Communication Abilities of Children With Aided Residual Hearing

Comparison With Cochlear Implant Users

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Objective: To compare the communication outcomes between children with aided residual hearing and children with cochlear implants.

Design: Measures of speech recognition and language were administered to pediatric hearing aid users and cochlear implant users followed up longitudinally as part of an ongoing investigation on cochlear implant outcomes. The speech recognition measures included the Lexical Neighborhood Test, Phonetically Balanced–Kindergarten Word Lists, and the Hearing in Noise Test for Children presented in quiet and noise (+5 dB signal-to-noise ratio). Language measures included the Peabody Picture Vocabulary Test: Third Edition (PPVT-III), the Reynell Developmental Language Scales, and the Clinical Evaluation of Language Fundamentals–Revised.

Subjects: The experimental group was composed of 39 pediatric hearing aid users with a mean unaided pure-tone average threshold of 78.2 dB HL (hearing level). The comparison group was composed of 117 pediatric cochlear implant users with a mean unaided pure-tone average threshold of 110.2 dB HL. On average, both groups lost their hearing at younger than 1 year and were fitted with their respective sensory aids at 2 to 2.5 years of age. Not every child was administered every test for a variety of reasons.

Results: Between-group performance was equivalent on most speech recognition and language measures. The primary difference found between groups was on the PPVT-III, in which the hearing aid group had a significantly higher receptive vocabulary language quotient than the cochlear implant group. Notably, the cochlear implant group was substantially younger than the hearing aid group and had less experience with their sensory devices on this measure.

Conclusion: Data obtained from children with aided residual hearing can be useful in determining cochlear implant candidacy.

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DECISIVE FACTOR IN DETERMINING COCHLEAR IMPLANT (CI) CANDIDACY FOR CHILDREN WITH PROFOUND HEARING LOSS IS THE DEMONSTRATION OF “LIMITED BENEFIT” FROM WELL-FITTED HEARING AIDS (HAs). INASMUCH AS PERFORMANCE WITH CIs IS CONTINUALLY IMPROVING, IT IS IMPORTANT TO DEFINE LIMITED BENEFIT ON AN ONGOING BASIS. SUCH CHARACTERIZATION IS PARTICULARLY RELEVANT FOR CHILDREN WITH SUBSTANTIAL RESIDUAL HEARING WHO, IN THE PAST, HAVE NOT BEEN CONSIDERED TYPICAL IMPLANT CANDIDATES.

In early clinical trials, the first generation of multichannel CIs was shown to be superior to other sensory aids available for children with near-total deafness, including vibrotactile devices, single-channel implants, and high-powered HAs. Outcomes in communication abilities have steadily improved with advances in technology and the implantation of CIs in younger children. Motivated by these improvements, centers began implanting CIs in children with residual hearing in the upper range of profound hearing loss (eg, 90-100 dB HL [hearing level]). The implant was shown to be even more beneficial for these cases, seemingly because of prior experience with HAs coupled with more intact auditory structures.

There is growing interest in considering implantation in children with even more residual hearing than typically has been considered. It has been our experience that teachers of the deaf, speech-language pathologists, and specialists in aural rehabilitation are referring more children for implant evaluation who have substantial aided residual hearing, operationally defined as mod-
erately severe–to–severe hearing loss. These professionals observe that a proportion of such children either are not progressing with their HAs at the same rate as children with implants or have reached a plateau in performance. Parents of such children also are asking CI professionals to consider implantation, despite knowing the potential risk of further damage to inner ear structures. The inability of some children with substantial residual hearing to attain expected levels of performance from HAs is not completely understood but may in part reflect technical limitations of the HA, such as reduced frequency bandwidth or acoustic feedback.12-14

Investigators from different CI centers also have begun to explore performance outcomes in children with aided residual hearing in the moderately severe–to–severe range of hearing loss as an indirect means of evaluating CI efficacy.15-18 Results generally have indicated that the highest performing implant users are attaining scores equivalent to children with losses ranging from 70 to 80 dB HL. On the basis of these findings, a more in-depth investigation has been initiated at our 2 centers to compare the speech recognition and language abilities of children with moderately severe–to–severe hearing loss who use conventional amplification to those of a large cohort of children with profound hearing loss to attain expected aided residual hearing.

The results from this ongoing investigation should provide useful guidelines for determining whether an individual child with aided residual hearing might benefit from a CI and, further, whether candidacy for an implant should generally be expanded to include children with substantial aided residual hearing.

## METHODS

### PARTICIPANTS

This project received approval from the institutional review boards that oversee human subjects research at the collaborating institutions. General demographics for the children enrolled to date with HAs (n=39) and with CIs (n=117) are given in **Table 1**. Comparison of best ear, unaided 3-frequency (500, 1000, and 2000 Hz) pure-tone average (PTA) hearing loss did not overlap between the 2 groups. The children in the CI group had hearing losses in the profound range (≥90 dB HL), whereas the children in the HA group had losses that ranged from 60.0 to 88.3 dB HL. Although the unaided PTA differed substantially between groups, the aided PTA was equivalent. The groups also were fitted with their sensory devices at approximately 2 years of age. The average age at onset of hearing loss generally was within the first 6 months of life for the 2 groups. The communication mode used by most children was oral communication.

### ASSESSMENT MEASURES

#### Speech Recognition

The speech recognition test battery comprised several tests designed for children of different ages. Data from the 3 most difficult tests of the battery were analyzed. These tests included the Lexical Neighborhood Test (LNT),19 the Phonetically Balanced–Kindergarten Word Lists (PBK),20 and the Hearing in Noise Test for Children (HINT-C).21 All 3 tests are open set, recorded, and typically presented to children older than 4 years. The tests were presented in the sound field at 50 to 55 dB HL with the loudspeaker facing the child (0° azimuth).

The LNT is composed of 25 lexically easy and 25 lexically hard words that were derived from the spoken vocabulary of children 3 to 5 years of age. Lexically easy words are those high in frequency of occurrence but phonemically dissimilar to other words, whereas lexically hard words are those low in frequency of occurrence but phonemically similar to other words. There are single-talker and multitalker recorded versions of the test. The multitalker version was administered for this study, because it better represented real-world listening demands. The PBK is a 50-mono-syllabic word test that is typically presented to children 5 years and older. Half lists of 25 words were administered for this study using the Auditec of St Louis recordings. The HINT-C is composed of 13 lists of 10 sentences that are identifiable by children with normal hearing as young as 5 and 6 years. One list per condition of the recorded test was administered in quiet and in noise at a +5 signal-to-noise ratio (SNR). The noise was presented at this level because it had been shown in an earlier study22 to produce scores in the middle range of the performance-intensity function for listeners with the magnitude of hearing loss as the HA participants in this study. The competing noise was shaped to the long-term average speech spectrum of the sentences.

#### Language

The language measures selected for this study were appropriate for younger and older children and were administered using the child’s communication mode. The language battery included the Peabody Picture Vocabulary Test: Third Edition (PPVT-III),23 Reynell Developmental Language Scales (RDLS),24 and Clinical Evaluation of Language Fundamentals–Revised (CELF-R).25 The PPVT-III is a closed-set measure of receptive vocabulary and is appropriate for ages 2.5 to 16.9 years. The RDLS is a test of receptive and expressive language that is appropriate for ages 1 through 8 years. The RDLS involves object manipulation and description based on questions that varied in length and grammatical complexity. The CELF-R measures language skills that develop from ages 5 through 16.9 years. The test evaluated the child’s knowledge of various syntactic and semantic categories, and instructions varied in length and grammatical complexity.

### Table 1. Demographic Information for the HA and CI Users

<table>
<thead>
<tr>
<th>Demographic</th>
<th>HA Users (n = 39)</th>
<th>CI Users (n = 117)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean unaided PTA (range), dB HL</td>
<td>78.2 (60.0-88.3)</td>
<td>110.2 (90.0-120.1)</td>
</tr>
<tr>
<td>Mean aided PTA (range), dB HL</td>
<td>37.7 (21.7-61.7)</td>
<td>35.5 (18.8-50.0)</td>
</tr>
<tr>
<td>Mean age at onset (range), mo</td>
<td>6.4 (0-53)</td>
<td>1.5 (0-29)</td>
</tr>
<tr>
<td>Mean age when fitted (range), mo</td>
<td>25.8 (2-70)</td>
<td>31.4 (7-58)</td>
</tr>
<tr>
<td>Communication mode</td>
<td>29 OC, 10 TC</td>
<td>66 OC, 51 TC</td>
</tr>
</tbody>
</table>

Abbreviations: CI, cochlear implant; HA, hearing aid; HL, hearing level; OC, oral communication; PTA, frequency pure-tone average; TC, total communication.
RESULTS

The mean data presented for each test represent the results obtained from the most recent test interval. These data, as displayed in Figure 1 and Figure 2, are segmented by communication mode (oral communication vs total communication) and sensory device (HA vs CI). Inasmuch as the number of participants differed across assessments, mean chronological age and device use for the speech recognition and language measures are presented in Table 2. The number of participants for each group per test is noted in each figure.

Figure 1. Mean percentage of correct scores on 3 tests for the hearing aid (HA) and cochlear implant (CI) groups: (A) Lexical Neighborhood Test (LNT), (B) Phonetically Balanced–Kindergarten Word Lists (PBK), and (C) Hearing in Noise Test for Children (HINT-C) speech recognition. The data are further divided by oral and total communication. The error bars represent 1 SD. SNR indicates signal-to-noise ratio.
The mean chronological age and number of years of device use for each test measure are presented in Table 2 for the HA and CI groups. The 2 groups were reasonably matched for the LNT and HINT-C but not for the PBK words. For the PBK, the HA group was more than 1 year older and had nearly 2 years more experience with their sensory aids than the CI group. This difference in years of device use was statistically significant ($t_{68}=3.22$, $P=.002$).

**Figure 2.** Mean language quotients on three language measures for the hearing aid (HA) and cochlear implant (CI) groups: (A) Peabody Picture Vocabulary Test: Third Edition (PPVT-III), (B) Reynell Developmental Language Scales (RDLS), and (C) Clinical Evaluation of Language Fundamentals–Revised (CELF-R). The data are further divided by oral and total communication. The error bars represent 1 SD.

**SPEECH RECOGNITION**

The mean chronological age and number of years of device use for each test measure are presented in Table 2 for the HA and CI groups. The 2 groups were reasonably matched for the LNT and HINT-C but not for the PBK words. For the PBK, the HA group was more than 1 year older and had nearly 2 years more experience with their sensory aids than the CI group. This difference in years of device use was statistically significant ($t_{68}=3.22$, $P=.002$).
LNT Easy and Hard Words

The average percentage of correct scores on the LNT are shown in the top panel of Figure 1, which compares the HA and CI groups within each communication mode group. Analysis of the results indicated that easy words were recognized more accurately than hard words \((F_{1,37}=5.59, P=.02)\). It also was shown that the orally communicating children obtained significantly higher scores than the manually communicating children \((F_{1,37}=8.64, P=.005)\). The performance difference between the HA and CI groups was not found to be statistically significant.

PBK Words and Phonemes

The average group data for word and phoneme scores are displayed in the middle panel of Figure 1 as a function of sensory aid and communication mode. As expected, the phoneme score was higher than the word score. Relative to the children who used total communication, the orally communicating children had significantly higher word scores \((t_{50}=3.28, P<.002)\) and phoneme scores \((t_{10}=2.16, P=.02)\) (equal variances not assumed). The performance difference between the HA and CI groups was not statistically significant for word or phoneme score when analyzed separately for the orally and manually communicating children or when collapsed across communication mode.

HINT-C Sentences

The mean number of words in sentences correctly recognized under quiet and noise conditions is shown in the bottom panel of Figure 1, further segmented by device and communication mode. As expected, words in quiet were recognized more accurately than words in noise \((F_{1,22}=7.05, P=.01)\). Furthermore, the orally communicating children recognized significantly more words in sentences than the manually communicating children \((F_{1,22}=15.08, P=.001)\). There was a significant interaction between listening condition and device \((F_{1,22}=13.13, P=.002)\), indicating that the difference in scores between quiet and noise conditions was greater for the CI group relative to the HA group (ie, the CI group had greater difficulty understanding sentences in noise than did the HA group).

LANGUAGE

The results from each language test were converted to language quotients, defined as the language age divided by the chronological age. Thus, if the language quotient equaled 1, the language age was equivalent to chronological age. A score below 1 indicated that the child’s language age was lower than chronological age, whereas a score above 1 indicated that the child’s language age was higher than chronological age. The HA and CI groups both had mean language quotients lower than 1 for all 3 tests, although the language age of some individuals exceeded chronological age as demonstrated by the error bars in Figure 2.

The mean chronological age and number of years of device use for each test measure are given in Table 2 for the HA and CI groups. The 2 groups were equivalent on these 2 variables for the RDLS and CELF-R but not for the PPVT-III. On average, the HA group was 2 years older \((t_{17.5}=3.47, P=.001)\) and used their sensory aids 3 years longer \((t_{17.1}=4.9, P<.001)\) than the CI group on the PPVT-III.

PPVT-III Results

Displayed on the top panel of Figure 2 are the mean results for the PPVT-III. Analysis of these data indicated that the HA group had a significantly higher language quotient than the CI group when the data were collapsed across communication mode \((t_{132}=3.25, P=.001)\). Differences between oral and total communication did not reach statistical significance.

RDLS Results

Receptive and expressive language quotients for the RDLS are displayed in the middle panel of Figure 2. When the data were collapsed across device and test, the orally communicating children had significantly higher language quotients than the children who used total communication \((F_{1,117}=7.78, P=.006)\). However, the difference in performance between oral and total communication was greater for the expressive measure, as evidenced by the significant interaction \((F_{1,117}=7.03, P=.009)\). Performance differences between HA and CI groups were not statistically significant.

CELF-R Results

Language quotients for the CELF-R are shown in the bottom panel of Figure 2. Statistical analysis results of these data indicated that the orally communicating children had significantly higher language quotients than the children who used total communication \((t_{14.8}=2.6, P=.02)\).
Differences between the HA and CI groups did not reach statistical significance.

**COMMENT**

This study sought to ascertain whether communication outcomes by children with moderately severe–to–severe hearing loss can serve as a reference for determining CI efficacy by comparing speech recognition and language outcomes of children with HAs to those of children with CIs. On measures of speech recognition, deaf children with approximately 5 years of CI experience performed comparably to hearing-impaired children with an average hearing loss of 78 dB HL and 5 to 6 years of HA experience. The CI group showed a greater discrepancy in scores between quiet and noise conditions than the HA group on the HINT-C sentences. This result may be explained by the SNR used in this study. Recall that the +5-dB SNR was chosen to avoid potential ceiling effects in the children with more residual hearing. Recent research has indicated that children with CIs require a greater SNR (+10 dB SNR) to obtain scores in this range. Thus, the assessment of speech in the presence of background competition may be a particularly sensitive means to determine whether a child with HAs should be considered a candidate for cochlear implantation.

Results on the language battery were similar to those observed for the speech recognition battery. Language quotients for the CI and HA groups were equivalent on 2 of the 3 language tests (CELF-R and RDLs). On the test of receptive vocabulary (PPVT-III), the HA group attained significantly higher language quotients than the CI group. Notably, the 2 groups were not matched on this test in terms of chronological age and device use; the HA group was 2 years older than the CI group and had 3 more years experience with their sensory aid. On the basis of findings from the other 2 language measures, this between-group gap might be expected to narrow as the CI group becomes older and acquires more experience with their implants.

For all but 1 test (PPVT-III), the orally communicating children obtained significantly higher scores than the manually communicating children. Although this result is not surprising, it underscores the importance of comparing an individual child’s scores with those from the appropriate communication group when using these data to determine implant candidacy. The fact that the CI group had a higher proportion of children who communicated manually than the HA group is indicative of the greater severity of hearing loss for this group. With little or no access to auditory information before implantation, educational and communication options for many of these children were limited. Approximately 30% of children in the HA group communicated manually, and performance scores for these children were lower than scores by their orally communicating peers. Such findings may reflect the fact that a conscious decision was made by the parents to select total communication when hearing loss was first detected or, alternatively, that communication skills were not developing adequately through oral methods.

These general results are encouraging because they verify that overall performance with the CI is steadily improving when compared with results from early investigations conducted on older children with first-generation implants. Performance outcomes may be expected to improve even more with a new generation of deaf children undergoing implantation as young as 12 months. The implant users in the present study have been followed up longitudinally, some over several years, and, thus, may have undergone implantation at older ages. On the basis of recent findings, which demonstrate the advantage of early implantation (ie, at younger than 3 years) future results are expected to be significantly higher for these very young children when they reach an age at which they may be tested on more linguistically challenging materials. The same also may be true for children with more residual hearing who are identified with hearing loss at birth and fitted with HAs within months of diagnosis. Such children will have the benefit of early identification, sophisticated HA circuitry, and more refined prescriptive fitting strategies.

Although results from this study have demonstrated that children with CIs are achieving levels of performance comparable to children with severe hearing loss, a more compelling comparison might have been to evaluate a select group of CI and HA users matched in degree of hearing loss between 80 and 90 dB HL. Because none of the children in the CI group had a preimplantation hearing loss in this range, such an analysis was not possible. However, a similar study is currently being conducted with children who have aided residual hearing in the range of 80 to 90 dB HL in the better hearing ear and have received an implant in the poorer hearing ear. Results to date suggest that these children, as a group, perform best in the bilateral (HA and CI) or CI-only condition relative to the HA-only condition.

To conclude, the results from this study provide evidence to support implantation of CIs in children with significant aided residual hearing who, for whatever reason, may not be achieving performance levels comparable to the average performance of CI children. Although this investigation is still in progress, results to date offer insight into CI candidacy.

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