Long-Term Performance for Children with Cochlear Implants

The University of Iowa

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Outline of Talk

- History of CI Program at University of Iowa (UI)
- Rationale of Long-term CI Study
- Methodology
- Results
- Conclusion
What is a cochlear implant?

• A prosthesis that provides direct electrical stimulation to the auditory nerve

• Used with individuals who have severe-to-profound HL and receive little benefit from hearing aids

• Intended benefit:
  – Improve auditory perception
  – Improve speech production
  – Improve language development
Microphone – picks up the acoustic signal

Transmitter coil - sends the signal from the external to the internal devices

Processor – converts the acoustic signal to an electrical signal
Electrode array – stimulates the auditory nerve

Implant/Receiver – receives input from external devices and sends it to the electrode array

Cochlea (inner ear)

Auditory nerve

Electrode array – stimulates the auditory nerve
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History of cochlear implants

- Volta stimulated the auditory system electrically by connecting a battery of 30 “couples” to two metal rods which were inserted into his ears.
- In 1964, Doyle inserted an array of electrodes into the cochlea of a patient with total deafness.
- Cochlear implants first introduced in clinical trials in 1985.
History of CI Program at UI

• 1980 – First adult cochlear implant recipient at the University of Iowa.
• 1985 – The first of five, five-year NIH multi-million dollar grants awarded to Dr. Bruce Gantz.
• 1987 – The first congenitally deaf child in the US was implanted at UI.
History of CI Program cont.

- 1998 – First adult implanted at UI with bilateral cochlear implants.
- 2001 – First adult implanted with a Hybrid short electrode to preserve residual hearing.
- 2004 – First child implanted at UI with bilateral cochlear implants.
- 2008 – First child implanted at UI to receive bilateral cochlear implants with a standard electrode in one ear and a short electrode in the contralateral ear to preserve anatomy.
- To date:
  - 900 people have received cochlear implants at UI
  - Nearly 400 in our research program
    - 125 pediatric and 250 adult
NIH/NIDCD P50 Grant

- A core group that supports all research sections:
  - Audiology, Medical, and support staff
- Five research sections:
  - Language/Speech Perception (Developmental Studies)
  - Electrophysiology (EP)
  - Music
  - Hybrid/electro-acoustic
  - Adult Bilateral
Early on, we compared language achievement in children with CIs to children with profound HL (Tomblin, Spencer, Flock, Tyler, & Gantz, 1999).
History of Language

- Standardized Language Tests
  - CELF-III
    - Concepts and Directions
    - Formulated Sentences
  - PPVT-III
- Length of CI Use (min 2 years)
  - CELF: 6.6 years
  - PPVT: 3 years

Average test age

<table>
<thead>
<tr>
<th>Language Test</th>
<th>Standard Score</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>CELF-Con Dir</td>
<td>80</td>
<td>54</td>
</tr>
<tr>
<td>CELF-Form Sent</td>
<td>70</td>
<td>59</td>
</tr>
<tr>
<td>PPVT-IV</td>
<td>90</td>
<td>32</td>
</tr>
</tbody>
</table>

N = 54 59 32
Electrophysiology (EP)

• Electrophysiology is “the branch of physiology that studies the relationship between electric phenomena and bodily processes.” (American Heritage Dictionary)

• Auditory Evoked Potentials (AEP) are very small electrical voltage potentials recorded from the auditory nerve or brain.

• Auditory Brainstem Response (ABR) is the most well-known AEP.

• ABRs used clinically to identify hearing loss, retrocochlear pathology and to estimate hearing sensitivity.
History of EP

- Although our early research focus was with electrically evoked ABR with adults, the work helped develop and refine EP techniques later used with children.

- Electrically evoked compound action potential (ECAP) was first recorded in humans in Iowa (in the late 80s).

- This later led to the development of ECAP recording systems implemented by the CI manufacturers (NRT/NRI/ART).

- Further investigations with ECAPs, as well as other objective measures are continuing. Are they useful in facilitating programming, tracking changes over time and/or diagnosing device malfunctions?
History of Music

• 1995—began testing pediatric implant recipients
• 7 years of age begin music testing (no infant or early childhood data)
• No existing standardized measures for music testing with children
• Evaluate music perception, appraisal, involvement, and rehabilitation
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Cochlear Implants in Children

- Cochlear implants are an accepted form of auditory (re)habilitation for children with pre- and post-lingual deafness.
- Over 150,000 listeners worldwide have received cochlear implants with half of those being children.
- Few reports demonstrate the long-term stability of performance for this population.
Literature on long-term outcomes

• Tomblin, Lu, Peng, and Spencer (2008) reported on speech production outcomes of children with a minimum of eight years of CI experience.

• Archbold, Nikolopoulos, and Lloyd-Richmond (2009) assessed factors involved in device non-use for children with seven years of CI experience.

• Geers, Tobey, Moog, and Brenner (2008) evaluated data on a large number of children (n=85) when the participants were 8 to 9 years of age and again at 15 to 18 years of age.
  – This study provided an extensive review of outcomes in terms of speech perception, language, and literacy.
Rationale of Long-term CI Study

• Examining performance over time
  – crucial step in verifying the long-term effects on the auditory system
  – provides information about the stability of performance in this growing population

• Little data focused on the impact of demographic factors over time
Rationale of Long-term CI study

The goals of this study were:

1. To examine how speech perception test scores, language test scores and EP measurements changed over time;

2. To determine the effect of age at implantation and PTA on speech perception and language; and

3. To describe the relationship between speech perception and music
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**Retrospective Study**

- Longitudinal data describing performance over time
  - age at implantation
  - pre-implantation residual hearing
- Subjects (n=111)
  - children who have eight years or more cochlear implant experience
  - pre-lingually deaf
  - no developmental delays
## Age at Implantation Distribution

<table>
<thead>
<tr>
<th>Age at implantation (in years)</th>
<th>N</th>
<th>Percent</th>
</tr>
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<tbody>
<tr>
<td>under 2</td>
<td>18</td>
<td>16.2</td>
</tr>
<tr>
<td>2~2.9</td>
<td>15</td>
<td>13.5</td>
</tr>
<tr>
<td>3~3.9</td>
<td>18</td>
<td>16.2</td>
</tr>
<tr>
<td>4~4.9</td>
<td>11</td>
<td>9.9</td>
</tr>
<tr>
<td>5~5.9</td>
<td>19</td>
<td>17.1</td>
</tr>
<tr>
<td>6 above</td>
<td>30</td>
<td>27</td>
</tr>
<tr>
<td>Total</td>
<td>111</td>
<td>100</td>
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## Residual Hearing Distribution

<table>
<thead>
<tr>
<th>Pure-Tone Average (.5, 1, 2 K Hz) (dB HL)</th>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>85~90</td>
<td>1</td>
<td>0.9</td>
</tr>
<tr>
<td>91~95</td>
<td>4</td>
<td>3.6</td>
</tr>
<tr>
<td>96~100</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>101~105</td>
<td>12</td>
<td>10.8</td>
</tr>
<tr>
<td>above 105</td>
<td>83</td>
<td>74.8</td>
</tr>
<tr>
<td>Could not test</td>
<td>1</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>111</td>
<td>100</td>
</tr>
</tbody>
</table>
Speech Perception Test Measures

- Consonant-Nucleus-Consonant Words (CNC)
- Phonetically Balanced – Kindergarten Words (PB-K)
Language Test Measures

- Clinical Evaluation of Language Fundamentals (CELF)
  - Concepts and Directions
  - Formulated Sentences
- Short/Long Articulation Measure
- Woodcock Reading Mastery (WRM)
  - Passage Comprehension
  - Word Identification
EP Test Measures (ECAPs)

- A measure of the voltage change in the auditory nerve following the presentation of an auditory stimulus.
- ECAPs use intracochlear CI electrodes for recording.
- ECAP threshold: lowest stimulation level which elicits a measurable response.
EP Test Measures (Subject Group)

- A subset of 41 children were studied overtime in EP.
- ECAPs are measurable in approximately 94% of our pediatric patients.
- ECAP measurements were tracked periodically over several years.
Music Test Measures

- Melody Recognition by Information Level (MRIL, Olszewski et al, 2005)
- Pure-tone measures of just noticeable difference* (JND, Gfeller et al, 2002)
- Of the 111 research participants, 45 children have completed testing of MRIL; 20 for JND-PT*

*Note: children implanted <2 years do not yet meet age criteria for this test
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Statistical Method – Speech Perception

- Generalized Linear Mixed Model (GLMM) with a Bonferroni adjustment for multiple comparisons
Speech Perception Results I

Effect of Pure-Tone Average (PTA) at 7 Years on PBK word Performance

Effect of Pure-Tone Average (PTA) at 7 Years on CNC word Performance
Speech Perception Results II

Effect of Age at Implantation at 7 Years on PBK word Performance

Effect of Age at Implantation at 7 Years on CNC word Performance
Speech Perception Results III

**PBK Overtime Performance**

- 0% - 10% - 20% - 30% - 40% - 50% - 60% - 70% - 80% - 90% - 100%
- 0 2 4 6 8 10 12 14 16 18 Years

**CNC Overtime Performance**

- 0% - 10% - 20% - 30% - 40% - 50% - 60% - 70% - 80% - 90% - 100%
- 4 6 8 10 12 14 16 18 Years
Speech Perception Results III cont.
Statistical Method – Language

- Linear Mixed Model with a Tukey adjustment for multiple comparisons
Effect of Pure-Tone Average (PTA) on CELF Concept Scores

Effect of Pure-Tone Average (PTA) on Short Phoneme Scores
Effect of Age at Implant on CELF Formulated Scores

Effect of Age at Implant on Passage Scores

Effect of Age at Implant on Word Scores

Language Results II
Relationship between Speech Perception and Language

• The relationships between speech perception and language performance, PTA, and age at implantation were examined by two linear mixed models.

• A positive relationship was found between CNC and Short Phoneme performance without PTA and age at implantation in the model.

• A positive relationship was also found for PBK and Short Phoneme performance with PTA and age at implantation in the model.
EP Results

ECAP threshold over time

- 41 children - current group
- 73 children - Brown et al 2009

Threshold (CL)

0 12 24 36 48 60 72 84 96

Month of Use
EP Results

Paired ECAP Thresholds

N = 37

Mean Change of Approximately 4CL

ECAP Threshold (CL)

early
(laverage 4 months)  late
(laverage 74 months)
Statistical Method - Music

- Correlations of MRIL (with lyrics and rhythm) and HINT sentences presented in quiet.
- Regression Analysis of age at implantation and JND-PT on MRIL-rhythm
Music Results I

Lyrics vs. HINT

- under 2
- 2~2.9 years
- 3~3.9 years
- 4~4.9 years
- 5~5.9 years
- 6 years +
Music Results II

Rhythm vs. HINT

- under 2
- 2~2.9 years
- 3~3.9 years
- 4~4.9 years
- 5~5.9 years
- 6 years +
Music Results III

- Regression Analysis of MRIL-rhythm with age at implantation and JND-PT
  - no significant predictors for performance on MRIL-no lyrics as a result of Age at implantation (p=.98) or JND-PT at any frequency (p=.35)
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In Conclusion

- The earlier children were implanted, the better they performed on speech perception and language.
- More pre-implantation residual hearing positively correlates to better performance for speech perception and language.
- ECAP thresholds were relatively stable over time. Degenerative changes in the auditory nerve following long-term electrical stimulation are not evident.
- Music recognition in children is dependent upon conditions where lyrics are present. Without lyrics, rhythm performance for children cannot be predicted by performance on speech perception or pure-tone measures.
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# The University of Iowa Children’s CI Team

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**We would like to acknowledge the many clinicians from years past that have contributed to acquiring this dataset.**