Hearing and Its Loss

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UT faculty from 1967 - 2011, studying
- various aspects of normal and abnormal hearing
- the effects of intense sound and ototoxic drugs on hearing
- the effects of prenatal hormones on hearing
- funded by NIH (thank you all for paying your taxes)

NOVA Lecture Series, Fall 2015

Overview of the Six Lectures

1. Background information and info about sound
2. Basics of Hearing, Conductive and Sensorineural Hearing Loss
3. Audibility, Loudness, Masking, Pitch Perception, Sound Localization
4. Congenital and Acquired Hearing Loss
5. Hearing Aids, Assistive Hearing Systems
Issues We Will Address During these Lectures

Some other topics we will cover:

- physical properties of sound
- how the cochlea works
- congenital and acquired hearing losses
- testing newborns for hearing loss
- surgeries for hearing loss
- the strengths and weaknesses of hearing aids
- electrical stimulation of the auditory system
  * cochlear implants
  * brainstem implants

General Comments

Copies of the slides will be posted to the NOVA website after each lecture

A GLOSSARY of terms already exists on the NOVA website

Currently, no weekly handouts are planned

If you have comments or questions outside of class, contact me:
  mcfadden@utexas.edu

Some technical comments/terms/ are required to tell my story, but
PLEASE do not be scared off by the technical bits
(I promise that you cannot fail the course)
Three Fundamental Points About These Lectures

(1) The Slides
- lots of them
- some quite complex
- don’t get bogged down reading every detail
- just listen to the story I tell
- two purposes for the slides

(2) We all live inside a machine
- made of skin and bone (and neurons)

The machine has a number of sensory systems through which we receive ALL the information we have about the external world
- hearing (and balance)
- vision
- taste
- smell
- touch

Our brain constructs an external world, a reality, using the information from those sensory systems
- we all live in a different "reality" because of (sometimes small) differences in our sensory systems
Three Fundamental Points About These Lectures

(2) We all live inside a machine

Obvious examples of differences:

People with
- color blindness
- taste or smell "blindness"
- hearing loss

Other Species
- hear, see, smell "better" than (different from) humans
  * can navigate using polarization of light or Earth's magnetic field
- if there is advanced life on other planets, they also will perceive their physical world differently from the way humans do

Three Fundamental Points About These Lectures

(2) We all live inside a machine (cont.)

Other human groups (abilities and "deficiencies")
- native speakers of different languages hear the world differently
- experts on bird songs (musicians with perfect pitch)
- memory wizards (Highly Superior Autobiographical Memory; HSAM)
  https://www.psychologytoday.com/blog/quirks-memory/201301/people-extraordinary-autobiographical-memory
- synesthesia
  https://en.wikipedia.org/wiki/Synesthesia
- aphantasia, hyperphantasia
- tetrachromatics (4 cones) – women only – quite rare
- schizophrenics, autistics
Three Fundamental Points About These Lectures

(2) We all live inside a machine (cont.)

A Corollary:
The brain itself is not sensitive to light, sound, smells, tastes, etc.
- only the receptors are
- we are totally dependent upon our sensory systems for information about the external world

(3) The importance of hearing to becoming human

The problems of deafness are deeper and more complex, if not more important, than the problems of blindness. Deafness is a much worse misfortune. For it means the loss of the most vital stimulus—the sound of the voice that brings language, sets thoughts astir and keeps us in the intellectual company of man.

Helen Keller (The Miracle Worker)
Letter to Dr. J. Kerr Love (1910), in Brian Grant, ed., The Quiet Ear (1987)

Being blind cuts you off from things. Being deaf cuts you off from people.

Also attributed to Helen Keller

The inability to hear is a nuisance; the inability to communicate is the tragedy.

Lou Ann Walker
A Loss for Words: The Story of Deafness in a Family (1986)
Functions of all Sensory Systems

To **Detect** stimuli

To **Localize** those stimuli in 3-dimensional space

To **Identify** the objects/events/ associated with those stimuli

A goodly fraction of human cerebral cortex is allocated to accomplishing these functions for vision and hearing

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Notable Hearing Abilities

Humans can hear extremely weak sounds in the quiet; also in noise

Humans can listen to one voice in a crowded room or to a single instrument in an orchestra (sound localization)

Humans can understand speech
* adults, children, non-native speakers of English

Many people can
* tell when familiar music is played in an atypical key
* identify the note on the scale corresponding to a played sound
  * relative or perfect pitch
* identify complex sequences of sounds from memory
  * bird songs, musical pieces

Humans can hear sounds over a wide range of sound levels

All this is accomplished with only ~4,000 receptor cells and ~40,000 neurons per ear
Types of Hearing Failures/Problems

Have you ever

- been able to hear just fine, just not understand what was said?
- not heard a ringing telephone in an adjacent room?
- had difficulty following a conversation in a noisy environment?
- had to ask someone to repeat what she said, and still not understand it?
- had ringing in your ears?
- had someone ask you to speak up, and when you did, she told you not to yell?
- have you ever had some hearing loss during a pregnancy?
- had a familiar piece of music sound out of key? wrong speed?
- heard something different from what a person said to you? (mishearings)
Some Mis-hearings from my Life

Do you want wine? (Do you want mine?)
Is your brain clearer? (Is your drain cleaner?)
Play like good girls (Play with ink wells)
I love Pachebel (I love Taco Bell)
I am going to be noisy (I am going to Boise)
He is a defeatist (He is a fetus)
He wasn’t home (I lost my comb)
Dog bumps

Some Mis-hearings from Oliver Sacks (NY Times; June 2015)

A big-time publicist (cuttlefish) was diagnosed with ALS
Tarot cards (Pteropods)
All-or-noneness (Oral numbness)
I am going to choir practice (I am going to the chiropractor)
Christmas eve (Kiss my feet)
Grocery bag (Poetry bag)

http://www.nytimes.com/2015/06/07/opinion/oliver-sacks-mishearings.html?_r=0

Sachs calls these mis-hearings Paracusis = an auditory illusion or hallucination
- I would quibble with this
- these are one-time errors of perception, not stable experiences as illusions are
About Mis-hearings

We DO hear something; we don’t NOT hear at all
- implication is that brain is trying to make sense of limited/weak/
  sensory information – it fills in what is missing

Often only one or two syllables or words of the mishearing is wrong
- wine vs. mine

Often the prosody (rhythm and intonation) of the original is preserved
- Taco Bell for Pachelbel; pteropods for Tarot cards

Often the mishearing makes absolutely no sense in context, but we struggle
  to try to understand it anyway
- the mishearing is so strong, we can’t ignore what (we think)
  we heard (we trust our sensory systems)

Some DEMOGRAPHIC Facts about Hearing Loss

The US Centers for Disease Control (CDC) estimate that
- approximately 36 million (15%) of US adults have some degree
  of hearing loss

  * this translates into about one-third of
    folks older than 60

- primary reasons: intense sounds, drugs, aging

- approximately 2 – 3 of every 1000 babies born in the US have
  a detectable hearing loss (about 0.25%) – mostly hereditary

  * corresponds to ~10k deaf babies annually

  * plus an additional 0.25% lose hearing before becoming
    teenagers – hereditary and congenital

- when pregnant women have human cytomegalovirus (CMV; also
  herpes virus 5), 14% of those babies develop some hearing loss

Source of stats: http://www.cdc.gov/ncbddd/hearingloss/data.html
AGE GROUP  PERCENTAGE
People in US with DISABLING HEARING LOSS
45 – 54  2%
55 – 64  8.5%
65 – 74  25%
75+  50%
People with HIGH-FREQUENCY HEARING LOSS due to Noise Exposure
20 – 69  15% (~26 million at the time)
People who Experienced TINNITUS in past year
U.S. Adults  10% (~25 million at the time)
People with Hearing Loss who EVER USED HEARING AID
20 – 69  16%
70+  30%

Some ECONOMIC Facts about Hearing Loss (cont.)

Estimates are that the typical person has hearing loss for 5 – 7 years before seeking treatment

Among people who could benefit from wearing a hearing aid, only 1 in 5 wears one

- BUT, in 2014, about 3 million hearing aids were sold (up 4.8%)
Some ECONOMIC Facts about Hearing Loss (cont.)

Children

- annually about 72,000 children receive special services for hearing loss
- total costs in US for special education programs for deaf and hard-of-hearing children equaled $652 million or $11,000 per child (1999 school year)
- lifetime educational costs of hearing loss (only) equaled $115,600 per child (2007 stats)
- when MD costs, drugs, special ed costs, assistive devices, lost wages, etc., are taken into account, lifetime cost for a person with hearing loss born in 2000 will equal $2.1 billion (2003 dollars)

so . . . prevention and early detection of hearing loss are important

Source of stats: http://www.cdc.gov/ncbddd/hearingloss/data.html

One of the most encouraging facts about hearing loss in 2015 (cont.)

- in most states, newborn infants are tested for hearing loss before they leave the hospital (~97% screened in 2011; ~1.8% fail)

- called Universal Neonatal Hearing Screening (UNHS)
  * began 1993; adoption dates differed across states

- ~4 million live births in US annually
  * about 97% are screened under UNHS
  * about 1.8% fail the screening (==> ~ 70,000 kids) (some are false positives)
One of the most encouraging facts about hearing loss in 2015 (cont.)

- *in most states, newborn infants are tested for hearing loss before they leave the hospital*

- as a consequence, children with hearing loss are
  * being diagnosed about 24 months earlier in life than before
  * being fitted with amplification about 24 months earlier in life
  * being enrolled in early-intervention programs about 20 months earlier in life
  * when treatment begins after ~6 months of age, there are measurable delays in speech and language later in life
  * when treatment begins before ~6 months of age, no noticeable delays in speech and language

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Table 3. Prevalence of Metabolic Disorders Screened at Birth in Texas*

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Rate per 100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adrenal hyperplasia</td>
<td>2</td>
</tr>
<tr>
<td>Galactosemia</td>
<td>2</td>
</tr>
<tr>
<td>Phenylketonuria</td>
<td>3</td>
</tr>
<tr>
<td>Hypothyroid disease</td>
<td>28</td>
</tr>
<tr>
<td>Sickle cell disease</td>
<td>47</td>
</tr>
<tr>
<td>Hearing Loss</td>
<td>250</td>
</tr>
</tbody>
</table>

*Finitzio, 1999*
Some Help Groups for Folks with Hearing Problems

- National Institute on Deafness and other Communication Disorders (NIDCD)
  www.nidcd.nih.gov
- US Department of Veterans Affairs (VA)
  www.research.va.gov/topics/hearing.cfm
- American Speech-Language Hearing Association (ASHA)
  www.asha.org
- American Tinnitus Association (ATA)
  www.ata.org/
- Tinnitus Talk Support Forum
  www.tinnitustalk.org
- Better Hearing Institute (BHI)
  www.betterhearing.org
- Hearing Loss Association of America (HLAA)
  www.hearingloss.org/
- Rochester Institute of Technology (RIT)/ National Technical Institute for the Deaf (higher education for vets with hearing loss)
  www.rit.edu/ntd/veterans/academics
- Association of Late-Deafened Adults (ALDA)
  www.alda.org

We need to learn a bit about the **Physics of Sound**

- we need some common vocabulary
- we do need to get a bit technical
- PLEASE do not be scared off by these technical discussions
- everything IS going to come together and make sense in the end
The Basics of Sound

Frequency
- cycles per second or Hertz (Hz)

Amplitude
- sound-pressure level or SPL
- decibels or dB

Quality (Timbre) of sounds
- complexity of the sound

The Basics of Sound (cont.)
Sounds are produced by vibrating objects in the environment
The vibrations compress the surrounding air molecules and that
wave of compression (and rarefaction) propagates
away from the vibrating object – a sound wave
Number of times this repeats per second = > cycles/sec or Hertz (Hz)

How FAR the plate moves determines Amplitude (SPL, dB) of the sound
Some Terms used to Describe Sounds

**Frequency:** number of full cycles of displacement per second of time
- called Hertz (Hz)

**Simple sounds** are single frequencies (or essentially so)
- called pure tones, sine waves, sinusoids
- quite rare in the everyday world
- e.g., tuning forks
- basically one tone/one frequency of vibration
- no fluctuations in frequency across time (although strength/amplitude/can decline, depending on the source)

Some Terms used to Describe Sounds

**Complex sounds** – basically all real-world sounds
- have several frequency components (several pure tones) summed together
Fourier Synthesis - Sum of sinusoids

Fundamental Frequency (not shown) = 200 Hz

All complex sounds can be thought of as sums of pure tones

< < the point-by-point sum across all the above pure tones

Some Terms used to Describe Sounds

Complex sounds - basically all real-world sounds

- have several frequency components (several pure tones) summed together

- the lowest frequency is called the fundamental frequency

- the other frequency components are called harmonics

- each harmonic is an integer multiple of the fundamental

  * 1f (the fundamental), 2f, 3f . . . .

- every doubling of frequency => a octave

- each harmonic has its own strength (called intensity, amplitude, or power, and measured as decibels (dB) of sound-pressure level (SPL) or dB SPL)

- quality (timbre) of a sound depends upon the number and strength of its harmonics
The Basics of Sound (cont.)

Real-world sounds are complex — composed of many frequencies.

When there are multiple complex sounds, they add together (in the air and in the cochlea) and the auditory brain has to unpack those different sounds.
A flute playing the G above middle C - (392 Hz, the fundamental frequency)
LOTS of harmonics, and they determine the Timbre (Quality) of the flute

The ranges of FUNDAMENTAL frequencies (notes) that different instruments can play
**Freqs, Notes, and Keyboard**

A typical standard for tuning is $A_4$ above middle C = 440 Hz. Then middle C = 261.6256 Hz; $C_5$ above middle C = 522 Hz; $C_6$ = 1044 Hz; $C_1$ = 32.6 Hz.

A typical standard for tuning is $A_4$ above middle C = 440 Hz.

For piano strings, and other musical sounds, the frequency given is the fundamental (lowest) frequency – lots of harmonics are present too.

Frequency = number of full vibrations per second.

For piano strings, and other musical sounds, the frequency given is the fundamental (lowest) frequency – lots of harmonics are present too.

**SO (damn) WHAT?**

The ear (the cochlea) analyzes complex sounds into their constituent elements ("pure tones")

- each sound frequency stimulates a specific part of the cochlea

  * high freqs at one end, low freqs at the other end
  * middle freqs in between

- complex sounds are filtered into a collection of simple sounds and higher brain centers put the information in those individual channels back together to create our perceived representation of the auditory world

- **frequency channels** are created at the cochlea, and they are maintained throughout the auditory nervous system

  * called tonotopic organization
Fourier Synthesis-Sum of sinusoids

All complex sounds can be thought of as sums of pure tones.

< < the cochlea receives THIS, and breaks it down into the individual frequencies above.

BTL Track: How We Hear (~2:00 minutes)

Gun shot
Horn
Birds
Fog Horn

Demo from Bell Telephone Labs CD:
The Science of Sound (1958)
Smithsonian Folkways Recordings, FX 6007
www.folkways.si.edu
BTL Track: Frequency (~3:10 minutes)
(cycles per second = Hertz or Hz)

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Equivalent (kHZ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>6000</td>
</tr>
<tr>
<td>50</td>
<td>8000</td>
</tr>
<tr>
<td>100</td>
<td>10,000</td>
</tr>
<tr>
<td>200</td>
<td>12,000</td>
</tr>
<tr>
<td>500</td>
<td>15,000</td>
</tr>
<tr>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>(~ highest note on piano keyboard)</td>
</tr>
</tbody>
</table>

Demo from Bell Telephone Labs CD: The Science of Sound (1958)
Smithsonian Folkways Recordings, FX 6007   www.folkways.si.edu

Frequency = number of full vibrations per second
For piano strings, and other musical sounds, the frequency given is the fundamental (lowest) frequency – lots of harmonics are present too

A typical standard for tuning is A₄ above middle C = 440 Hz
Then middle C₄ = 261.6256 Hz; C₅ above middle C₄ = 522 Hz;
C₆ = 1044 Hz; C₇ = 32.6 Hz
**Fundamentals (and Overtones)**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 Hz</td>
<td>Fundamental; 1(^{st}) harmonic</td>
</tr>
<tr>
<td>400</td>
<td>2(^{nd}) harmonic of 200 Hz</td>
</tr>
<tr>
<td>600</td>
<td>3(^{rd}) harmonic</td>
</tr>
<tr>
<td>800</td>
<td>4(^{th}) harmonic</td>
</tr>
<tr>
<td>1000</td>
<td>5(^{th}) harmonic</td>
</tr>
<tr>
<td>1200</td>
<td>6(^{th}) harmonic</td>
</tr>
<tr>
<td>1400</td>
<td>7(^{th}) harmonic (except maybe in musical acoustics)</td>
</tr>
<tr>
<td>1600</td>
<td>8(^{th}) harmonic</td>
</tr>
<tr>
<td>1800</td>
<td>9(^{th}) harmonic</td>
</tr>
<tr>
<td>2000</td>
<td>10(^{th}) harmonic</td>
</tr>
</tbody>
</table>

In acoustics, **OVERTONES is an obsolete term** except maybe in musical acoustics. Instead, **HARMONICS is the preferred term**. The Fundamental Frequency is the First Harmonic.

Demo from Bell Telephone Labs CD: *The Science of Sound* (1958)
Smithsonian Folkways Recordings, FX 6007  www.folkways.si.edu

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*Fig. 11.7: As the bottom are two complex tones with six sinusoidal components. When the components are in cosine phase (left), the periodicity of the wave is 5 times (200 Hz) because the components represent the fifths through the tenth harmonics. When the components are in random phase (right), the periodicity is greatly reduced, if not absent. After Wrightman and Greene (52).*
**BTL DEMO: “Quality”**

BTL Track: Quality (~2:45 minutes)

Factory horn
Soprano
Piano note

Message: it is the number and strength of the harmonics (overtones) that give various sounds their different Qualities (Timbres)

When most of the harmonics have been filtered out, the three sounds above sound very similar

Demo from Bell Telephone Labs CD: The Science of Sound (1958)
Smithsonian Folkways Recordings, FX 6007  www.folkways.si.edu

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**BTL DEMO: “Filtered Music/Speech”**

BTL Track: Filtered Music and Speech (~4:35 minutes)

**MUSIC (Grieg’s Weddingday at Troldhaugen)**

SPEECH

375 – 2000 Hz; lows and highs missing
All frequencies present
375 -->>
375 -->> ; lowest frequencies missing
2000 -->>
2000 -->>> ; lower frequencies missing
<<-- 2000
<<-- 4000 ; highest freqs missing
<<-- 375
<<-- 2000 ; higher freqs missing
375 – 2000
All frequencies present
All frequencies present

Demo from Bell Telephone Labs CD: The Science of Sound (1958)
Smithsonian Folkways Recordings, FX 6007  www.folkways.si.edu
The Decibel (dB)

- a logarithmic unit of measure – a relative measure

\[ dB = 10 \log \left( \frac{\text{(some acoustic power)}}{\text{(a reference power)}} \right) \]

\[ dB_{SPL} = 10 \log \left( \frac{\text{(some acoustic power)}}{10^{-12} \text{ watt/m}^2} \right) \]

- small dB differences represent large changes in stimulus strength
- every 10 dB of change represents 10 times the stimulus power
- dB is used because of the wide range of stimulus strength humans are able to hear (~120 - 140 dB)
- it is easier, and less errorful, to work with dB measures
- lots of electronic devices and software work in dB units
- BUT dB are less familiar to laypeople than typical units of measure – thus confusing

* EARTHQUAKE amplitudes also measured with a log scale

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Some Rough Estimates of Sound-Pressure Levels

**HOUSE and GARDEN**
- Chainsaw: 116 dBA
- Leaf blower: 103 dBA (gas)
- Lawn mower: 95-120 dBA
- Power saw: 95-115 dBA
- Food blender: 88 dBA
- Vacuum cleaner: 88 dBA
- Home stereo: 80-115 dBA
- Aver. home interior: 50 dBA

**EVERYDAY SOUNDS**
- Firecrackers*: 140 dBA
- Ambulance siren: 120 dBA
- Thunderclap*: 120 dBA
- Rock concerts: 105 dBA & more
- Referee whistle: 103-107 dBA
- Jack hammer: 102-111 dBA
- Sporting events: 95-100 dBA & more
- Clubs and discos: 91-96 dBA
- Jazzercise class: 90-92 dBA
- Hammer*: 87-95 dBA
- Motorcycle: 80-115 dBA
- Heavy traffic: 76 dBA
- Moderate rainfall: 50 dBA
- Whisper at 5 feet: 30 dBA
- Leaves rustling: 20 dBA

**FIREARMS**
- Toy pistols*: 150-160 dBA peak
- 12-gauge shotgun*: 150-165 dBA peak
- Rifles*: 143-170 dBA peak
- .22 Caliber rifle*: 132-139 dBA peak

*impulsive, not continuous sounds

For purposes of hearing loss, 90 dBA is a critical value for continuous sounds

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A Classroom DEMO of Sound-Pressure Levels

Sound is a wide-band noise (bandwidth about 400 – 6000 Hz)
Amplifier gain ("volume") is adjusted
Measurements made with Sound-Level Meter

An Important Distinction

<table>
<thead>
<tr>
<th>Physical Domain</th>
<th>Psychological (Perceptual) Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Stimulus</td>
<td>Perceptual Response</td>
</tr>
<tr>
<td>Frequency(ies)</td>
<td>Pitch</td>
</tr>
<tr>
<td>Sound-pressure Level, Decibels, Intensity</td>
<td>Loudness, Strength, &quot;Volume&quot;</td>
</tr>
<tr>
<td>Harmonic Structure, Complexity, Quality Bandwidth</td>
<td>Timbre</td>
</tr>
</tbody>
</table>

For other senses
- Wavelength of light - Color (hue)
- Specific Molecule - "salty" or "musky"

There are ways to measure Perceptual Responses (behavioral tests), but they are not the same as measuring the physical stimulus