Extending the frequency range for audiometry

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Outline - Goals
• Reasons to consider use of extended high frequency audiometry
• Describe the LiSN-S test and relation to high frequency hearing

Did you ever wonder why?
• Are sound isolation booths necessary?
• Why don’t we test frequencies above 8 kHz?
• Why do we usually test speech understanding in quiet?
• If your car could travel at the speed of light, would the headlights still work?

Thinking outside the booth does not just mean thinking differently.
It means thinking “are we too limited by our sound booths?”
Why are sound booths needed?
• To test sound field thresholds for normal hearing people
• Controlled, but don’t replicate the real world
• At a cost of $75k, they are a very expensive way to test threshold of normal hearing people
• Some people find booths to be claustrophobia-inducing at best
• Yet...much of our counseling happens in these same booths
• Is there a better, more efficient and patient-friendly way to test auditory threshold?

Which environment is better?

One Solution: Circumaural Earphones
• More comfortable for patients
• Easily placed by assistants
• Better sound isolation
• Avoids ear canal collapse
• Prevents low frequency leaks
• Fewer calibration issues (TM perforations)
• Allows extended high frequency testing

Speech in Noise Tests
• Still rarely used in audiologic assessment
• Yet...hearing in noise is main patient complaint
• Patients with “normal hearing” may also complain of listening problems in noise
• Traditional speech recognition tests have ceiling effects, high variability and poor prediction of functional outcomes
• Adaptive tests in noise don’t require sound booth, can simulate head related transfer function; better prediction of functional outcomes

LiSN-S Test
1. Adaptive speech-in-noise
2. Target: sentences (designed for children and adults)
3. Competing speech: looped children’s stories
4. 3-D auditory environment under headphones
   • Laptop computer
   • Sound card
   • Sennheiser HD 215 headphones

Spectrum of LiSN-S Sentence and Distractor Compared to BKB-Sin and Noise Floor
Participants and Enrollment

• Prospective longitudinal study of children
  • Aged 6-12 years
  • LiD: n=51; Parent questionnaire (ECLiPS, Barry & Moore, 2014) and diagnosis by audiologist at Cincinnati Children’s
  • TD: n=63; Typically developing, no listening problems on ECLiPS
  • Both groups: No major neurologic, cognitive or brain injury,
  • Normal hearing (<25 dB HL, .5-8 kHz), Otoscopy and tympanometry (226 Hz)

Physiologic Test Methods

• Wideband tympanometry .25 to 8 kHz (Keefe et al., 2016, Hunter et al., 2016);
• Wideband acoustic reflex thresholds, ipsilateral and contralateral presentation; BBN and 5, 1, 2 kHz pure tone stimuli
• DPOAE using 65/55 dB SPL tone pairs 2-10 kHz
• ABR using clicks, recorded SP, CAP with gold foil ear canal electrodes

RESULTS: Standard and EHF Hearing Thresholds
RESULTS: Individual Standard and EHF Hearing

(1+ high freq threshold >20 dB HL)

All children had 'normal hearing'. Children with LiD were more likely to have one or more threshold > 20 dB HL at frequencies 10 – 16 kHz.

TD: 4/31 have abnormal HF hearing (13%)
LiD: 14/46 have abnormal HF hearing (30%)

RESULTS: Distortion Product Otoacoustic Emissions

TD - typically developing, LiD - listening difficulties
Data points: mean ± SEM
*   p < 0.05
** p < 0.01

Hearing loss associated with OM and PE tube history, speech/language therapy

Frequent Earaches
Tubes
SLP History

Wideband Tympanometry – Absorbance and Group Delay

TD - typically developing
APD - listening difficulties
Data points: mean ± SEM
* * * p < 0.001
* * p < 0.01

Wideband Acoustic Reflexes – Ipsilateral and Contralateral

Afferent and efferent pathways:
Middle ear > cochlea > cochlear nucleus > MN VII N > stapedial nerve > middle ear
Sensitive to HHL (Valearo et al., 2016)

LiSN-S Results versus Hearing Thresholds

Hardest
Easiest
Easier
Easier
Previous Evidence of Extended High-Frequency Hearing Loss and OME: Prospective Study

- EHF HL increased with frequency in children with OME aged 3-11 yr.
- EHF HL in OME directly related to # of tubes and frequency of OME episodes during follow-up.
- Animal studies show RWM transmission of bacterial endotoxins and basilar OHC damage (Paparella, Morizono).

Hunter et al., Ear Hear 1996

Multiple bottom up acuity, binaural processing and top down deficits?

- Childhood Recurrent Otitis Media (Gravel et al.)
- Fluctuant conductive hearing loss – poorer phonetic mapping (Wallace et al)
- Speech-language delay – poorer prediction of semantic with loss of high frequency speech cues (Roberts et al.)
- Binaural processing cues – conductive hearing loss (Moore et al; Hall et al; Cameron & Dillon)
- Acuity in extended high frequencies (Hunter et al, Margolis et al)

Summary – EHF & LiD

- About 30% of children aged 6-12 years with listening difficulties (aka APD) have hearing loss above 8 kHz
- Hearing acuity above 8 kHz is related to some aspects of challenging speech perception in competing spatial conditions (shown in older adults: Besser et al., 2015)
- Hearing acuity above 8 kHz is related to a history of OME, PE tubes and speech-language difficulties
- Both top-down and bottom-up mechanisms should be considered in LiD or APD

Cystic Fibrosis and Hearing Loss Study

Background: CF and Hearing

- AG antibiotics are known to induce ototoxicity (hearing and balance problems).
- Prevention of hearing loss from intravenous (IV)-AG exposure in patients with CF uncertain, contributing to the lack of ototoxic monitoring in many CF clinics.
- The prevalence of hearing loss from AG treatment in adults with CF is about 47% compared to 11-18% in age-matched groups of adults without a history of CF or AG exposure.

Increasing Lifespan of CF Patients

2014 Annual Report, CF Foundation
**Test Protocol**

- 21 CF participants (13 analyzed thus far)
- Mean age at test: 15.5 yrs (Range: 13-19 yrs)
- Tests completed over 1 or 2 days
  - Hearing and Balance Questionnaire
  - Audiometric Thresholds (standard and high frequency)
  - Tympanometry and acoustic reflexes
  - Speech-in-Noise Testing
  - Clinical DPOAEs (2-10 kHz)
  - Chirp-evoked Otoacoustic Emissions (up to 16 kHz)
- Goal is to retest at every admission

**Hearing and Balance Questionnaire**

<table>
<thead>
<tr>
<th>Questions</th>
<th>Parent Report</th>
<th>Patient Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concerns with Hearing</td>
<td>3/6 (50%)</td>
<td>3/12 (25%)</td>
</tr>
<tr>
<td>Tinnitus</td>
<td>2/6 (33%)</td>
<td>5/12 (42%)</td>
</tr>
<tr>
<td>Balance Issues</td>
<td>1/6</td>
<td>5/12 (42%)</td>
</tr>
<tr>
<td>History of OM</td>
<td>2/6</td>
<td>4/12 (33%)</td>
</tr>
<tr>
<td>PE Tubes</td>
<td>1/6</td>
<td>1/12</td>
</tr>
<tr>
<td>Childhood HL</td>
<td>0/6</td>
<td>1/12</td>
</tr>
<tr>
<td>Past Hearing Test</td>
<td>6/6</td>
<td>9/12</td>
</tr>
</tbody>
</table>

**Audiometric Thresholds**

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>Right HL</th>
<th>Left HL</th>
<th>Percent HL Either Ear</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25-8 kHz</td>
<td>4/13</td>
<td>2/13</td>
<td>30.7%</td>
</tr>
<tr>
<td>10-16 kHz</td>
<td>8/13</td>
<td>6/13</td>
<td>61.5%</td>
</tr>
</tbody>
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* HF Audiometry not completed for CF1005.
* 1 patient had middle ear conductive hearing loss.

**Speech-in Noise Function BKB-SIN**

- SNR Loss Interpretation:
  - 0-3 dB: Normal or near normal
  - 3-7 dB: Mild Difficulty
  - 7-15 dB: Moderate Difficulty

*Significant relationship between SNR Loss and EHF Hearing (p<0.047)
Preliminary Findings

- The rate of hearing loss among teen IV-AG histories in the CCHMC cohort is high, especially for high frequency hearing.
- Based on previous reports, these hearing losses will increase over time into adulthood.
- The functional impact is hearing speech in noise, such as in the classroom.
- Expanded study is planned with R01 submission to NIH.

Questions?