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Longitudinal Outcomes of Children with Mild to Severe Hearing Loss: Auditory Experience Matters

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Course Objectives

- Identify aspects of language that are especially vulnerable in early-identified children who are hard of hearing and factors that contribute to risk or protection.
- Describe the influence of age at hearing aid fitting and degree of hearing loss on longitudinal outcomes.
- Explain which children are at greatest risk for low device use, and how consistency of hearing aid use relates to the inconsistent access hypothesis.

NIDCD Working Group: Research Gaps

Donahue (2007); Eisenberg et al. (2007); Tomblin & Hebbeler (2007)
Ambiguity in the problems posed by mild to moderate hearing loss

<table>
<thead>
<tr>
<th>Delayed relative to peers</th>
<th>n</th>
<th>Age (yr)</th>
<th>Compare typical peers</th>
<th>n</th>
<th>Age (yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Davis et al., 1986</td>
<td>40</td>
<td>5-18</td>
<td>Briscoe et al., 2001</td>
<td>19</td>
<td>5-10</td>
</tr>
<tr>
<td>Elfenbein et al., 1994</td>
<td>40</td>
<td>5-18</td>
<td>Gilberston &amp; Kamhi, 1995</td>
<td>20</td>
<td>7-10</td>
</tr>
<tr>
<td>Blair et al., 1985</td>
<td>24</td>
<td>7-10</td>
<td>Norbury et al., 2001</td>
<td>19</td>
<td>5-10</td>
</tr>
<tr>
<td>Delage &amp; Tuller, 2007</td>
<td>19</td>
<td>11-15</td>
<td>Wolgemuth et al., 1998</td>
<td>13</td>
<td>10-15</td>
</tr>
</tbody>
</table>

Even mild HL has consequences
Persistent risks in speech, grammar

Many = hearing peers and > Language Disorders
Selected children impaired

Post NHS: Risk or Resilience?

Role for aided hearing (audibility)
Stiles, Bentler, & McGregor (2012)
Translational Research Questions

- To what extent are children who are hard of hearing at-risk for delayed speech and language outcomes?
- To what extent do clinical interventions such as early service provision and hearing aids offer protection?
- What additional factors contribute to risk or resilience?

Theoretical Considerations

- To what degree is the language acquisition system dependent on input?
  - Robust learner accounts
    - Beyond a minimum level, additional amounts of exposure are not important
  - Input dependent learning systems
    - Language acquisition is based on general-purpose learning systems
    - From initial learning to mastery, experience matters
- Findings from CHH could inform these positions
Background: Access to Input

- Exposure to linguistic input essential for language development
- Characteristics of input associated with differences in language growth
- Language learning may draw heavily on statistical learning processes
  - Requires access to acoustic-phonetic properties in the input
- Access to input and quality interaction support spoken language development

Inconsistent Access Hypothesis

- Children with hearing loss experience variations in the consistency of their access to linguistic input
  - Any factor that constrains the child’s access to language input may reduce learning efficiency
  - Constraints could create challenges for recovery of statistical properties in the input
  - Inconsistent access over time reduces cumulative language experience
- Enhanced audibility with hearing aids should offer protection against this risk
**Barriers to Access**

- Limitations of HAs
- Environmental effects
- Delays in HA fitting
- Inconsistent HA use
- Variations in exposure

**Modeling Factors Influencing Access**

- Degree of HL (PTA) → Audiological Intervention → Cumulative Linguistic Experience: Audibility, Hearing aid use, Linguistic input → Outcomes

Factors that influence relationship between PTA and outcomes.

METHOD

Accelerated Longitudinal Design

- Inclusion criteria:
  - English spoken in home
  - No major secondary disabilities (cognitive, motor delays, autism, vision)
  - Permanent bilateral mild to severe HL (25 – 75 dB HL)
  - No cochlear implants
### CHH and CNH Groups

<table>
<thead>
<tr>
<th></th>
<th>CHH</th>
<th>CNH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>317</td>
<td>117</td>
</tr>
<tr>
<td>Gender</td>
<td>173 male; 144 female</td>
<td>54 male; 63 female</td>
</tr>
<tr>
<td>Hearing</td>
<td>$M = 48.88$ dB HL</td>
<td>&lt; 20 dB HL</td>
</tr>
<tr>
<td></td>
<td>7 without amplification</td>
<td></td>
</tr>
<tr>
<td></td>
<td>76% identified from NHS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Confirmation: 7.32 mos</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Late group: 29 mos</td>
<td></td>
</tr>
</tbody>
</table>

- Matched on income & maternal education
- Higher than typical US sample

**Comprehensive Outcomes**

- Language Skills
- Speech Production
- Pre-Academic Abilities
- Psychosocial and Behavioral
- Hearing
- Background characteristics of child/family
- Interventions (clinical, educational, audiological)
Language Measures

- Age-appropriate measures
- Norm-referenced
  - parent report
  - clinician administered
- Interactive language samples
- Focused probes

Derived a **composite language score** for each child at each age using Principal Components Analysis (2 to 6 years of age).


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* $p < .0001$  CHH differed significantly from SES-matched age mates.

**Conclusion:** CHH are at risk for depressed language development

Tomblin et al., *Ear & Hearing*, 2015
Systematic relationship between degree of hearing loss and language levels.

All groups were significantly different than control group (p < 0.0001)

<table>
<thead>
<tr>
<th>Predictors</th>
<th>Parameter</th>
<th>F value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maternal education</td>
<td>18.74</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>1.0</td>
<td>10.62</td>
<td>0.001</td>
</tr>
<tr>
<td>Degree of loss</td>
<td>50.72</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Age * BEPTA</td>
<td>0.0002</td>
<td>0</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Tomblin et al. (2015)

What Else Accounts for Individual Differences?

Let’s contrast two 3-year-old children with moderate-severe HL

Example 1

Example 2

Cumulative Linguistic Experience:
- Audibility
- Hearing aid use
- Linguistic input

Outcomes
Factors in the Access model

Audibility
- Does aided audibility contribute to variance in language growth?
- Are HAs fit to optimize audibility?

What is audibility?
- Proportion of the speech spectrum that can be heard
  - Measured across a number of frequency bands (weighted for importance)
- Quantified with the Speech Intelligibility Index (SII)
  - Fit to computer based prescriptive targets

SII = 0.0 not audible
SII = 1.0 fully audible
Measuring “boost” from HA

Solution:
- Residualized SII (rSII)
- Measures “boost” from HA independent of degree of hearing loss

Degree to which hearing aids can boost SII is constrained by severity of hearing loss

Tomblin et al. JAMA OTO, 2014; Tomblin et al., E&H, 2015

Audibility Contributes to Language GROWTH

- Quartiles of Aided Benefit, after controlling for degree of loss
- Audibility did not have an overall effect ($p = 0.88$), but was significantly associated with differential growth ($p = 0.009$)
- Benefit holds for mild to severe degrees of HL

Conclusion: Children who receive the most benefit from HAs show steeper growth in language skills

Determining how close HA fittings are to target?

“The characteristics of hearing aid fittings in infants and young children” (McCreery, Bentler, & Roush, 2013)

RMS = root-mean-square

**Compare DSL target SII to measured SII**
- 0-1, with 1 = completely audible

**RMS error to DSL target at 4 frequencies**
- RMS error < 5 dB = optimal HA fitting


55% missed targets, which affects audibility
26% of group with audibility (SII values) below .65

Conclusion: Substantial number of HA’s could be BETTER fit. This can be improved with best practice and it matters for outcomes.
Factors in the Access Model

**Hearing Aid Use**
- How consistently are HAs worn? Does it matter?
- Does age at fit influence outcomes?

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**How consistently are HAs worn?**

Infants of mothers with H.S. education
- 9 times more likely to be low users
- Compared to college educated moms

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Consistent HA Use Benefits Language Growth

Conclusion: Children who wear HAs more than 10 hours/day show steeper growth in language skills than children wearing HAs less than 10 hours/day


Duration of Fit Benefits Growth

- Early fitting associated with strongest outcomes
- Later-fit children showed promising growth once aided

Tomblin et al. (2015)
Benefit Extends to Children with Mild Losses


Factors in the Access model

Linguistic Input
- How does caregiver input directed to CHH compare to that directed to CNH at 36 months of age?
Caregiver Input

- Compared parental input at 36 months
  - Coding of interactions
  - $n = 41$ CNH; $n =$
  - CHH exposed to:
    - fewer abstract ideas
    - more directive statements
    - Use of abstract (higher level) language positively related to language outcomes
    - Directive utterances negatively related to outcomes

Ambrose et al., *E&H* (2015)

Conducive Environment: LENA Samples

- 28 children with mild to severe HL
  - Better ear pure tone average
    - $M = 49.9$, $SD = 14.0$, Range: 23-83
  - Age at hearing aid fitting
    - $M = 4.8$ months, $SD=3.0$, Range = 2-12

Language ENvironment Analysis System (LENA)

Ambrose, VanDam, & Moeller, *Ear & Hearing* (2014)
RESULTS

Mean of 60 conversational turns/hour
1400 adult words/hour

8% electronic media on average.
Highest quartile: 5 times greater exposure to media

Ambrose, VanDam, & Moeller, *Ear & Hearing* (2014)

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RESULTS

High electronic media → Fewer conversational turns → Lower language outcomes

Ambrose, VanDam, & Moeller, *Ear & Hearing* (2014)
Summary

Audibility
- Does aided audibility contribute to variance in language growth?
  Yes
- Are HAs fit to optimize audibility?
  Not always

Hearing Aid Use
- Are HAs worn consistently? Does this matter?
  Not by all; Yes it matters
- Does age at fit influence outcomes?
  Yes, but...

Linguistic Input
- Is caregiver input directed to CHH comparable to that directed to CNH at 36 months of age?
  No
- Electronic media reduces conversation

Are there differential areas of vulnerability?

Grammar: Word Endings

Speech Production

Other? Social?
Differential Vulnerability?

- Greater risk for domains that depend on access to phonetic structure?
  - HL reduces opportunities for perceiving elements that are perceptually subtle
  - Speech production & grammar
  - She wants more cookies.

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Child with bilateral mild-moderate hearing levels
Speech Outcomes by Degree of HL

Speech at 3 Years of Age (GFTA)
**Grammar: Morphology Elicitation Task**

<table>
<thead>
<tr>
<th>Form</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary</td>
<td>He’s mixing it.</td>
</tr>
<tr>
<td>Copula</td>
<td>She’s a dancer</td>
</tr>
<tr>
<td>Progressive</td>
<td>He is knocking on the door</td>
</tr>
<tr>
<td>Third singular</td>
<td>Everyday she dances. He wants more milk.</td>
</tr>
<tr>
<td>Irregular past</td>
<td>He fell off the chair</td>
</tr>
<tr>
<td>Regular past</td>
<td>Sara walked fast</td>
</tr>
<tr>
<td>Possessive</td>
<td>Dad’s shirt</td>
</tr>
<tr>
<td>Plural</td>
<td>Three balls</td>
</tr>
</tbody>
</table>

This is dad’s coat. Whose dress is this? It’s __________ (baby’s).

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**Morphology is at Greater Risk than Vocabulary**

\[ n = 154 \text{ CHH}; 69 \text{ CNH} \quad \text{Age} = 4 \text{ years} \]

- Basic concepts & vocabulary versus Production of word endings
- Morphology has a specific relationship with hearing beyond that found for semantic scores.

Conclusion: CHH show differential areas of vulnerability in language development

Social Vulnerability?  IRONY/SARCASM

Method

- 9 Picture-Supported Stories
- de Villiers & de Villiers
- Presented in standard A-V format
- Child answered questions requiring interpretation or reasoning
1. What did the big brother mean when he said that?

2. Did the brother think that the little boy was a bad hitter or a good hitter?
   - Bad _____
   - Good _____

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**Sarcasm (Grade 2)**

- CNH = 68
- CHH = 134 (59 Mild, 47 Mod, 28 Mod-Severe)
- Main effect of hearing category
  - Mod-Severe group < Moderate and CNH
  - Distribution for children with moderate HL = CNH
  - Distribution for children with Mild HL = Moderate-Sev
  - Sweet spot?

Positive Predictors: (36% of variance)
- Language
- Social Cognition

Not maternal education or audibility
Additional Considerations: Maternal Education

Mean Ages at Follow-up by Maternal Education

- High School or less (n=34)
- Some college (n=65)
- Bachelors (n=50)
- Post Graduate (n=43)

Lower SES: Later fit and at risk for children to be less consistent users of devices (Walker, et al., 2015)

Conclusions and Implications

- HL does have an effect on speech and language development during the preschool years
  - Even the mild group was significantly poorer
  - Children with moderate to severe HL were in the low average to poor range
- Audibility provided by HAs resulted in improved language growth
- Early identification and clinical management including well-fit HAs that are worn consistently improved outcomes
Theoretical Implications

- The data support the importance of language input
  - Findings are consistent with input-dependent learning
  - Modest variations in auditory access are associated with individual differences
  - Constraints on acoustic phonetic details differentially affect phonology and grammar
- Results have implications for theories about sensitive periods and role of experience in language development
  - The language development system appears to remain open to experience
  - Possibly at a lower level of learning efficiency

Future Research Directions

1. Cascading effects of early delays (literacy, psychosocial)?
2. Impact of complex listening environments on learning and listening effort?
3. Protection offered by working memory & linguistic knowledge?
4. Can strategic interventions protect against risk and better support families at risk?
Thank you to the NIDCD and the families and children for their dedicated participation.