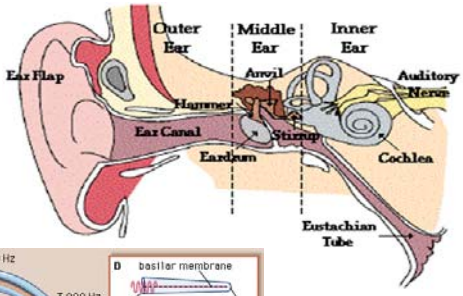
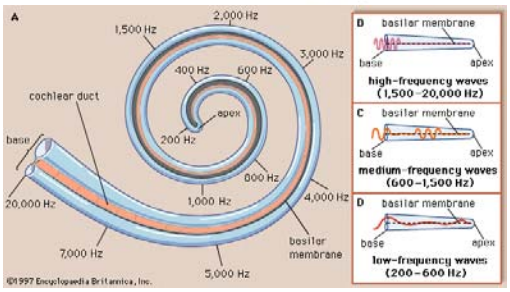
CMPE 80A: Universal Access: Disability, Technology, and Society

Hearing

The Ear



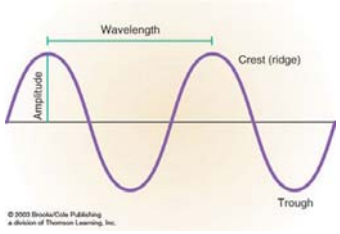


Structure of the Ear

- sound waves enter the ear and strike the *eardrum* (*tympanic membrane*)
- ear drum vibrations move the three tiny bones in the ear (*hammer, anvil, stirrup)*
  - bones amplify sound and transmit it to the *basilar membrane*, which is inside the cochlea
- basilar membrane lined with tiny projections called hair cells
  - hair cells : hearing :: rods and cones : vision
  - vibration in bones causes basilar membrane to vibrate
  - vibration in basilar membrane causes hair cells to fire, triggering neural impulses to brain

Sound Waves

- sound waves are created by a vibrating object
  - any type of molecules (gas, liquid, solid) that can move and create a pressure wave can produce sound
- waves received by ears, transduced into neural signals
- amplitude corresponds to volume
  - Larger/smaller amplitude = louder/softer sound
- wavelength corresponds to pitch
  - Longer/shorter wavelength = lower/higher pitch



Sound Waves

- Pitch
  - 20Hz – 15KHz, tuned to 3Khz by shape of outer ear
  - Human is less accurate in distinguishing high frequencies than low ones
- Timbre
  - 'signature' of sound source
  - complex set of resonance overlaying the fundamental frequency
- Amplitude and loudness
  - *Loudness* is a psychological property of sound
  - Our ears are capable to cope with 0 to 160db (pain at 130db!)
- Spatialisation – positioning of a sound in 2D or 3D space

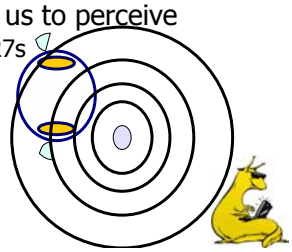
Auditory Transduction

- Two explanations of how basilar membrane converts pressure waves to perceived sound (i.e. how we perceive pitch):
  1. *place theory*: different frequencies activate different parts of the basilar membrane
  2. *frequency theory*: higher frequencies = greater neural firing

  But neurons can fire, at most, 1000 times per second. How do we hear sounds that are at a much greater frequency? (e.g. the upper third of a piano's keyboard) → *volley principle*
- primary auditory cortex in temporal lobe
  - different pitches registered by different neurons within auditory cortex (like feature detectors in vision)

Locating Sounds

- two ears work together to locate the source
  1. difference in phase: sound waves reach ears at slightly different points in wave cycle
  2. difference in loudness: ear closer to sound source registers louder signal
  3. difference in onset: ear closer to sound source registers signal slightly sooner
- tiny differences, but enough for us to perceive
  - e.g. difference in onset of 0.000027s can be distinguished

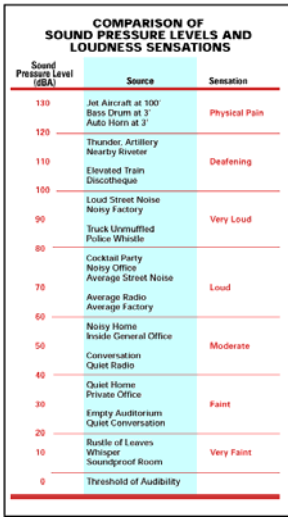


Audio transmission

- The **organ of Corti** contains the auditory sensor cells (*hair cells*)
  - 15,000 to 20,000 auditory nerve receptors
  - Each receptor has its own hair cell
- Nerve fibers from haircell connect to the brainstem, then to the primary auditory nuclei, up to the thalamus, then to the **primary auditory cortex**
  - Auditory nerve has 30,000 nerve fibers

Sound Intensity

- sound intensity are measured in *dB*
  - logarithmic measure of the volume of different stimuli as compared to a reference point
- threshold – ambient sound intensity above which sounds stand out
- prolonged exposure above 85 dB can cause hearing damage → noise-induced hearing loss (NIHL)
- Types of auditory 'damage'
  - *nerve damage*: occurs when the hair cells are destroyed by loud sounds
  - *conduction damage*: physical damage of the outer or middle ear, e.g. broken eardrum



Threshold of injurious sound

Hearing Impairment

- 28+M Americans have hearing problems
  - can be inherited or acquired
  - more than 30 genes have been linked to deafness
- 1 in 1,000 born deaf worldwide
  - 0.3% of children under 5 years deaf
- 1 in 1,000 will develop deafness (mostly aging)
- Marginal, mild, and moderate losses: 2-60 dB loss
- Profoundly impaired/deaf: 60-75 dB loss in hearing capacity in the better ear
- Causes: 50-75% prenatal, 10-20% perinatal (rubella), 20-30% postnatal (aging)

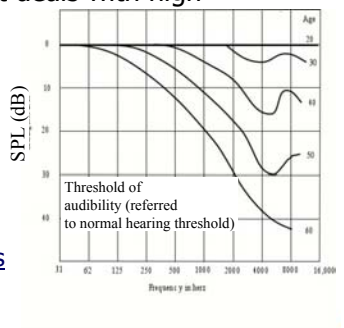
Loud but not Clear?

- We may hear the conversation but not understand it.
- **Speech discrimination** is measured by the percentage of monosyllabic words recognized in a list
  - Played back well above the hearing threshold in quiet environment

90-100%	Normal
75-90%	Slight disability
60-76%	Moderate disability
< 60%	Severe difficulty

Hearing Loss: Presbycusis

- Gradual loss of hearing as we get older
- 75% of people over 60 have significant hearing loss
  - More common in men
- Due to loss of hair cells that deals with high frequencies
- Consonants contain higher frequencies
  - Inability to hear consonants leads to poor speech discrimination
- Test:
  - Speech
  - Speech w/o high frequencies
- Check mosquito ringtone



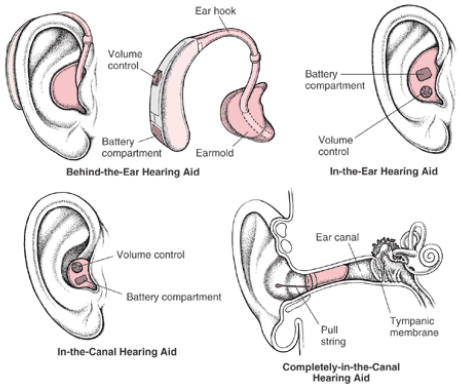
Causes of Hearing Loss

- Menier's disease
  - High fluid pressure in the inner ear
  - Gives a low frequency hearing loss
  - Instead of being progressive, it fluctuates
  - Also affects balance (gives vertigo)
- Otosclerosis
  - Excessive growth of bone surrounding middle and inner ear
    - May block stirrup and pinch auditory nerve
  - Hereditary; also may develop after childhood measles infection
- Sudden hearing loss
  - Usually afflicts older adults
  - Typically only one ear
  - Can be viral or due to vascular accidents
- Tinnitus (ringing in the ear)
  - Often accompanies hearing loss, but can be caused by reaction to aspirin

Causes of Hearing Loss

- Ear infection (Otitis)
- Meningitis
- Usher syndrome (also causes blindness)
- Autoimmune diseases
  - E.g., rheumatoid arthritis, lupus
- Auditory neuropathy
  - Sound enters inner ear normally but transmission from inner ear to brain is impaired
  - May involved damage to hairy cells or faulty connection between hairy cells and auditory nerve
- When loss is progressive in only one ear, it may be due to causes beyond the inner ear
  - Acoustic nerve or auditory part of the brain

Hearing Aids



Hearing Aids

- Components:
  - Microphone
  - Battery-operated amplifier
  - A means of transmitting sound to the user
    - Speaker
    - Direct transmission to bones or skull (requires surgical implant)
- May selectively amplify high frequencies
  - Some have digital equalizers that can be programmed depending on the environment
- Difficult to use with a telephone
  - Some accept Direct Audio Input, which allows an external source (e.g. a telephone) to connect directly to the hearing aid

Hearing Aids

- Common problems
  - Over amplification
  - Occlusion effect → Hollow sound due to ear canal blockage
  - Larsen feedback (whistling) → Largely eliminated using digital technology
  - Poor speech discrimination in noise
- Can only amplify signal - won't work for deafness
- Economic considerations → cost per ear:
  - $800-$1500 (analog)
  - $1200-$3000 (digital)
  - Cost mostly due to service (fitting etc.)
  - Not covered by Medicare
  - Partly covered by Medicaid
  - Only some insurances cover it

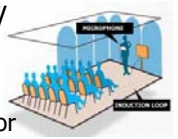
Assistive Listening Devices (ALD)

- Amplified telephones
- Alarms/alerts with loud signals, flash and shake bed
- Directional microphones that allow you to hear the person talking to you in a noisy environment
- FM or infrared link from stereo/TV or microphone
  - E.g. in class: teacher speaks to mic, signal transmitted via FM to student's ALD → Reduces problems with reverberation, noise, distance

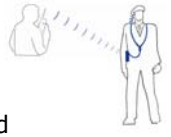



Telecoils

- *Telecoil*-equipped hearing aids can receive electromagnetic signal via an *induction coil*

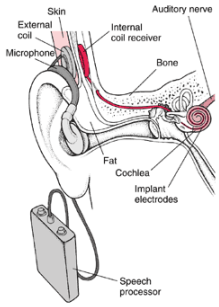


- The signal can be generated by:
  - A room loop: an *induction loop* (wire) surrounding an audience (e.g., in the floor or in the ceiling), connected to the source of sound (e.g., microphone)
  - A neck loop: a necklace-sized wire loop that can be connected to a radio, TV, some telephones, or an ALD and transmits the signal wirelesslY to the coil in the hearing aid
  - A silhouette: works like a neck loop but it is kept behind the ear

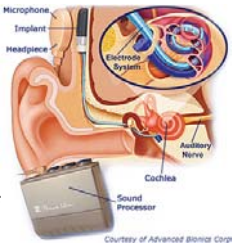


Cochlear Implant

- Can be used when the auditory nerve is still working but the inner ear isn't
  - Provides electrical signal directly to the auditory nerve by means of multiple electrodes inserted into the cochlea
  - Sound is collected at the ear level and processed by an external module, or via FM, DAI or telecoil from ALD
  - Processor splits sound up into different nerve electrical impulses
  - Electrical impulses transmitted via external coil to internal coil through the skin
  - Electrodes in the cochlea stimulate different auditory nerve fibers



Cochlear Implant



- Up to 24 electrodes wound through the cochlea, to stimulate the auditory nerve
  - Each electrode stimulates a portion of the cochlea
  - The signals transmitted to the electrodes are matched to the corresponding frequencies
- About 100,000 have received an implant so far
  - Roughly half adult, half children
  - Nearly 3000 with bilateral implant
- Need to decide which ear to implant
  - The anatomy of the cochlea needs to be intact for the implant


Implant Performance

- Depends on:
  - Quality of technology
  - Cause of hearing impairment
  - Amount of functioning nerve fibers
  - Central processing by the brain
- Here is an acoustic simulation of cochlear implant
- Transforms from totally deaf to hard of hearing
  - E.g., many can use the telephone
- Cost: $45K to $70K (all included)
  - Some of this can be covered by health insurance

Windows of Opportunity

- Children: If implanted early enough, a child's brain can learn to make use of the hearing information
- Otherwise brain used for other sensory modality
- FDA guideline: 12 months
  - 6 months with special approval
  - Can be educated in regular schools
  - Most are able to engage in conversation at at or near normal level
- No upper age limit
  - Better if individual was deaf for a short period of time
  - Otherwise it may be difficult to re-adapt to sound