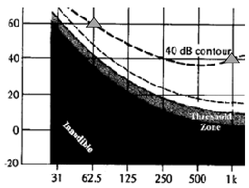


Contour of tones equal in loudness to 100dB SPL sinusoid @ 1kHz

Contour of tones equal in loudness to 40dB SPL sinusoid @ 1kHz

The Phon scale of loudness

- "A sound has a loudness of *X* phons if it is equally as loud as a sinewave of *X* dB SPL at 1kHz"



e.g. A 62.5Hz sinusoid at 60dB SPL has a loudness of 40 phons, because it is equally as loud as a 40dB SPL sinusoid at 1kHz

Summary

- Concerned only with the loudness of sinusoids
- Characteristics of sensation of loudness
- Head/Pinna/Canal/Middle ear all modify amplitude of sinusoids
- Overall sensitivity to sinusoids can be explained by combined frequency response
- Plot hearing loss on an Audiogram in units of dB HL (= difference in thresholds to normal hearing)
- Loudness (at least of sinusoids) can be measured on the Phon scale

Lab Experiment

- Audiometry with
  - Sinewave generator
  - Attenuator
  - Headphones
- Measure each other's pure-tone thresholds
- Use calibration data to calculate thresholds in dBHL
- Find class average in dBSPL

Tuesday 12th March

- 09.00 Lecture (B01)
- 10.30 Tutorial Group A (G06) Paul
- 11.30 Tutorial Group B (G06) Paul
- 10.30 Tutorial Group C (Lab) Geoff
- 11.30 Tutorial Group D (Lab) Mark
- 13.00 End-of-term Test (B02)
- 14.00 Finish