REVIEW ARTICLE

Intelligibility of spontaneous conversational speech produced by children with cochlear implants: A review

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Summary
Objective: The emergence of cochlear implant technology has raised hopes about improved outcomes for children with severe and profound hearing impairments. This study sought to examine the current literature to help evaluate whether the new technology is living up to its promise specifically relative to the intelligibility of conversational speech produced by these children.

Method: At least 20 studies to date have reported findings for the intelligibility of speech produced by children fitted with cochlear implants. The current review involved a descriptive, summary examination of 10 of these studies that analyzed spontaneous conversational speech.

Results: The review suggested that intelligibility outcomes for these children appear to be considerably better than we have historically seen in this population (i.e., prior to the development of cochlear implant technology). For children implanted very early it appears that progress toward intelligible speech is more rapid, and the development of fully intelligible speech may be a reasonable goal for many such children. Even for children implanted somewhat later, progress on speech intelligibility appears to continue for at least 10 years post-implantation.

Conclusion: It would appear that cochlear implants are providing much better outcomes compared to older intervention approaches, at least relative to the intelligibility of spontaneous conversation.

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1. Introduction

Up until the early 1980s, the prognosis for children born with severe and profound hearing impairments to develop intelligible speech was generally very poor. In a comprehensive review of the then-available literature, Gold [1] reviewed a series of studies of children age 6—15 years with severe to profound hearing impairments who had been tested either while reading or speaking spontaneously. Gold [1] concluded that “… only about 20% of the speech output of the deaf is understood by inexperienced listeners” (p. 397). More recently however, renewed prospects have emerged because of a combination of two major developments. First, improvements in assessment technology such as auditory brainstem response (ABR) and otoacoustic emission (OAE) measures have permitted reliable identification of hearing loss in newborn infants (i.e., much earlier than previously). These developments, along with studies demonstrating better outcomes with earlier identification [2,3] and the 1993 NIH Consensus Development Conference on Early Identification of Hearing Loss were likely the prime motivations behind the establishment in the United States and other countries of universal newborn hearing screening programs. The second major development that appears to have improved prospects for speech intelligibility in children with significant hearing impairment has been the availability of multi-channel cochlear implants (CIs) since at least the late 1980s. These technological developments have dramatically altered the intervention landscape. Subjective reports by clinicians and parents, as well as an informal scan of the literature would also suggest that we are now witnessing dramatic improvements in speech and language outcomes in this population. The question is whether the available research actually supports such observations. The current report attempts to answer that question by asking whether speech intelligibility outcomes of children with severe and profound hearing impairments are better than we have historically seen in such children who did not have access to this technology (i.e., those described in [1]).

For purposes of the current review, intelligibility of speech will be assumed to refer to the accuracy with which a normal-hearing listener can recover the speaker’s intended message [4]. Relative to speech produced by children fitted with CIs, at least 20 studies to date have reported intelligibility outcomes using a variety of approaches. In particular, these studies have variously looked at production of speech at different linguistic levels including single words, sentences, conversation, and narratives. As the most socially valid level at which to measure intelligibility, spontaneous conversation was chosen as the focus of the current report which then included examination of 10 such studies [5—14]. As these reports have been largely descriptive in nature, a descriptive summary approach was taken herein.

2. Analysis

Of the 10 studies under consideration, seven made use of the Speech Intelligibility Rating Scale (SIR) which is shown in Table 1. According to Allen et al. [15], the SIR “… was designed as an outcome measure accessible to parents, professionals, and health-care purchasers. It is a ‘real-life’ descriptive rating scale …” (p. 631). No specific directions or limitations on its use appear to have been published, but a high level of inter-observer reliability

| Table 1 Speech Intelligibility Rating Scale (SIR) criteria |
|-----------------|------------------------------------------------------------|
| Category | Rating criteria                                           |
| 5       | Connected speech is intelligible to all listeners. Child is understood easily in everyday contexts |
| 4       | Connected speech is intelligible to a listener who has a little experience of a deaf person’s speech |
| 3       | Connected speech is intelligible to a listener who concentrates and lip-reads |
| 2       | Connected speech is unintelligible. Intelligible speech is developing in single words when context and lip-reading cues are available |
| 1       | Connected speech is unintelligible. Pre-recognizable words in spoken language. Primary mode of communication may be manual |
has been reported for its application by speech—language pathologists [15]. Findings in the current review were compared with those of Gold [1] as that study appeared to represent the most recent broad review of studies of speech intelligibility prior to the introduction of the cochlear implant. Only an indirect comparison of the SIR findings with those of Gold [1] was possible, however, as Gold reported mean % intelligible (i.e., words understood), while the studies using the SIR reported % of individuals who qualified for each rating category. An examination of the descriptions of each of the SIR categories suggests that a value of 20% words understood in connected speech as reported in [1] would be equivalent to something between an SIR category of 2 (Connected speech is unintelligible. Intelligible speech is developing in single words . . .) and an SIR category of 3 ("Connected speech is intelligible to a listener who concentrates and lip-reads"). For purposes of the current review, a conservative approach was taken, and it was assumed that a rating of at least 3 (i.e., 3, 4, or 5) would represent outcomes in children with CIs that would be equal to or superior to those summarized in [1]. One other study [12] used a rating scale other than the SIR. The scale used was as follows: "4, complete intelligibility; 3, satisfactory intelligibility with some difficulty in spontaneous speech; 2, Intelligibility depending on context/voice and speech difficulties; 1, poor intelligibility/no control of voice/incomplete phonological system; 0, no intelligibility or no speech production" (p. 11). In this case, using a similar rationale to that of comparisons with the SIR, a rating of at least 2 was conservatively thought to represent findings that would be comparable to or superior to Gold’s [1] mean finding of 20% intelligible. For the remaining two studies being examined [11,9], more direct comparisons with the 20% mean value were possible as specific % understood values were reported.

3. Findings

Findings from the seven studies which used the SIR are shown in Table 2. The language environments are provided in Table 2 for information only as such information was not usually stated in the original sources but was inferred from the location of the facility where the participants were recruited. Such inference does point to at least three languages being represented (English, French, Persian). To examine the potential influence of two important variables (age of implantation and amount of implant experience), the

<table>
<thead>
<tr>
<th>Study</th>
<th>n</th>
<th>Language environment</th>
<th>Implantation age</th>
<th>SIR = 3+</th>
<th>SIR = 4+</th>
<th>SIR = 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>[6]</td>
<td>47</td>
<td>Persian</td>
<td>1–5.8 years (Mean = 3.4)</td>
<td>91%</td>
<td>36%</td>
<td>0%</td>
</tr>
<tr>
<td>[8]</td>
<td>63</td>
<td>French</td>
<td>1–10 years (median 3.9)</td>
<td>17%</td>
<td>8%</td>
<td>2%</td>
</tr>
<tr>
<td>[13]</td>
<td>16c</td>
<td>English</td>
<td>Not specified</td>
<td>11%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>[11]</td>
<td>82</td>
<td>French</td>
<td>1.9–14.0 years (Mean = 4.8)</td>
<td>84%</td>
<td>68%</td>
<td>41%</td>
</tr>
<tr>
<td>[7]</td>
<td>30</td>
<td>English</td>
<td>2.5–11.1 years (Mean = 5.3)</td>
<td>83%</td>
<td>73%</td>
<td>37%</td>
</tr>
<tr>
<td>[10]</td>
<td>135</td>
<td>Not specified</td>
<td>1.9–14.0 years (Mean = 4.8)</td>
<td>26%</td>
<td>14%</td>
<td>7%</td>
</tr>
</tbody>
</table>

SIR = ratings on the Speech Intelligibility Rating Scale (SIR2).

Table 2 Summary of findings from studies using the Speech Intelligibility Rating Scale (SIR)
studies in Table 2 are arranged vertically in approximate order of mean age of implantation and horizontally by amount of implant experience. The data entries represent the percentage of participants who were rated as 3, 4, or 5 (SIR = 3+), 4 or 5 (SIR = 4+), or 5 only (SIR = 5). An examination of Table 2 suggests several general observations. First, within each study there is a clear trend for intelligibility to improve over time (i.e., with amount of implant use). Second, progress appears to be faster for those who receive their implants the earliest. Also note that in the study in Table 2 with the earliest mean age of implantation [6], 100% of their participants achieved an SIR rating of 4 or 5 after 5 years of implant use and fully 78% achieved a rating of 5 or 'fully intelligible'.

Put another way, children implanted the earliest not only appear to make the most rapid progress, but there also appears to be a relatively high likelihood of them achieving fully intelligible conversational speech. Third, at least two studies [7,14] indicate that, even for children implanted at slightly older ages, progress toward fully intelligible speech appears to continue even up to 10 years after implantation. And finally, the poorest outcomes appear to have been obtained in the study that focused specifically on children whose deafness was attributed exclusively to cytomegalovirus [13], although even these children appeared to be making significant progress 5 years after implantation.

With respect to the study that used the different rating scale [12], 40 children were included who had been implanted between 2;10 and 20 years of age (mean = 7;0) and intelligibility was measured after between 4 months and 6 years of implant use (mean = 2 years). Extrapolation from plots in that paper suggested that 73% of the children were rated 2, 3 or 4, 35% were rated as 3 or 4, and 8% were rated as 4 only (fully intelligible). Age of implantation was closest to [14] and [7], but amount of implant use in [12] was much shorter. If one extrapolates the findings in [14] and [7] back to earlier levels of implant use, the findings in [12] would appear to be relatively consistent with those studies.

The last two studies that were reviewed [11,9] used quantitative measures of intelligibility rather than rating scales. In [11] the exact procedure was not specified beyond the statement that “Speech intelligibility was judged by undergraduate students...” (p. 166). That study included 33 children who had been implanted at ages between 2 and 14 years. Testing was conducted after between 24 and 60 months of implant use. For children implanted at 2–4 years of age, intelligibility was reported to be 60–90%. For children implanted at 5–8 years of age, intelligibility ranged from 30 to 90% and for those implanted at 9–14 years of age, intelligibility was 40%. Findings from this study support the above observation that earlier implantation results in better outcomes. The last study, by Flipsen and Colvard [9], measured intelligibility using word for word transcription (which was accompanied by phonetic transcription). Flipsen and Colvard noted that one problem encountered during the transcription process is that exact word counts for the unintelligible portions may be difficult to obtain. However, unintelligible syllables can be counted, because every syllable contains only a single vowel which can be detected because of their greater loudness compared to consonants. The transcriber in [9] identified and grouped unintelligible syllables into words using context and/or prosodic cues where these proved helpful. In cases where such cues were not helpful, the transcriber grouped the syllables into words based on a rule of 3 monosyllabic words for every 1 disyllabic word [16]. Counts of unintelligible words were then combined with counts of intelligible words to yield % words understood. Flipsen and Colvard [9] included 6 children who had been implanted between 1;8 and 3;0 (mean = 2;4); note that this represented the earliest mean age of implantation for the 10 studies being considered herein. Samples were collected multiple times from each child and included 23–61 months of implant use. A significant correlation (r = .65) was obtained between intelligibility values and amount of implant use. The relative strength and positive direction of the correlation supports the previous observation from Table 2 that intelligibility improves with amount of implant use. Actual intelligibility values ranged from 65 to 97% (mean = 85.7%) across the samples. Comparing these results with the two younger age groups in [11] would suggest fairly consistent findings and also supports the observation from Table 2 that the best outcomes appear to occur with earlier implantation.

4. Discussion

Findings from the studies reviewed herein would appear to be superior to those reported in the review by Gold [1]. This conclusion is also supported by a more direct comparison with the findings reported in a single (albeit national) study [17] of children age 4–23 years with
hearing impairments who had largely (96.8%) been identified with hearing loss prior to age 3 years. The classroom teachers of the children were asked to rate the intelligibility of their students’ speech to unfamiliar listeners. Considering only the 741 children with hearing impairments of 71 dB or worse (those most comparable to those in the studies reviewed herein), 114 (15.4%) reportedly ‘would not speak’, 184 (24.8%) were rated as ‘not intelligible’, 188 (25.4%) were rated as ‘barely intelligible’, 199 (26.8%) were rated as ‘intelligible’ and the remaining 56 (7.6%) were rated as ‘very intelligible’. Assuming that the category ‘barely intelligible’ is approximately equivalent to a rating of 3 on the SIR, 59.8% of the children in [17] might have been rated as 3+ on the SIR. Although mean age of the children was not reported in [17], the largest group in the overall study was age 8–11 years. With identification having been before age 3 years, the most relevant comparison would be with the two longest periods of implant use in Table 2 (5 and 10 years). Such a comparison once again suggests equal and likely superior outcomes for children with CIs. Thus, it would appear that the available research supports the idea that for children with severe and profound hearing impairments who are fitted with CIs, the outlook for the intelligibility of their speech is considerably better than we have historically seen in these children. Indeed, despite considerable individual variability, the prospects for the development of fully intelligible conversational speech appear to be quite good for many of these children.

As noted earlier, the potential influence of both earlier identification and new intervention technologies were operating concurrently in these studies. The current analysis does not permit any definitive conclusion about which, if either, of these developments had greater influence. The fact that those children implanted the earliest appeared to have the best outcomes certainly reinforces the benefits of both.

The conclusions reached in the current review are of course only preliminary as they are based on a small number of studies. As well, these studies largely reflect outcomes for children implanted at somewhat older ages than is currently the norm. Further studies, particularly of very early implantees, are clearly warranted. As well, the somewhat poorer speech intelligibility findings for the one study of children whose hearing loss was attributed to cytomegalovirus suggest the need for additional outcome studies relative to children with particular causal pathways for their hearing loss.

Conflict of interest
The author has no financial and/or personal relationships with other people or organizations that could inappropriately influence or bias the work presented herein.

References


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