Audiological Assessment: Procedures and Implications

Routine examination performed in order to evaluate an individual's hearing abilities

Why Test Auditory Function?
1. Assess individual’s hearing ability/disability so that appropriate rehabilitation decisions can be made
2. Obtain site-of-lesion information to assist in medical Dx and Rx
3. Information pertinent to prognosis (monitoring)
4. Medical - legal
   - Eligibility for compensation
   - Other forensic reasons

Basic Audiological Assessment
- Case Hx
- Otoscopy
- Immitance (middle ear function)
- Otoacoustic Emissions (OAEs)
- Pure tone tests (air & bone)
- Speech Audiometry

Basic Audiological Assessment
- Case Hx
- Otoscopy
  - Identify any condition which might interfere with testing or rehabilitation
  - require medical Rx

Outer Ear Problems

Immitance Measures
- Tympanometry
  - Eardrum mobility and resting position
- Equivalent ear canal volume
  - Intact or perforated eardrum
- Middle ear muscle measures
  - Middle ear
  - Inner ear
  - Neurological pathways thru lower brainstem
Measuring Equipment

• Probe tone loudspeaker – Usually 226 Hz
• Air pump – Manometer (daPa)
• Analysis system – Microphone – Sound level meter

• To elicit reflex:
  – Earphone for contralateral reflex
  – Mini-earphone in probe assembly for ipsilateral reflex

Measurement Principles and Quantities

How easy (or how hard) is it for sound energy to enter the middle ear system?

Immitance

• Generic term which refers to all of the various quantities used to evaluate the response of the middle ear transmission system to sound energy
  – Impedance = opposition to the flow of energy
  – Admittance = how easy it is for energy to enter
  – Compliance = volume of air that has an impedance equivalent to that measured at the TM

Tympanometry

• Definition = measurement of eardrum immitance as a function of air pressure in the ear canal.
• Procedure
  – Probe is sealed in the ear.
  – Record immitance while air pressure is varied from about +200 daPa to around -400 daPa
  – Resulting graph = tympanogram.
• Greatest value = evaluating cases with middle ear infections (otitis media)
Tympanogram Types

- **Most important features:**
  - Shape of the tympanogram
    - Peaked, or flat.
    - Gradient, or tympanometric width (TW)
  - Position of peak

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Tympanogram Types

- **Type A**
  - Z is smallest (compliance or Y is greatest) when the eardrum is in its normal resting position.
  - Z increases (Y decreases) when you:
    - Push on the TM (positive EAC pressure), or
    - Pull on the TM (negative EAC pressure).
  - Normal eardrum mobility = smooth, "V" shaped pattern with peak at or near ambient air pressure

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Tympanogram Types

- **Type C**
  - Early stage of otitis media = vacuum
  - With vacuum, tympanogram is "V" shaped, but peak = displaced to negative pressures
    - Pressure at peak = negative pressure in me.

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Tympanogram Types

- **Variants**
  - A₃
    - May indicate pathology
      - Scarring
      - Disarticulation
  - A₄
    - May indicate pathology
      - Fixation of the ossicles (otosclerosis, glue ear, etc.)
Tympanogram Types

- Type B
  - Later stages of otitis media = fluid-filled me cavity.
  - Impedance = high (admittance = low) over entire range of air pressures
  - Yields flat or slightly tilted tympanogram
  - Other things can cause a Type B:
    - Plugged ear canal (e.g., ear wax)
    - Perforation

Tympanogram Interpretation

<table>
<thead>
<tr>
<th></th>
<th>Peak Y (mho or cc)</th>
<th>TW (daPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean 90% Range</td>
<td>Mean 90% Range</td>
</tr>
<tr>
<td>Children</td>
<td>0.5 0.2-0.9</td>
<td>100 60-150</td>
</tr>
<tr>
<td>Adults</td>
<td>0.8 0.3-1.4</td>
<td>80 50-110</td>
</tr>
</tbody>
</table>

Equivalent Ear Canal Volume $V_{ec}$

- Definition - volume of air with impedance = patient’s ear canal.
- Most useful for distinguishing causes of flat (Type B) tympanograms.
  - Small $V_{ec}$ = plugged ear canal.
  - Large $V_{ec}$ = perforation.

Vec Norms

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>90% Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children (3-5)</td>
<td>0.7</td>
<td>0.4-1.0</td>
</tr>
<tr>
<td>Adults</td>
<td>1.1</td>
<td>0.6-1.5</td>
</tr>
</tbody>
</table>

- Screening criteria (ASHA, 1997)
  - Refer if $V_{ec} > 1.0$ cm$^3$

Acoustic Reflex Arc after Borg (1973)

- Diagram of the acoustic reflex arc with labels for different parts of the ear and brainstem.
Acoustic Reflex Tests

Threshold

Decay

Acoustic Reflexes

• Thresholds
  – Definition - lowest sound intensity which causes a detectable immitance change due to middle ear muscle contraction.
  – Mean TAR for normals = 85 dB HL
  – With middle ear or neural pathology:
    • Sometimes elevated > 95 dB HL
    • Usually absent.

Acoustic Reflexes

• Reflex Decay
  – Loud sound is left on for a period of time, the response of the mem reflex diminishes
  – Patients with neural pathology (tumors of the auditory nerve, multiple sclerosis, etc.) often an abnormally rapid decrease (or decay) of the mem contraction.

Otoacoustic Emissions

• Low level echo recorded in ear canal
• Reflects response of outer hair cells in cochlea

Diagnostic Value of OAEs

• Present = probably normal hearing
• Absent, with no outer or middle ear problems = probable inner ear hearing impairment
  – Rough correlation between OAE amplitudes and hearing thresholds
  – Can estimate degree and configuration of hearing loss

Pure Tone Testing

• Step 1 = measure hearing thresholds via air conduction using headphones
• Define what sounds a person can and cannot hear in everyday life. Specifically:
  – Do they have any loss, or is hearing WNL?
  – What is the degree of loss?
  – What is the configuration of the loss?
Auditory Area

Frequency Limits of Audibility
- Best sensitivity = between 2 - 5 kHz
- Drops off by several orders of magnitude at higher and lower frequencies
- Conventional limits = 20 - 20,000 Hz
- Measurement at higher and lower frequencies = calibration problems:
  - Threshold at frequency extremes approaches 140 dB SPL

Audiograms
- Abscissa
  - Frequency in semi-octave intervals
- Ordinate
  - Level (reverse order)
- Hearing Level (HL) (HTL)
- Sensation Level (SL)

Categorization of Hearing Impairment

<table>
<thead>
<tr>
<th>Hearing Level in dB</th>
<th>Hearing Loss Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10 - 25</td>
<td>Normal</td>
</tr>
<tr>
<td>16 - 25</td>
<td>Slight</td>
</tr>
<tr>
<td>26 - 40</td>
<td>Mild</td>
</tr>
<tr>
<td>41 - 55</td>
<td>Moderate</td>
</tr>
<tr>
<td>56 - 70</td>
<td>Moderately severe</td>
</tr>
<tr>
<td>71 - 90</td>
<td>Severe</td>
</tr>
<tr>
<td>above 90</td>
<td>Profound</td>
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after Clark, 1981

Configuration of Loss

Bone Conduction Testing
- Interpretation depends on relation to AC
  - AC = all of ear
  - BC = inner ear and up
Bone Conduction Testing

- If AC = BC
  - IE or N must be broken (sensorineural)
  - O or ME can't be broken, since results are same if we go through them or bypass them

- AC > BC, and BC = normal
  - Ear is broken at O or ME (Conductive)
  - IE = OK

- Air-bone gap
  - Size of conductive loss
  - Max ~ 60 dB

Bone Conduction Testing

- If BC = down, but AC = worse
  - Both conductive and SN losses
  - “Mixed”

Masking to Avoid Cross-hearing

- When AC thresholds are asymmetrical
  - must play masking noise in good ear in order to test bad ear accurately

- Ear-specific BC thresholds cannot be obtained without masking non-test ear

Hearing Ability

<table>
<thead>
<tr>
<th></th>
<th>Conductive</th>
<th>Cochlear</th>
<th>Neural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft</td>
<td>Can’t hear</td>
<td>Can’t hear</td>
<td>Can hear sometimes</td>
</tr>
<tr>
<td>Medium</td>
<td>Soft</td>
<td>Soft</td>
<td>Softer</td>
</tr>
<tr>
<td>Loud</td>
<td>Medium</td>
<td>Loud</td>
<td>Can’t hear</td>
</tr>
</tbody>
</table>

Loudness Recruitment

Fig. A. Normal loudness recruitment for pure tones. Thresholds from both ears, fusion in silence.
Speech Audiometry

• 1st = speech threshold (SRT)
  – Degree of loss for speech
  – Baseline level for word recognition testing
  – Validity check
  • Difference between SRT and tone thresholds?
    Something’s wrong!!!!
      – Administered test inaccurately
      – Equipment malfunction
      – Inaccurate or inappropriate patient response

Speech Audiometry

• 2nd = word recognition scores under optimum conditions (WRS, or PBmax)
  – Diagnostic information
    • VIII N. lesion classic sign = very poor WRS
  – Degree of hearing handicap
  – Prognosis for aural rehabilitation
    • High PBmax = good indicator for success with amplification.
    • Unable to discriminate any speech sounds = poor prognosis for hearing aid use. Suggests need for alternative treatment

SRT

• Speech Reception Threshold (SRT)
  – Oldest and most widely used term
• Speech Recognition Threshold (SRT)
  – Recommended by ASHA guidelines

SRT Materials

• Spondees = standard stimuli for measuring speech thresholds
  – 2-syllable word with equal stress on each syllable
  – E.g., baseball, cowboy, hotdog
  – Easiest kinds of words to hear and understand

Word Recognition Score

• Terminology
  – Synonyms = Speech/Word recognition/identification score
  – Speech Discrimination (Discrim) = still most common term, although not really accurate
• Purpose
  – Evaluate ability to understand speech when it is made loud enough for them to hear easily.

WR Test Procedure

• Presentation level
  – Usually use 40 dB SL
• Materials
  – Phonemically balanced (PB) lists of monosyllabic words
    • PB = if a speech sound is used a lot in real-life, it appears in the list of test words often. If a speech sound rarely occurs in real-life, it appears in the test infrequently (or not at all).
    • Monosyllables, because they’re easy to score.
  – Scoring = % of test items correct.
Word Recognition Categories

<table>
<thead>
<tr>
<th>WRS</th>
<th>Performance Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 to 100%</td>
<td>Excellent</td>
</tr>
<tr>
<td>80 to 89%</td>
<td>Good</td>
</tr>
<tr>
<td>70 to 79%</td>
<td>Fair</td>
</tr>
<tr>
<td>50 to 69%</td>
<td>Poor</td>
</tr>
<tr>
<td>30 to 49%</td>
<td>Very Poor</td>
</tr>
<tr>
<td>Below 30%</td>
<td>Extremely poor</td>
</tr>
</tbody>
</table>

Levels of Auditory Function

• **Symbolic Level**
  – Fine Speech Discrimination
  – WRS > 70%
  • Can understand amplified speech by hearing alone
  • Still problems in difficult listening situations

• **Signal-Warning**

• **Awareness**

Levels of Auditory Function

• **Symbolic Level**
  – Fine Speech Discrimination
  – WRS between 50 and 70%
  • Partial understanding of amplified speech by hearing alone under good listening conditions
  • Vision must supplement, especially in difficult listening situations

Levels of Auditory Function

• **Symbolic Level**
  – Gross Speech Discrimination
  – WRS between 30-50%
  • Amplification helps for perception of gross speech cues:
    – syllabic stress
    – intonation
    – etc.
  • Vision and hearing are equally important

Levels of Auditory Function

• **Symbolic Level**
  – Gross Speech Discrimination
  – WRS < 30%
  • Vision is 1°
  • Amplification may be of 2° benefit, OR NOT: Evaluate
    – aided vs. unaided lip reading
    – CI test battery
Levels of Auditory Function

• Signal-Warning
  – Vision for communication
  – Hearing = for grossly different environmental sounds:
    • Doorbell
    • Phone ring
    • Car horn
    • Etc.

• Awareness
  – Vision for communication
  – Amplification:
    • Contact with world of sound
    • No meaningful discriminations

Speech Signal Characteristics

Long-term Characteristics

• Intensity:
  – Conversational level = 60 dB SPL
  – Hearing impaired listeners set gain as if input = 70 dB SPL
  – Quiet conversation = 45 dB SPL
  – Whisper = 25 dB SPL
  – Shout = 88 dB SPL

• Dynamic Range
  – Classic data
    • Dunn & White (1940)
      – Peak intensity = 12 dB > average level
    • French & Steinberg (1947)
      – Dynamic range of speech = 30 dB
    • Softest levels = 18 dB < average level
  – Modern data
    • Dynamic range is almost certainly > 30 dB

Long Term Average Spectrum
**Speech Spectrum dB HL**

- contribution to intelligibility:
  - <500 Hz
    - 60% of power
    - 5% of intelligibility
  - >1000 Hz
    - 5% of power
    - 60% of intelligibility

**Short-term Characteristics**

- Phoneme = smallest unit of speech that can signal a change in linguistic meaning

**Formants**

- Vocal tract acts as a series of resonators which increase the intensity of speech energy in frequency regions determined by the shape of the tract when the sound is produced.
- Formant frequencies = spectral peaks
  - \( F_1 \) & \( F_2 \) = most important
  - \( F_3 \) = less important

**Vowels**

- Greatest energy at fundamental
  - Average male = 130 Hz
  - Average female = 200 Hz
- At higher frequencies, energy decreases about 10-12 dB/octave

**Consonants**

- Manner
  - Articulatory gesture used in production
  - Stops, fricatives, nasals, semivowels
- Voicing = presence or absence of vocal fold vibration
- Place = point of production in vocal tract
Speech Perception of the Hearing Impaired

Generally, can be predicted from the relation of the phoneme’s spectrum and the individual’s audiogram.

Speech Perception Errors

- **Vowels**
  - Errors are rare
  - When errors do occur, they tend to be for front vowels which have higher frequency $F_2$

Vowel Formants

Speech Perception Errors

- **Consonants**
  - Much higher error rates
  - Voicing feature is usually correct
  - Manner errors are also rare, but are somewhat more common
  - Exception: rising audiograms
    - Some difficulty with nasals
    - Distinctive feature = peak around 300 Hz

Speech Perception Errors

- **Consonants**
  - Place confusions are most common
  - Place cues occur in a relatively narrow frequency range around 2000 Hz
  - Difficult for hearing impaired because:
    - Restricted range of acoustic cues
    - Low intensity
    - Poor high-frequency Hearing Levels

Most Common Errors

- Phonemes with relatively weak, high-frequency second formants
  - Unvoiced fricatives
  - Unvoiced stops