Cochlear Implant Outcomes and Variability in Adults and Children

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Factors Predictive of Open-Set Word Recognition in Adults with Cochlear Implants

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ACKNOWLEDGEMENTS

Appreciation is expressed to all the subjects who gave their time and effort to participate in this study. This research was supported by Grants R01DC00581 (Skinner) and R21 DC006665 (Finley) from NIDCD
Advances in CI technology have lead to significant increases in benefit for adults; however, significant variability in performance still exists.

Considerable variability in speech perception outcomes for adult CI users remains unexplained (Waltzman and Cohen, 1999).
Variables that have been indentified as predictor variables for adult speech recognition

- Prelingual vs. Postlingual onset of HL
- Duration of HL
- Age at implantation
- Etiology
  
  (e.g. Sarant et al., 1994; Blamey et al., 1996; Schramm et al., 2002; Teoh et al., 2004; Kaplan et al., 2003; etc.)
Cognitive Factors and Adult Speech Recognition with CI’s

- Visual monitoring task
- Processing speed
- Working Memory measures
- General intellectual capacity
- Visual memory
- Nonverbal reasoning
  (Gantz et al., 1993; Knutson et al., 1991; Lyxell et al., 1996; Kropp et al., 2000)
Cognitive Factors

Study by Heydebrand et al., (2007) examined cognitive factors as predictors of CNC word recognition at 6 months.

Cognitive factors: Wechsler Intelligence Scale III, working memory, processing speed, verbal learning as measured by California Verbal Learning Test (CVLT; Delis, 2000).

Scores from CVLT emerged as significant cognitive factor.
Aim of Study

- Examine the contribution of **cognitive** and **electrode placement** variables in addition to known demographic variables on CNC word recognition scores in adult CI users.

- 4 stage multiple regression analysis used to examine unique contribution of predictor variables.
Cognitive Factors for Current Study

- Principal components analysis revealed that dominant cognitive factors predictive of word recognition were the four scores from the CVLT (Heydebrand et al., 2007)
- One dominant cognitive factor derived from CVLT scores using PCA
Electrode Placement Factors

- Position of electrodes in the cochlea was analyzed with a new CT analysis technique (Skinner et al, 2007)
- Allowed estimates of:
  1. Electrode position (i.e. whether an electrode is positioned in scala tympani (ST) or scala vestibuli (SV))
  2. Electrode trajectory (longitudinal insertion depth of the array inside the cochlea from the cochleostomy to the most apical electrode).
Hypotheses

1. Electrode array insertion depth and scalar position estimated from CT scans will predict significant variance in CNC word recognition scores.

Electrode array insertion depth and scalar position estimated from CT scans will be strong predictors of word recognition based on the tendency of deep insertions to distort place pitch coding and the potential of scalar vestibuli placement to increase cross turn stimulation, respectively.

2. Cognitive test measures will predict significant variance in CNC word recognition scores.

Cognitive test measures will be strong predictors of word recognition because of the importance of cognitive function in facilitating processing verbal stimuli and supporting plasticity in the central auditory system.
Figure 2.

S3 Good CNC Scores
S4 Poor CNC Scores
S5
S6

Nucleus Contour Array
Adv. Bionics Hi-Focus Array
Subjects

- 54 postlinguistically or perilinguistically deaf adults
- Gender: 31 Female, 23 Male
- Mean age at CI: 56.3 yrs (range 23 - 80 yrs)
- PTA (.5,1& 2 kHz) at CI ear: 100 dB HL (range 65-123 dBHL)
- PTA at unimplanted ear: 99 dB HL (Range 63-123 dB HL)
- Ear Implanted: 34 Right ear, 20 Left Ear
- CI Devices Used: Advanced Bionics 8, Nucleus 46
- All Had complete insertion of electrode array
Methods

- Two lists (50 words/list) of CNC words from the original recording in the Minimum Speech Test Battery (Luxford, 2001) were presented at 60 dB SPL at 0° azimuth in the sound-field.

- Subjects tested over 21 test sessions from two weeks to 2 years after hookup with CI.
Data Analysis and Regression

Results

- Significance of 9 independent variables in predicting variance in each of 3 dependent variables analyzed across 4 stage regression analysis
Dependent Variables

- Minimum CNC word recognition score
- Maximum CNC word recognition score
- Rate of growth between minimum and 95% of maximum CNC word score over 2 year period
- Actual Scores fit with logistic curve to predict scores as a function of time
Figure 1.

CNC Maximum Predicted by Logistic Curve Fit

Goodness of Fit = 0.94

CNC Minimum Predicted by Logistic Curve Fit

Goodness of Fit = 0.87

Growth Rate = (Max - Min)/ Time

Time to Achieve CNC Maximum

Time to Achieve Max

CNC Minimum
Independent Variables

- Age at hookup
- Duration of HL
- Duration of preimplant HA use
- Lip-reading score for sentences
- Preoperative sentence recognition
- Education level
- Electrode Array Position (ST vs. SV)
- Electrode Array Trajectory
- Cognitive Factors
Four Stages in Regression

- Stage 1 Hook-up age, Pre-operative aided sentence score, duration of HL, education level
- Stage 2 Stage 1 Plus Cognitive Factor
- Stage 3 Stage 2 Plus Lipreading scores
- Stage 4 Stage 3 Plus Postoperative array position and trajectory
Results
Significant predictors for CNC Minimum Score

- Duration of severe/profound hearing loss
- Electrode Array Trajectory
- Educational Level
- These three variables together accounted for 28% of total variance
Significant Predictors for CNC Maximum Score

- Cognitive Factors
- Duration of Severe/Profound HL
- Array Position
- Educational Level

These variables together accounted for 33% of total variance
Significant Predictors for CNC Growth

- Age at hook-up
- Cognitive Factors
- Array Trajectory and Position
- Duration of HL

These variables together accounted for 42% of total variance
Conclusions

The CT measures of Array Trajectory or Array Position were significant predictors of CNC word recognition for all 3 dependent variables (Minimum and Maximum Predicted CNC Word scores, and Rate of Growth from Minimum to Maximum Predicted CNC Word score.)
Conclusions

- Cognitive factors related to verbal learning and memory were predictive of Maximum CNC score and Growth of CNC Score.
Conclusions

- In addition to demographic variables that have been shown to be predictive of adult word recognition with CI’s, electrode array and cognitive measures were significant predictors of performance.
- Surgical techniques specifically related to array trajectory and insertion depth may improve speech perception for adult CI users.
- Increased understanding of cognitive factors may assist in developing realistic expectations for CI outcomes as well as developing rehabilitation strategies aimed at facilitating learning to process auditory input with CI.
Long-Term Benefits of Cochlear Implantation in Preschool

Ann Geers and Emily Tobey
University of Texas at Dallas

Jean Moog and Chris Brenner
Moog Center for Deaf Education

Lisa S. Davidson
CID Research @
Washington University School of Medicine
St. Louis, Missouri

NIH-NIDCD R01 DC008335 “Long term outcomes of cochlear implantation in early childhood. (Geers)
Original Sample

Recruited between 1996 and 2000

N = 181

Ear and Hearing Supplement, 2003
181 Subjects

Canada 1997-2000

United States 1997-2000

- 4 or more (18)
- 3 (4)
- 2 (5)
- 1 (7)
- 0 (17)
Sample Selection

1. Between 8 and 9 years of age
2. Onset of deafness by age 3
3. 4-6 years of implant use
4. Implanted before 5 years of age
5. No additional disabilities
6. Monolingual English home environment
7. No open set speech perception
Data Collection

Summer Research Camps

15 Children per Camp

All expenses paid

3 Mornings of Testing

Afternoon Activities
Outcome Variables

Speech Perception
Speech Production
Language
Reading
Communication Mode (n=181)

Subject (n=181)

- Aud-Verbal
- Aud-Oral
- Cue
- TC speech
- TC =
- TC sign

- TC
- Oral

n=89
n=92
Follow-up Sample

Recruiting between 2004 and 2009

CA = 15-18 Years

Targeted N = >100
86 Follow-up Participants

40 boys / 46 girls

Age at Implant: 1;11 – 5;4

Year of Implant: 1990-96
# Sample Comparison

<table>
<thead>
<tr>
<th></th>
<th>Returned (N=86)</th>
<th>Not returned (N=95)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implant Age</td>
<td>3.5</td>
<td>3.4</td>
</tr>
<tr>
<td>PIQ (WISC)</td>
<td>103</td>
<td>101</td>
</tr>
<tr>
<td>Comm. Mode Average</td>
<td>3.9</td>
<td>3.8</td>
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<tr>
<td>BKB Sentences % Correct</td>
<td>58</td>
<td>56</td>
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<tr>
<td>Reading Standard Score</td>
<td>88</td>
<td>84</td>
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</table>
Classroom Placement

<table>
<thead>
<tr>
<th>Subject (n=86)</th>
<th>age 8-9</th>
<th>age 16-17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Special Ed</td>
<td>17%</td>
<td>4%</td>
</tr>
<tr>
<td>Partial MS</td>
<td>24%</td>
<td>20%</td>
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<tr>
<td>Mainstream</td>
<td>58%</td>
<td>76%</td>
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</tbody>
</table>
Communication Mode over Time

Early Communication Mode Rating

- TC age 8
- OC age 8
- current mode

Subject (n=86)

n=44
n=42

speech

speech + sign
Subject Characteristics

- 86 Subjects; 46 Female, 40 Male
- Mean age at implant 3;6 (1;11 – 5;4)
- All implanted between 1990 and 1996
- All Nucleus CI users started with the N22 electrode array, 78% with the MSP processor, 22% with Spectra (one child started with Clarion 1.2 CI)
- 12 subjects were re-implanted, 79 were unilateral CI users, 7 had a 2nd CI,
- 73% of the sample did not use an FM system in high school
## Device Characteristics

<table>
<thead>
<tr>
<th>Device</th>
<th>Age 8-9</th>
<th>Age 16-17</th>
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</thead>
<tbody>
<tr>
<td>MSP</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Spectra</td>
<td>76</td>
<td>10</td>
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<tr>
<td>Sprint</td>
<td>NA</td>
<td>1</td>
</tr>
<tr>
<td>Esprit 22</td>
<td>NA</td>
<td>22</td>
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<tr>
<td>Esprit 3G</td>
<td>NA</td>
<td>47</td>
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<tr>
<td>Freedom</td>
<td>NA</td>
<td>5</td>
</tr>
<tr>
<td>Clarion 1.2</td>
<td>1(S Series)</td>
<td>1(P-BTE)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>86</strong></td>
<td><strong>86</strong></td>
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</table>
## Method

<table>
<thead>
<tr>
<th></th>
<th>Session 1</th>
<th>Session 2</th>
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</thead>
<tbody>
<tr>
<td>Age</td>
<td>8-9</td>
<td>16-17</td>
</tr>
<tr>
<td>Duration CI</td>
<td>5.53 yrs</td>
<td>13.15 yrs</td>
</tr>
<tr>
<td>Word Perception</td>
<td>LNT in quiet (tested at 70 dB SPL)</td>
<td>LNT in quiet (tested at 70 dB SPL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LNT in quiet (soft level 50 dB SPL)</td>
</tr>
<tr>
<td>Sentence Perception</td>
<td>BKB Sentences in quiet (at 70 dB SPL)</td>
<td>BKB Sentences in quiet (at 70 dB SPL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BKB Sentences in Noise (+10 SNR)</td>
</tr>
<tr>
<td>Detection</td>
<td></td>
<td>Aided Sound Field Thresholds</td>
</tr>
</tbody>
</table>
Lexical Neighborhood Test

Subject (n=86)

Percent Correct

age 16-7  average at 16-17
age 8-9  average 8-9

57
47
Sentence Perception, Keywords Correct

Subject (n=86)

Percent Correct

age 16-7
average 16-17
age 8-9
average 8-9
Listening at different levels, ages 16-17

Average Percent Correct

LNT score

70 dB SPL
57

50 dB SPL
43

70 dB SPL
50 dB SPL
Loud and Soft subject scores

LNT (70 dB SPL) average (70 dB SPL)
LNT (50 dB SPL) average (50 dB SPL)

Percent Correct

Subject (n=86)
Listening in quiet and noise, ages 16-17

Average Percent Correct

BKB Sentence Score

- Quiet: 77%
- Noise: 50%
Quiet and Noise Subject Scores

Percent Correct

Subject (n=86)
Aided PTA is a significant predictor of speech perception at a soft level.

After statistically controlling for perception at louder levels, aided PTA still added explained variance to the regression. (F=93.5, p<.0001, $R^2=.69$, $IR^2=.16$).
Conclusions

- Speech perception in optimal conditions improved from age 8-9 to age 16-17.
- Listening to soft speech was a challenge, but those with better aided PTAs received more benefit.
- Listening in noise remains a significant challenge for the majority of the group as evidenced by the marked decrease in sentence recognition from quiet to noise.
- It is of interest to note that the majority (73%) of these children reported that they were NOT using an assistive device (FM system).
- Counseling regarding FM system capability and benefit should be implemented.
<table>
<thead>
<tr>
<th></th>
<th>Session 1</th>
<th>Session 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9 years 1 mo</td>
<td>16 years 8 mos</td>
</tr>
<tr>
<td><strong>Wechsler</strong></td>
<td><em>Wechsler</em></td>
<td></td>
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<tr>
<td><strong>Intelligence Scale</strong></td>
<td>Similarities</td>
<td>Similarities</td>
</tr>
<tr>
<td></td>
<td><em>Language Content</em></td>
<td><em>Verbal IQ</em></td>
</tr>
<tr>
<td>Vocabulary</td>
<td></td>
<td>Peabody Picture Vocabulary Test</td>
</tr>
<tr>
<td>Language Content</td>
<td></td>
<td>Clinical Evaluation of Language Fundamentals</td>
</tr>
</tbody>
</table>
WISC Similarities: Age 8-9

Scaled Score

Subject (n=86)

63% > normal range
WISC Similarities over time

77% > normal range

Subject (n=86)
## READING

<table>
<thead>
<tr>
<th>Session 1</th>
<th>Session 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 years 1 mo</td>
<td>16 years 8 mos</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peabody Individual Achievement Test</th>
<th>Recognition Comprehension</th>
<th>Recognition Comprehension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test of Reading Comprehension</td>
<td>Vocabulary Syntax Sentence Sequencing Paragraph Reading</td>
<td></td>
</tr>
</tbody>
</table>
PIAT Reading Age 8-9

56% > normal range

Subject (n=86)
Note: 88 is the mean at the younger age, 83 is the mean at age 16-17
PIAT Reading Grade Score and Age

![Graph showing the relationship between Grade Equivalent Score and Chronologic Age for Primary and Secondary levels.](image)

- **Primary**
- **Secondary**

The graph illustrates the correlation between grade equivalent scores and chronologic age for both primary and secondary levels.
Language and Reading Results

1. Verbal development was faster than expected normal growth.

2. Reading development was only slightly below normal rate.

3. Half of the sample achieved age-appropriate language and reading levels in high school.
Grade and Age

Grade

Chronologic Age

![Graph showing the relationship between grade and chronologic age.](image-url)
# Quality of Life

<table>
<thead>
<tr>
<th></th>
<th>Session 1</th>
<th>Session 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI Satisfaction</td>
<td>9 years 1 mo</td>
<td>16 years 8 mos</td>
</tr>
<tr>
<td>Communication</td>
<td>Parent Questionnaires</td>
<td>Student Questionnaires</td>
</tr>
<tr>
<td>Socialization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clubs, Activities,</td>
<td></td>
<td>Student Questionnaires</td>
</tr>
<tr>
<td>Jobs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Satisfaction with Cochlear Implantation
Elementary School
Parent Responses

- 85% - Satisfied with progress in school
- 72% - Progress exceeded expectations
- 86% - Improved job prospects
- 96% - Fuller participation in the hearing world
High School
Teen Responses

- 90% said CI helped them understand others
- 98% said they would replace CI if it broke
- 94% said they would recommend a CI to parents of newly diagnosed deaf children
Communication and Socialization
Students from Early Oral Communication Settings

- 93% had intelligible speech
- 38% reported using sign language
- 10% used sign interpreter for some classes
- 95% used speech without sign in everyday communication
- 13% reported minimal proficiency in sign language
Communication for Early Sign Users

- 50% communicated using only speech
- 67% intelligible speech
- 64% sign interpreter in some classes
- 11% discontinued sign by high school
How are they doing in High School?

- 95% mainstreamed
- 72% used the telephone
- Comfortable with deaf and hearing friends
- Most expected to go to college
Extra Curricular Activities, Sports, Jobs

- 93% active in high school activities
- 51% held jobs – similar to hearing teens
Activities and Clubs

Honor Society
Habitat for Humanity
Student Council
Newspaper / Yearbook Staff
Band    Chess Club
Foreign Language Club
Deaf Teen Club
Team Sports

- soccer
- basketball
- rowing
- football
- curling
- lacrosse
- volleyball
- softball
- baseball
- hockey
Individual Sports

- martial arts
- figure skating
- cheerleading
- wrestling
- track
- horseback riding
- cycling
- tennis
- golf
- bowling
- weight lifting
- dirt bike racing
- motocross racing
- swimming
Jobs: High Communication Demands

Retail sales
- Toy store
- Parts store
- Bagel shop
- Art store
- Concession stand
Jobs: High Communication Demands

Teaching

• Figure skating
• Teacher’s Aide
• Tutoring
Jobs: High Communication Demands

Service Positions

- Daycare
- Veterinary Clinic
- Photographic Company
- Lifeguard
- Theater Group
Jobs: Low Communication Demands

- bagging at a grocery store
- babysitting
- cutting the grass / landscaper
- cooking and serving food
- putting cabinets together
- data entry
- working at a stable
Conclusion

- By most measures these teens who were profoundly deaf seemed much like their hearing peers in terms of the lives they led and their adjustment in the world.
- Future generations are likely to benefit even more from cochlear implants.
Thank You

Sincere Appreciation is Extended to ARA for Remembering and Honoring Dr. Margaret Skinner and Her Contributions to the Field