Hearing

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

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

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)

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 Pressure Levels and Loudness

<table>
<thead>
<tr>
<th>Sound Source</th>
<th>Level (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Noise</td>
<td>85</td>
</tr>
<tr>
<td>Construction</td>
<td>80</td>
</tr>
<tr>
<td>Indoor Noise</td>
<td>55</td>
</tr>
</tbody>
</table>

Threshold of injurious sound

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
► 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

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](http://www.youtube.com/watch?v=L3du7uz36V4)
- 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

Cochlear Implant

- 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
- For something inspiring: http://www.youtube.com/watch?v=L3du7uz36V4
Deaf Culture
► ASL used for communication
► Pride in “Deaf” history and culture
► Label oneself as capital “D” Deaf and use the lower-case “deaf” to refer to medical deafness
► View deafness as a social rather than a medical condition
► Usually attend or attended state residential school for the deaf where ASL was used
► May be opposed to cochlear implants
► May belong to “Deaf Clubs” for socialization
► Deaf theatre, poetry, jokes, sports, storytelling, art and music.
► Magazines, journals, and books written by and about Deaf people and devoted to Deaf interest and concerns.

History of Deaf Culture
► Early 1800’s, Rev. Thomas Hopkins Gallaudet traveled to Europe seeking effective teaching methods for educating deaf children.
► Gallaudet returned with Laurent Clerc, a deaf teacher from the Paris Institute for the Deaf.
► Gallaudet learned sign language for reasons of bringing the “gospel to deaf people.”
► Sign language brought from Paris by Clerc, commingled with sign languages deaf students brought from across the country---and out of this mix came modern American Sign Language.
► For more info: http://my.gallaudet.edu/bbcswebdav/institution/Deaf%20Eyes%20Exhibit/index.htm

Sign Language
► NOT derived from spoken language → different grammar
► It’s just like spoken language, ASL, BSL, SSL are different
► Five basic parameters
  ▪ Shape of the hand
  ▪ Hand location → mother vs. father
  ▪ Movement → I vs. J
  ▪ Palm orientation (to the body and to each other)
  ▪ Facial expressions
► Fingerspelling/manual alphabet
  ▪ Words without assigned signs may be spelled

This week’s assignment
► This week’s assignment, learn A-Z and 1-10:
  ▪ Follow the rest of the videos.