Longitudinal Outcomes of children with hearing impairment (LOCHI)

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National Acoustic Laboratories, Australian Hearing; HEARing CRC

Motivation

• 1-2 children/1000 have a permanent hearing loss
  (Russ et al, 2003; Ching et al, 2006)

• Hearing loss impacts negatively on children’s development
  • Language and Literacy (Moeller et al, 2007)
  • Speech recognition and production (Eisenberg, 2007)
  • Perceptual processing (Jerger, 2007; Rudner et al, 2007)
  • Psychosocial development (Watson et al, 1990; Moeller, 2007)
  • Educational attainment (Punch et al, 2004)

• Early detection makes early treatment possible
  (USPSTF, 2001; 2007).

• No clear evidence on efficacy of early intervention
  (USPSTF 2001; Wolff et al., 2010)
Outcomes study, Phonak Pediatric Conference, Stuttgart, April, 2010.

Teresa Ching, NAL

### Current evidence

<table>
<thead>
<tr>
<th>Study</th>
<th>n</th>
<th>Entry to EI / HA fitting</th>
<th>Age at Evaluation</th>
<th>Outcomes measured</th>
<th>Effect of Age of Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yoshinaga-Itano et al. 1998</td>
<td>150</td>
<td>0 - 34 mo (72 &lt; 6 mo)</td>
<td>13 – 36 mo</td>
<td>Parent report (CDI)</td>
<td>✓</td>
</tr>
<tr>
<td>Moeller 2000</td>
<td>112</td>
<td>1 - 54 mo (24 &lt; 11 mo)</td>
<td>5 yrs</td>
<td>Receptive vocab (PPVT)</td>
<td>✓</td>
</tr>
<tr>
<td>Wake et al, 2004</td>
<td>89</td>
<td>5 to 54 mo (11 &lt; 6 mo)</td>
<td>7 – 8 yrs</td>
<td>Language</td>
<td>X</td>
</tr>
<tr>
<td>Kennedy et al, 2006</td>
<td>120</td>
<td>10 - 40mo (57 &lt; 9 mo)</td>
<td>5.4 – 11.7 yrs, mean =7.9 yrs</td>
<td>Receptive language, Expressive language, Speech (Parent report)</td>
<td>✓ X X</td>
</tr>
<tr>
<td>Fitzpatrick et al, 2007</td>
<td>65</td>
<td>6.6 - 18mo (15 &lt; 6 mo)</td>
<td>3 – 5 yrs</td>
<td>Receptive vocab (PPVT), Language (PLS-4), Speech prod (GF2)</td>
<td>X</td>
</tr>
<tr>
<td>Vohr et al, 2009</td>
<td>30</td>
<td>13 &lt;= 3 mo 16 &gt; 3 mo</td>
<td>12 – 16 mo</td>
<td>Words (parent report), gestures (parent report)</td>
<td>✓</td>
</tr>
<tr>
<td>Sininger et al, 2010</td>
<td>44</td>
<td>1 to 72 mo (23 &lt; 6 mo)</td>
<td>60 – 100 mo</td>
<td>Speech perception, Speech production, Language</td>
<td>✓</td>
</tr>
</tbody>
</table>

No prospective study that directly compared Outcomes of early and later-identified children on a population basis

In 2005, we commenced

Longitudinal Outcomes of Children with Hearing Impairment
Aims

• Directly compare outcomes of early- and later-identified children;
• Examine the effect of a range of factors, including child, family, intervention, device setting and etiology, on different outcomes.
• Examine factors affecting individual development prospectively.

Participants

475 children in New South Wales (NSW), Queensland (QLD) and Victoria (VIC).

- Gender: 54% M
- Add disabilities: 25%
- Fit age < 6 mo: 53 %
Degree of hearing loss

Hearing loss

- Profound: 29%
- Severe: 20%
- Moderate: 35%
- Mild: 16%

Hearing aids: 69%

Test intervals

- 8 mo
- 12 mo
- 3 yrs
- 5 yrs
- 6 yrs
Factors

Child
- Age at fitting
- Hearing thresholds
- HA – Prescription, Fitting accuracy, Use, Frequency compression
- Additional needs
- Auditory neuropathy
- Phonology
- Cognitive ability

Family
- Maternal education
- Socio-economic status
- Communication mode
- Involvement in intervention

Intervention
- Communication mode
- Hours of intervention
- Family involvement
- Age at enrolment

Outcomes

Language
- Expressive communication
- Auditory comprehension
- Receptive vocab.
- Expressive vocab.

Speech
- Articulation
- Phonological dev
- Speech perception
- Spatial release from masking

Literacy & numeracy
- Reading
- Writing
- Math reasoning
- Numerical operations

Psycho-social skills
- Aural-oral function in real life
- Pragmatics
- Strengths and difficulties

Education & employment
- Educational attainment
- Employment
Pre-school Language Scale (PLS-4) (Zimmerman et al, 2002)

- 0 to 6 yrs 11m
- Examiner presents different activities and observes
  - What the child understands
  - What the child says
- Total Language scale, 2 subscales
  - Auditory comprehension
  - Expressive communication

Parent’s Evaluation of Aural/oral performance of CHildren (PEACH) (Ching & Hill, 2007)

- Parents observe and record children’s functioning in real-world situations in a diary
- Examiner interviews parents
- 1 m to 16 yrs
- Total score, 2 subscale scores
  - Quiet
  - Noise
RESULTS: HEARING AIDS

Language at 6 months after intervention (n=194)

Covariate means:
- F6AV3FAMD: 56.47526 (n = 26)
- n = 39
- n = 58
- n = 71

Current effect: F(1, 189)=0.41183, p=0.52182
Vertical bars denote 0.95 confidence intervals

Fitting age: p < 0.0001
Hearing loss: p < 0.0001
Prescription: p = 0.8
To examine factors affecting language outcomes,

1. For each outcome,
   - Regression
     - Backward
     - Forward
     - Standard
     - Best 4
     - Best 5
     - Best 6

   5 imputations

2. Repeat for other outcomes
3. Compile set of all significant variables (20)
4. Perform standard regression against each outcome for each imputation
5. Averaged Beta across imputations, …
Outcomes study, Phonak Pediatric Conference, Stuttgart, April, 2010.

At 6 and 12 months post-fitting,

<table>
<thead>
<tr>
<th></th>
<th>Age fit (log)</th>
<th>Birth weight</th>
<th>Aud Neuro pathy</th>
<th>Carer - com diff</th>
<th>Carer - NESB</th>
<th>Home - only spkn</th>
<th>EIA hours</th>
<th>Use of HA</th>
<th>Add Disabilities</th>
<th>HTL</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC (6 m)</td>
<td>-0.30</td>
<td>0.17</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
<td>0.21</td>
<td>-0.36</td>
<td>-0.31</td>
<td></td>
</tr>
<tr>
<td>AC (12m)</td>
<td>-0.13</td>
<td>0.23</td>
<td>0.14</td>
<td>0.19</td>
<td>-0.21</td>
<td>-0.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EC (6 m)</td>
<td>-0.31</td>
<td>0.24</td>
<td>0.21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.25</td>
<td>-0.21</td>
<td></td>
</tr>
<tr>
<td>EC – (12m)</td>
<td>-0.34</td>
<td>0.15</td>
<td>0.22</td>
<td>0.13</td>
<td>-0.31</td>
<td>-0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comp (12m)</td>
<td>0.17</td>
<td>-0.16</td>
<td>0.21</td>
<td>-0.25</td>
<td>-0.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exp (12m)</td>
<td>0.18</td>
<td>-0.16</td>
<td>-0.42</td>
<td>-0.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comp W&amp;G</td>
<td>0.21</td>
<td>0.24</td>
<td>-0.16</td>
<td>-0.22</td>
<td>-0.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prod W&amp;G</td>
<td>-0.39</td>
<td>0.19</td>
<td>-0.25</td>
<td></td>
<td>-0.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calculate residuals and perform ANOVA to examine effect of:

- Communication mode in intervention
  - Levels: Spoken only vs Sign or combination
  - Results: Main effect not significant

- Maternal education
  - Levels: University vs Diploma/certificate vs School
  - Results: significant (p<0.05) only for CDI Expressive Language at 12months post-fitting.
After adjusting scores for the effect of all significant variables, we examined

- hearing level
- age at fitting

Hearing level affects Auditory comprehension, but …

Critical hearing: 70 dB HL
But less so for expressive communication

Fitting age affects Auditory comprehension, but …

Critical age: 14 mo
But less so for expressive communication

But not Expressive language, …
Language at 3 years of age

Covariate means:
F6AV3FAMD: 51.8864

Current effect: \( F(1, 169) = 0.08865, p = 0.76627 \)
Vertical bars denote 0.95 confidence intervals

Current effect: \( F(1, 100) = 0.13813, p = 0.71093 \)
(Computed for covariates at their means)
Vertical bars denote 0.95 confidence intervals

Language at 5 years of age

Covariate means:
F6AV3FAMD: 52.79968

Current effect: \( F(1, 100) = 13.813, p = 0.0001 \)
Hearing loss: \( p < 0.0001 \)
Prescription: \( p = 0.03 \)
Multi-linear regression

<table>
<thead>
<tr>
<th>Yr 3 Axs</th>
<th>Gend</th>
<th>Age fit</th>
<th>Pres</th>
<th>Hearing Level</th>
<th>Maternal Education</th>
<th>SES (IRSAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory comprehension</td>
<td></td>
<td></td>
<td>Beta = 0.15</td>
<td>Beta = -0.26</td>
<td>Beta = -0.25</td>
<td>Beta = 0.16</td>
</tr>
<tr>
<td>(n=173)</td>
<td></td>
<td></td>
<td>p = 0.03</td>
<td>P &lt; 0.0001</td>
<td>P &lt; 0.001</td>
<td>P = 0.02</td>
</tr>
<tr>
<td>Expressive communication</td>
<td></td>
<td></td>
<td>Beta = -0.28</td>
<td>P &lt; 0.0001</td>
<td>Beta = -0.31</td>
<td>Beta = 0.16</td>
</tr>
<tr>
<td>Speech production</td>
<td></td>
<td></td>
<td>Beta = -0.20</td>
<td>p = 0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 114)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receptive vocabulary</td>
<td></td>
<td></td>
<td>Beta = 0.10</td>
<td>Beta = -0.18 p = 0.03</td>
<td>Beta = -0.21</td>
<td>Beta = 0.23</td>
</tr>
<tr>
<td>(n = 131)</td>
<td></td>
<td></td>
<td>p = 0.03</td>
<td>p = 0.024</td>
<td>P = 0.008</td>
<td>P = 0.005</td>
</tr>
<tr>
<td>CDI -Language</td>
<td></td>
<td></td>
<td>Beta = 0.25</td>
<td>Beta = -0.29 p = 0.001</td>
<td>Beta = 0.23</td>
<td>Beta = 0.30</td>
</tr>
<tr>
<td>(n=159)</td>
<td></td>
<td></td>
<td>P = 0.001</td>
<td>P &lt; 0.001</td>
<td>P = 0.001</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>PEACH</td>
<td></td>
<td></td>
<td>Beta = 0.3</td>
<td>Beta = -0.30</td>
<td>Beta = 0.30</td>
<td>Beta = 0.30</td>
</tr>
<tr>
<td>(n=121)</td>
<td></td>
<td></td>
<td>P &lt; 0.001</td>
<td>P &lt; 0.001</td>
<td>P &lt; 0.001</td>
<td>P &lt; 0.001</td>
</tr>
</tbody>
</table>

In summary,

• At 6 and 12 months post-fitting,
  – Better outcomes were associated with earlier fitting, lesser hearing loss, greater birth weight, and absence of auditory neuropathy or additional disabilities
  – Choice of prescription, Socio-economic status, hearing status of carer, gender, communication mode in intervention did not affect outcomes
  – Accuracy of fitting did not affect outcomes, provided that achieved gain was within 5 dB of prescribed gain
At 3 years of age,

• Age of fitting did not have a significant effect, but,
• Hearing loss and maternal education significantly affected outcomes.
• Many confounding factors still to be allowed for, when all data become available.

As part of the LOCHI study, we also examined

EFFECT OF FREQUENCY COMPRESSION
Outcomes study, Phonak Pediatric
Conference, Stuttgart, April, 2010.

**Trial of frequency compression**

- **Recruitment**
  - All LCOHI
    - N = 475
- **Selection criteria**
  - Eligible
    - N = 187
  - Not Eligible
- **Parent’s consent**
  - Yes
    - N = 116
  - No
- **Random assignment**
  - Fit
    - N = 63
  - Not Fit

**Age 3 yrs: Naida vs Other**

**Receptive and Expressive Language**
- Hearing loss: p < 0.03;
- Hearing aid: p = 0.16

**Speech Production**
- Hearing loss: p = 0.9;
- Hearing aid: p = 0.047

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Covariate means:
- MonFit: 6.329153
- A36D_PCS
- Naida Other
- Hearing aid condition
- CV
- A36P_AC
- A36P_AD
- N = 40
- n = 23
- 60
- 110
- PLS-4 Standard score

Current effect: F(1, 40)=1.4565, p=.23457

Vertical bars denote 0.95 confidence intervals
Measure Cortical auditory evoked potential (CAEP) to examine audibility

**Stimuli** - /g/, /t/, /s/

- Presentation level: 55, 65, or 75 dB SPL via loudspeaker at 0º azimuth
- Cortical responses were recorded by using the HEARLab equipment developed at National Acoustic Laboratories.
- Recording electrodes at Cz, C3, C4

**Methods: CAEP**
Results: Cortical responses at 55 and 65 dB input level

**Naida vs own aid**

Current effect: $F(1, 21) = 10.947, p = 0.0034$

Vertical bars denote 0.95 confidence intervals

- **Naida**: $p < 0.001$
- **Own aid**: $p = 0.1$
Parents’ Preference rating (PEACH)

Vertical bars denote 0.95 confidence intervals

Instructions in Noise
Conversation in Noise
Recognise voice
Conversation in playground
Name in noise
Story
Environmental sounds
Conversation in Quiet
Name in Quiet
Instructions in Quiet

A lot poorer
A bit poorer
Same
A bit better
A lot better

Correlation between Peach and cortical detection

Correlation: $r = 0.61, p = 0.007$

$n = 18$
In summary,

• On average, choice of frequency compression did not significantly affect auditory comprehension or expressive communication.
• On average, speech production was better (just significant).
• On average, the use of frequency compression improved audibility of sounds at low input level.
• Increased audibility was associated with improved everyday functional performance.
Outcomes study, Phonak Pediatric Conference, Stuttgart, April, 2010.

Teresa Ching, NAL

Language at 6 months after implantation

![Graph showing PLS-4 at 6 months after implantation with age at implantation (months) on the x-axis and PLS-4 Standard score on the y-axis. The graph includes vertical bars denoting 0.95 confidence intervals. Implant age: $p < 0.0001$.]

Language at 12 months after implantation

![Graph showing PLS-4 at 12 months after implantation with age at implantation (months) on the x-axis and PLS-4 Standard score on the y-axis. The graph includes vertical bars denoting 0.95 confidence intervals. Implant age: $p < 0.0001$.]

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Outcomes study, Phonak Pediatric Conference, Stuttgart, April, 2010.

Teresa Ching, NAL

PLS-4 at age 3 years

PLS-4 at 3 yrs of age
Vertical bars denote 0.95 confidence intervals

PLS-4 Standard score

AC
EC

n = 24
n = 37

< 12 mo
12 mo+

Age at implantation (months)

Implant age: \( p < 0.004 \)

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PLS-4 at age 5 years

PLS-4 at 5 yrs of age
Vertical bars denote 0.95 confidence intervals

PLS-4 Standard score

AC
EC

n = 8
n = 36

< 12 mo
12 mo+

Age at implantation (months)

Implant age: \( p = 0.09 \)

T Ching, NAL, CRC HEAR
### Multi-linear regression

<table>
<thead>
<tr>
<th>Yr 3 Axs</th>
<th>Gender</th>
<th>Mat Edn</th>
<th>Age at Implantation</th>
<th>Bimodal experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory comprehension</td>
<td>Beta=-0.32</td>
<td>P=0.01</td>
<td>Beta = -0.22</td>
<td>P = 0.07</td>
</tr>
<tr>
<td>(n = 61)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expressive communication</td>
<td>Beta=-0.37</td>
<td>P=0.002</td>
<td>Beta = -0.16</td>
<td>P = 0.2</td>
</tr>
<tr>
<td>CDI Language Quotient</td>
<td>Beta = -0.38</td>
<td>P = 0.006</td>
<td>Beta = -0.14</td>
<td>P = 0.3</td>
</tr>
<tr>
<td>(n=51)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PEACH</td>
<td>Beta=0.3</td>
<td>P = 0.02</td>
<td>Beta = -0.25</td>
<td>Beta = -0.45</td>
</tr>
<tr>
<td>(n=43)</td>
<td></td>
<td></td>
<td>P = 0.06</td>
<td>P = 0.001</td>
</tr>
</tbody>
</table>

In summary,

- Better outcomes were associated with implantation before 12 months of age
- Bimodal experience was associated with better outcomes
- Multiple confounding variables need to be allowed for, when all data become available.
When children in the LOCHI study turn 5 years of age, we also evaluated

**SPEECH PERCEPTION AND SPATIAL RELEASE FROM MASKING**

Speech perception

- $S_0N_0$
- $S_0N_{\pm90}$

T Ching, NAL, CRC HEAR
Speech perception in noise

Current effect: F(3, 62)=3.1617, p=.03071

Vertical bars denote 0.95 confidence intervals

<table>
<thead>
<tr>
<th>Device</th>
<th>HA CIHA BCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRT dB SNR</td>
<td></td>
</tr>
<tr>
<td>0-90 SP60N0</td>
<td>n = 46</td>
</tr>
<tr>
<td>0-90 SP60N90</td>
<td>n = 13</td>
</tr>
<tr>
<td>0</td>
<td>4.9 dB</td>
</tr>
<tr>
<td>0</td>
<td>4.7 dB</td>
</tr>
</tbody>
</table>

OVERALL SUMMARY
Summary of interim findings:

- Early detection and intervention enabled children to make a good head start in language development.
- Implantation < 12 months was associated with better outcomes.
- Longer term effects of early intervention will be investigated when all data are available.
- Some children demonstrate deficits in spatial masking release.
- Multiple factors affect level of attainment and rate of development.

At 6 and 12 months post-fitting,

- Early amplification
- More intervention hours
- Spoken communication at home
- More device use

- Low birth weight
- Additional disabilities
- Auditory neuropathy
- Greater hearing loss
- Non-English speaking background
- Caregiver has communication difficulties
Message for rehabilitationists

- Fit hearing aids early
- Fit hearing aids accurately
- Encourage hearing aid use consistently
- Encourage spoken communication at home
- Provide more intervention early

Harvey Dillon, Jo Ashdown, Kate Crowe, Sam Youn, Chris Flynn, Karen McGhie, Brooke Wekenborg, Sanna Hou, Gerrie Krynda, Jessie Sjahalam-King, Vivienne Martin, Vicky Zhang, Iva Djula, Patricia van Buynder, Julia Day, Nicole Mahler, Julia Day, Cassie Cook, Laura Street, Angela Wong.
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