PERCEPTION OF SOUND AND AUDITIVE EFFECTS OF NOISE

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The Ear

- External
- Middle
- Inner
External Ear

- Auricle and ear canal
- Helps direct sound to ear drum
- Locate source of sound in space

Middle Ear

- Space between the ear drum (tympanic membrane) and inner ear
- Air filled space containing the 3 ossicles (malleus, incus, and stapes)
  - Aerated via Eustachian tube
How do we hear?

- Sound waves travel down the ear canal and vibrate the ear drum and ossicles.
- Vibrations transferred via the ossicular chain to the inner ear.
- Vibrations cause movement of inner ear fluid which stimulates tiny nerve fibers, converting mechanical to electrical energy.
How do we hear?

External Ear:
- Pinna
- Meatus Acusticus Externus

Middle Ear:
- Tympanic Membrane
- Ossicles
  - Malleus (hammer)
  - Incus (anvil)
  - Stapes (stirrup)
  - Ligaments
  - Muscles
  - Amplitude reduction
  - Pressure amplification
  - Attenuation reflex (protection, low frequency masking)

Inner Ear:
- Oval Window
- Cochlea
- Auditory Nerve
- Auditory Cortex
Mechano-transduction at OHCs. Ending of OHC stereocilia leads to K⁺ entry and OHC depolarisation.

Electromotility and reverse transduction. Depolarisation of its membrane results in OHC contraction which magnifies the motion.

Mechano-transduction at IHC: OHC contraction enhances the motion, IHC stereocilia are bent.

IHC-auditory nerve synapse activation as a result of the IHC depolarisation: an auditory message is sent via the type I afferent (blue).
Cochlea cross-section

• Outer / Middle / Inner Ear
Histopathology

- Industrial Noise

NORMAL HAIR CELLS
Histopathology

- Effect of Noise

Histopathology

- Industrial Noise
DAMAGED HAIR CELLS

Sound Transmission Through Outer, Middle, and Inner Ear

1. Sound wave impinges on eardrum, causing it to vibrate
2. Ossicles vibrate as unit
3. Stapes moves in and out of oval window
4. Sound waves transmitted via perilymph
5. High-frequency (short) waves at base of cochlea
6. Descending wave
7. Wave transmitted across cochlear duct from scala vestibuli to scala tympani
8. Cochlear nerve
9. Impact of wave causes secondary tympanic membrane in round window to move in and out
9. Low-frequency (long) waves at apex of cochlea
Route of auditory impulses from the receptors in the ear to the auditory cortex

- Yüksek gürültüye maruz kalma geçici veya kalıcı işitme kaybı ile sonuçlanabilen bir durum olup akustik travma endüstriyel ülkelerde işitme kayıplarının ana nedenidir.
What Do We Hear?

- Human ear capable of hearing 20-20,000 Hz
- Highest Sensitivity: 1,000 - 3,000 Hz
- Standard audiometric testing done at octave frequencies in between 250-8000 Hz typically
- Lowest Detectable Intensity: 0 Db Hearing Level
- Sound intensity (loudness) is logarithmic. A 5 dB increase represents doubling of loudness

Hearing Loss

- Conductive loss
- Sensorineural (nerve or sensory) loss
- Mixed hearing loss: combination of conductive and sensorineural losses
Conductive Hearing Loss

- Hearing loss due to impairment of conducting sound down ear canal to inner ear.

Sensorineural Hearing Loss

- Hearing loss due to loss of nerve function.
- Cochlea (inner ear), auditory nerve (from cochlea to brain), and auditory cortex (brain)
- Noise exposure produces sensorineural hearing loss, never conductive hearing loss
• Akustik travma veya gürültüye bağlı işitme kayıplarında, pür ton odyometride herhangi bir bulgu vermeyip TEOAE testinde yanıtlarında düşüş gözlenebilir.
• Bu nedenle TEOAE testi iç kulağın etkilenmesinde erken dönemde bulgu verebilir.
Noise Induced Hearing Loss

- High Frequencies affected more than low or mid frequencies
- 4000 Hz “notch” is typical
- Mid and lower frequencies may be affected over time
Noise induced Hearing Loss

The Audiogram

- Reliability
  - BELIEVE IT OR NOT PEOPLE LIE!
- Calculation of Pure Tone Averages
- Determination of the average of 500, 1000, 2000, and 3000 hz. Average > 30dB = hearing loss
- Use of sensorineural or conductive thresholds?
- State of Wisconsin says we must use conductive thresholds, however in the presence of a conductive loss we use sensorineural levels- Remember why?
The Audiogram
"Red Flags"

- "Poor" reliability
- Inconsistent responses on audiogram
- Hostile patient
- Normal prior hearing with recent decline after years of exposure
- "Severe loss" but no difficulty with exam questions spoken softly

Pseudohypacousis

- Deliberate misrepresentation of severity of hearing loss
- = Insurance fraud
The Audiogram
What we test

- Air Bone thresholds
  - Pure tone averages
- Tympanometry
- Speech discrimination
- Pattern of loss
- Severity of loss

Severity of Hearing Loss

- Pure tone averages
  ave. at 500, 1k, 2k, 3k Hz
- This example:
  - R= 20 dB
  - L= 20 dB
- Utilize air thresholds because no conductive loss present.
NO EVOKED OAE

EVOKE OAE PRESENT

Test data
Ear: Left
Test Date/Time: 24.05.2006 14:52:34
Stim: QuickScreen
File: 85PG5033.DTA

Numerical Data
Resp: -1.0 dB
Noise: 4.8 dB
Stim: 78.2 dB
Test time: 23 secs
Status: review data
Two Types of Noise-Induced Loss

1. Acoustic trauma: Result of exposure to impulsive, short and high noise
2. Chronic Noise-Induced Hearing Loss: Long term effect of moderate-to-high level of noise

Daily exposure limits
Maximum permissable sound levels in dB

- 8 h  90 dB
- 4 h  93 dB
- 2 h  96 dB
- 1 h  99 dB
- 1/2 h  102 dB
- 1/4 h  105 dB
Representative SPLs

<table>
<thead>
<tr>
<th>Sound</th>
<th>approximate SPL (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet takeoff (at 200 ft)</td>
<td>125</td>
</tr>
<tr>
<td>Cutoff saw</td>
<td>105</td>
</tr>
<tr>
<td>Inside sports car (at 50 mph)</td>
<td>80</td>
</tr>
<tr>
<td>Near freeway (auto traffic)</td>
<td>65</td>
</tr>
<tr>
<td>Average residence</td>
<td>50</td>
</tr>
<tr>
<td>Soft whisper (at 5 ft)</td>
<td>30</td>
</tr>
<tr>
<td>Normal breathing</td>
<td>10</td>
</tr>
</tbody>
</table>

Sound Measurement Devices

The device on the left is a sound level meter and is primarily used for noise abatement activities and acoustical work such as determining noise control criteria for an occupancy or for ambient noise analysis and control. The device in the center is a sound level meter/noise dosimeter which accumulates, or logs noise exposure for an entire work shift. This instrument is primarily used for OSHA hearing conservation activities. The device on the right is a previous-generation sound level meter.
A, B, and C Scales

Cochlea

- Oval Window
- Stapes
- Round Window
- Scala Vestibuli & Scala Media
- Scala Tympani
- Basilar Membrane Organ of Corti Hair cells
- Helicotrema

High Frequency ↔ Low Frequency
Hearing

- The pitch sensation depends on which region of the basilar membrane vibrates and which area of the auditory region of the brain is stimulated.
- The volume depends on the amplitude of sound waves. Loud noises cause the fluid of the cochlea to vibrate more which causes the basilar membrane to move up and down to a greater extent.
- The impulses generated travel to the auditory area of the brain and are interpreted as high volume sounds.
- Hearing loud noises may damage the hair cells and result in loss of hearing.

Limits
Temporary Hearing Loss

• Noise-induce hearing loss
• Continuous noise leads to hearing loss
• Temporary threshold shift at 2 min (TTS₂)
  – 70 - 75 dBA : no TTS₂
  – 80 - 105 dBA: TTS₂ proportional to exposure
  – i.e. 100 dB noise for 100 minutes, TTS = 60 dB

Permanent Hearing Loss

• Continuous noise may lead to permanent hearing loss
• Begins at ~ 4000 Hz
• Generally restricted to 3000 - 6000 Hz
• Age-related hearing loss (particularly at high frequencies)
Hearing Loss

Noise - Induced Hearing Loss
Noncontinuous Noise

- **Impact Noise** (e.g. drop forge)
- **Impulse Noise** (e.g. gunfire)

Noncontinuous noise may lead to permanent hearing loss.

OSHA Standards: Continuous Noise

<table>
<thead>
<tr>
<th>PERMISSIBLE NOISE EXPOSURES ACCORDING TO OSHA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound level, dBA</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>85</td>
</tr>
<tr>
<td>90</td>
</tr>
<tr>
<td>95</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>105</td>
</tr>
<tr>
<td>110</td>
</tr>
<tr>
<td>115</td>
</tr>
<tr>
<td>120°</td>
</tr>
<tr>
<td>125°</td>
</tr>
<tr>
<td>130°</td>
</tr>
</tbody>
</table>

*Exposures above 115 dBA are not permitted regardless of duration; but should they exist, they are to be included in computation of the noise dose.

Source: OSHA, 1983
**OSHA standards for impulsive noise**

<table>
<thead>
<tr>
<th>Peak sound-pressure level, dB</th>
<th>Maximum number of impulses per 8h*</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>100</td>
</tr>
<tr>
<td>135</td>
<td>316</td>
</tr>
<tr>
<td>130</td>
<td>1,000</td>
</tr>
<tr>
<td>125</td>
<td>3,162</td>
</tr>
<tr>
<td>120</td>
<td>8,913</td>
</tr>
<tr>
<td>115</td>
<td>31,623</td>
</tr>
<tr>
<td>112.4</td>
<td>57,600</td>
</tr>
</tbody>
</table>

*Based on following formula: number = $10^{10} \times 10^{-P}$ (where $P$ = peak decibels)

This would be considered continuous noise.


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**DID YOU KNOW......?**

↓ Noise-induced hearing loss is the number one occupational disability

↓ It is generally **Painless**

↓ It is **Progressive over time**

↓ It is **Permanent**

↓ **IT IS PREVENTABLE!!!**

**THE 4 PS**
WHAT IS NOISE?

• Simply stated... noise is any unwanted sound

WAYS TO CHARACTERIZE OF NOISE

• **FREQUENCY**- perceived as pitch

• **INTENSITY**- perceived as loudness

• **NATURE**- steady-state vs. impulse/impact

• **DURATION**- length of time exposed
Noise Induced Hearing Loss

- Initially, exposure to noise causes a loss of sensitivity to high frequency (high pitch) sound.
- Continued exposure results in damage to mid frequency region as well.
- One can experience progressive high frequency hearing loss and not be aware of it until it becomes severe (doesn’t affect loudness perception).

HOW CAN IT HAPPEN?

- ACOUSTIC TRAUMA - ONE TIME EXPOSURE TO LOUD SOUND
  OR
- DAILY EXPOSURES TO MODERATELY LOUD SOUNDS
HOW DO WE KNOW SOMETHING IS TOO LOUD?

• Could use 3 foot rule
  – If you have to raise your voice to be heard by someone standing within 3 foot (arm’s length) then the level is most likely above the hazardous noise level
  or
  – Objectively measure loudness with proper equipment

When is noise scientifically defined to be a hazard?

- Duration of exposure, intensity (volume) of sound, repeated exposure, individual susceptibility
- 85dBA for steady-state noise sources
- 140dBP for impulse/impact noise sources
Steady-State Noise Examples

- Rustling Leaves  20dB
- Conversation     60dB
- Automobile      70dB
- Alarm Clock     80dB
- Screaming Child 90dB
- Pneumatic Drill 100dB
- Helicopter      110dB
- Live Concert    130dB

Loss of hearing sensitivity due to hazardous noise exposures from either steady state noise or impulse noise does occur even before we can measure the change!....

And it does carry negative consequences!!!
PTS vs. TTS

• A permanent threshold shift (PTS) vs. a temporary threshold shift (TTS)

• Bounce-back effect...not complete recovery

• Immediate medical referral (Audiology / ENT)

Permanent Effects of Noise Induced Hearing Loss

- Difficulty understanding conversation, particularly in background noise...high frequency hearing loss affects ability to hear consonants. Quality of environmental sound is diminished.

- “Ringing in Ears” - tinnitus
The Audiogram

Conductive vs. Sensorineural loss

Noise Induced Hearing Loss

- Always sensorineural (cochlea + cochlear nerve) loss
  - Excessive sound injures the inner ear. It does not interfere with the conduction of sound to the inner ear
- Never a conductive loss
OSHA Guidelines

- No oversight, monitored by employers
- "The employer shall establish and maintain an audiometric testing program as provided in this paragraph by making audiometric testing available to all employees whose exposures equal or exceed an 8-hour time-weighted average of 85 dBA."
- "As used in this section, a standard threshold shift is a change in hearing threshold relative to the baseline audiogram of an average of 10 dBA or more at 2000, 3000, and 4000 Hz in either ear."
- "Employees shall make hearing protectors available to all employees exposed to an 8-hour time-weighted average of 85 dBA or greater at no cost to the employees. Hearing protectors shall be replaced as necessary."
- Any patient exposed to time weighted average of 90 dBA or who has threshold shift at 85 dBA is required to wear hearing protection.
- Maximum 140 dBA peak

<table>
<thead>
<tr>
<th>Permissible Noise Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration per day (hours)</td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>1-1/2</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1/2</td>
</tr>
<tr>
<td>¼ or less</td>
</tr>
</tbody>
</table>


At Risk Individuals

- Machinery and equipment operators.
- Regular use of power/pneumatic tools.
- Exposure to material on material impacts
- Individuals who do not utilize hearing protection
- Individuals with years of exposure
- Individuals who began work prior to implementation of Hearing Conservation Programs
Sound
(Noise)

- Sound
- Gunshot (peak level) 140 to 170
- Jet takeoff 140
- Rock concert, chain saw 110 to 120
- Diesel locomotive,
  - stereo headphones 110 to 120
- Motorcycle, lawnmower 90
- Conversation 60
- Quiet room 50
- Whisper 30 to 40

OSHA = Occupational Safety and Health Administration; dB = decibels.
*Measurement expressed as dB(A), a scale weighted toward sounds at higher frequencies. OSHA level for hearing 85* (8-hour time-conservation program weighted average)
OSHA Permissible Noise Exposures

- Duration (hrs) | dBA
- 8             | 90
- 6             | 92
- 4             | 95
- 2             | 100
- 1             | 105
- .5            | 110

Noise Induced Hearing Loss

- Not everyone is susceptible to noise at 90dB and not everybody is immune from the effects of loud noise at less than 85dB

- Bell curve phenomenon
Medical Evaluation of Hearing Loss

- History and physical examination
- Review of hearing tests and noise exposure data
- Determination of the existence of significant hearing loss
- Calculation of severity or percentage loss
- Establishment of causation and liability

History and Physical Examination: History

- Duration
- Dizziness
- Ear drainage
- Infections
- Ear surgery
- Medications
- Trauma
- Type of work performed
- Known noise exposure
- Use of hearing protection
- Noisy hobbies
- Gun fire
- Military experience
- Prior audiograms
- Family history of hearing loss
Pure tone audiogram
What We Observe?

• Is there any evidence of hearing loss
  – If not, no further evaluation, testing or need for
determination of causation or liability
• Conductive, sensorineural or mixed hearing loss
• Pattern of loss
• Severity of loss
• “Reliability” of test result
• Symmetry of loss
• Comparison to other tests
• Intertest variability

Calculation of Hearing Loss Severity

• Determine (from tables) percent loss for
each ear
• Better hearing ear loss multiplied by 5
• Worse hearing ear multiplied by 1
• Results added and then divided by 6 to
arrive at percentage of bilateral hearing
loss
Determination of Severity of Hearing Loss

R = 35 dB = 8%
L = 35 dB = 8%
Equals 8% bilateral hearing loss
Pattern consistent with noise
Reliability on test: good

Conclusion:
This individual has an 8% bilateral sensorineural hearing loss. Compatible with noise induced loss.

Conclusions

• Hearing loss evaluation utilizes the history, physical exam, audiograms and noise level data to determine the presence or absence of hearing loss, causation and liability.
Conclusion

**Workplace:**
- Reduce occupational noise
- Identify those at risk
- Protect hearing and prevent loss if possible
- Reduce incidence of noise induced hearing loss, reduce claims, reduce costs, improve quality of life of employees

**Employee/individual:**
- Protect hearing when exposed to loud noise
- Avoid loud noise when possible
- Work with management to reduce noise levels when possible

Conclusions

**Noise induced hearing loss:**
- Always sensorineural
- Never conductive
- Typically progressive over years
- Affects higher frequencies initially
- "Pseudohypacusis" indicates deliberate attempt to misrepresent severity of hearing loss
What About the Soldier who Can’t Hear Within Normal Hearing Range?

- A normal listener can hear
  - footsteps at 100 meters
  - voices at 180 meters
  - rifle bolt closing at 1000 meters

- A person with a hearing loss can hear
  - footsteps at < 1 meter
  - voices at 32 meters
  - rifle bolt closing at 46 meters

THINK ABOUT IT...

- Listening posts
- Walking point on patrol
- Call for fire
- Urban Warfare
Annual Hearing Testing

- Why do annually?
  - Feedback *BEFORE* it becomes a problem….not five years down the road when it definitely is a problem

- What is your score???
  - Are you practicing good hearing conservation or aren’t you???

Medical Research

- Hazardous exposure initiates inner ear oxidative process which results in hair cell death cycle
- New medication may be able to *limit* permanent damage by arresting oxidative process
TO SUMMARIZE......

➡️ HEARING LOSS HAPPENS!

➡️ Noise induced hearing loss is 100% preventable

➡️ Your hearing health starts with YOU while at work or home

➡️ If YOU don’t protect it YOU will lose it

CONVENTIONAL TEACHING

Noise Induced Hearing Loss (NIHL) is a loss in sensitivity, primarily at about 4 kHz
SELECTIVITY MECHANISM

Current theories suggest that the IHC are signal detectors which form a positive feedback loop with the brain and with the OHC supplying energy, so increasing gain and selectivity.

SELECTIVITY

Noise induced hearing loss reduces both sensitivity and frequency selectivity.
SELECTIVITY

Many persons with sensorineural hearing loss can understand speech well in the quiet but have progressively greater difficulty as background noise levels increase.

Pathogenic mechanisms that contribute to noise-induced hearing loss and factors that can attenuate cochlear damage.
NOISE INDUCED HEARING LOSS

Persons with noise induced hearing loss often have sufficient hearing sensitivity to be aware that someone is speaking but may have insufficient selectivity to be able to decipher speech signals in noisy environments.

AUDIOMETRY

What is the purpose of audiometry?
Required audiometric sensitivity

The objects of early diagnosis and preservation of hearing mean that < 50% of the maximum NIHL at critical frequencies must be reliably detected in individual subjects.