A Comparison of Language Achievement in Children With Cochlear Implants and Children Using Hearing Aids

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English language achievement of 29 prelingually deaf children with 3 or more years of cochlear implant (CI) experience was compared to the achievement levels of prelingually deaf children who did not have such CI experience. Language achievement was measured by the Rhode Island Test of Language Structure (RITLS), a measure of signed and spoken sentence comprehension, and the Index of Productive Syntax (IPSyn), a measure of expressive (signed and spoken) English grammar. When the CI users were compared with their deaf age mates who contributed to the norms of the RITLS, it was found that CI users achieved significantly better scores. Likewise, we found that CI users performed better than 29 deaf children who used hearing aids (HAs) with respect to English grammar achievement as indexed by the IPSyn. Additionally, we found that chronological age highly correlated with IPSyn levels only among the non-CI users, whereas length of CI experience was significantly correlated with IPSyn scores for CI users. Finally, clear differences between those with and without CI experience were found by 2 years of post-implant experience. These data provide evidence that children who receive CIs benefit in the form of improved English language comprehension and production.

KEY WORDS: cochlear implants, language development, prelingually deaf, children

Multichannel Cochlear Implants (CIs) have been available to profoundly deaf children for over a decade. One of the primary benefits intended for children receiving CIs is an improvement in communication skills. More specifically, the selection of a CI for a child implies an obvious desire by the parents to have the child participate within, and use the language of, the hearing community. Therefore, one of the expected benefits in communication derived from CIs in an English speaking community is the acquisition of spoken English. These expected benefits have been questioned recently by some (Tyler, 1993). Lane (1992) and Crouch (1997) have voiced strong opposition to the use of CIs in congenitally deaf children. Lane (1992) stated

> It is highly unlikely that an impoverished auditory signal such as the implant provides will yield the same benefits for later language acquisition that normal hearing does; indeed, the coding carried out by the speech processor of the implant may work against the usefulness of the auditory input for language development, since the human nervous system did not evolve to acquire language from cochlear prostheses (pp. 224–225).

Crouch (1997) noted that it remains to be shown that children receiving CIs obtain sufficient linguistic benefit from these devices to permit

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them to be fully participating members of the hearing community.

Similar skepticism is found concerning the effectiveness of CIs on speech perception and speech production (Tyler, Davis, & Lansing, 1987). However, several programs of research have demonstrated that children receiving CIs show improvements in speech perception and speech production skills (Fryauf-Bertschy, Tyler, Kelsay, & Gantz, 1992; Geers & Toby, 1992; Osberger et al., 1991; Tobey, Geers, & Brenner, 1994; Tye-Murray & Kirk, 1993). Results such as these led the National Institutes of Health (1995) to conclude that, with respect to cochlear implants, "Improvements in the speech perception and speech production of children are often reported as primary benefits" (p. 9).

If CIs are to provide functional communication skills for children receiving them, the communication gains must extend beyond speech perception and production and include the lexical, grammatical, and discourse skills of the hearing community. These are the higher level communication skills necessary for social and academic achievement in these communities. Because the participants in this study resided in English speaking communities, the English language will be the focus of this paper. The lexical and grammatical development of spoken languages such as English have been shown to be very challenging to children who are prelingually, profoundly deaf (Osberger, 1986; Quigley, Power, & Steinkamp, 1977). However, children who are provided with a natural sign language exposure, such as American Sign Language, beginning in early childhood have been found to show typical patterns of language learning in this modality (Bellugi, 1988). Thus, most children with prelingual deafness should be fully capable of acquiring any lexical and grammatical aspects of a language regardless of its modality, so long as the sensory system provides appropriate input and there are mature language users providing adequate communication experiences (Nelson, Loncke, & Camarata, 1993). The positive results from the studies of speech perception and production strongly suggest that CIs provide an improved sensory experience of spoken language and thus should provide gains in the acquisition of higher levels of language involving the lexicon, grammar, and discourse.

Results of research on language acquisition in children with CIs are just emerging. Initial reports consisted of case studies that provided evidence of changes in language associated with receipt of CIs (Coerts & Mills, 1995; Dawson, Blamey, Dettman, Barker, & Clark, 1995; Hasenstab & Tobey, 1991). More recently, Geers and Moog (1994) compared the language development over a 3-year period of a group of 13 children who received CIs, with similar groups of children fitted with hearing aids or tactile aid. All three groups were provided with intensive oral speech and language training. Children with CIs equaled or exceeded the language growth of the other groups on receptive and expressive measures of spoken English. In fact, the children with CIs approached the language levels of a group of children using hearing aids who had, on average, 20-dB better hearing. McConkey-Robbins, Osberger, Miyamoto, and Kessler (1995) used a within-subjects design to examine the impact of CIs on language. These investigators followed prelingually deaf children for 15 months after they received their CIs, testing them with the Reynell Developmental Language Scales–Revised (RDLS; Reynell & Huntley, 1985). The language-age equivalent scores obtained at 6 and 15 months post-implant were compared to predictions of scores based on a pre-implant language quotient. Mean receptive and expressive quotients exceeded the predicted means; furthermore, the difference between obtained and predicted at 15 months was greater than that at 6 months. This study suggests that rates of language development increase from pre-implant levels. Later, this group (Miyamoto, Svirsky, & Robbins, 1997) examined the growth in RDLS expressive scores over the 1st year of implant experience and compared these changes with those predicted from cross-sectional data obtained from similar children who were deaf, but who had not received CIs. They found that even 12 months of CI experience was sufficient to produce significant gains in expressive language over predictions based on non-implanted children.

Research, thus far, suggests that children receiving CIs have better English language skills than would have been expected had they not received a CI. However, the current research continues to be limited. Only two studies (Geers & Moog, 1994; Miyamoto, Svirsky, & Robbins, 1997) used a comparison group of children who used hearing aids. In each case, none of the children had been followed for more than 3 years, and none of these studies reported the variability in language outcomes. Research on speech perception and production development in children receiving CIs has shown that there is considerable variation in the rates of development; however, the basis of this variability has yet to be explained.

The current study was conducted to examine the following questions:

1. Do children who have received CIs exceed achievement levels obtained by children who use hearing aids with respect to the comprehension and production of sentences?
2. Is language achievement of CI users associated with the amount of experience with an implant independent of chronological age?
3. What is the pattern of expressive sentence achievement over 5 years of implant experience, and, if benefit is obtained, how soon does this appear?

4. Does pre-implant and early post-implant language status predict later language status?

Method

Participants

Two groups of children participated in this study. Demographic data, including age at implantation; pre-operative, unaided, pure-tone thresholds; etiology; and educational program for both groups can be found in the Appendix. One group of children had CI experience, and the other group had only hearing-aid experience (HAs). The CI group comprised 29 prelingually deaf children, who received the Nucleus 22-channel cochlear implant between ages 2 and 13 years (*M* = 4.76, *SD* = 1.57). Prior to their implant surgery, they were profoundly deaf. The mean pure-tone average for this group was 111.9 dB (*SD* = 5.48) for the right ear and 114.8 dB (*SD* = 4.8) for the left ear. All children performed at or below chance levels on the following speech perception tests: the Monosyllable, Trochee, Spondee Test (MTS; Erber & Alencewicz, 1972), the Four-Choice Spondee Test from the Early Speech Perception Test Battery (Geers & Moog, 1990), the Vowel Perception Test (Tyler, Fryauf-Bertshcy, & Kelsay, 1991), and the Phonetically Balanced Kindergarten Word Lists, (Haskins, 1949). As of the most recent test date, the average age in the CI group was 10.0 years (*SD* = 2.9). Most wore their implant daily; however, 2 were non-users and 6 were minimal users. At the time they received their implants, all the children were in educational and home environments that provided them with simultaneous communication, thus they relied on both sign and speech. Participant CI-25 transferred to a private, oral school during the course of this study, and Participants CI-2 and CI-28 transferred to state schools for the deaf. The rest of the children remained in local public school programs that used both signed English and speech. None of the children in either the CI or HA groups were identified by their local school districts as having concomitant disabilities such as mental retardation, learning disorders, or behavioral disorders. Conversely, none of the children were in a gifted or talented educational program. This would indicate that cognitive abilities were within normal limits for both groups. In addition, because over half of the HA group consisted of children who eventually became part of the CI group, the variability between the groups can be assumed to be very low. The protocol used to obtain expressive language data was instituted 6 years prior to the final test date and was administered to all children participating at that time. Some children had several years of CI experience before the expressive language data were collected and, therefore, did not contribute to pre-implant or early post-implant observation intervals. Other children who had received CIs more recently provided data on pre-implant language status, and for 2 or 3 years thereafter. Appendix Table A3 shows the observation intervals for which expressive language data were available.

The second set of participants included 29 children who were prelingually, profoundly deaf. They were implant candidates but used HAs. Although this group will be referred to as hearing-aid users, they were selected as a comparison group because they had no CI experience despite their eligibility. Thus, this study was not viewed as a contrast between hearing-aid use and cochlear implant use. The HA group was included to provide language samples in a group of children with similar pre-implant hearing, using the same protocol as that used with the CI group. These children had an average age of 9.0 years (*SD* = 3.65) and ranged from 3.6 years to 14.3 years. The children in the HA group were profoundly deaf, and the mean pure-tone average for the right ear was 110.34 dB (*SD* = 7.3 dB) and for the left ear 110.69 (*SD* = 8.2 dB). All of the children in the HA group received scores that were below chance on the speech perception testing listed above. Their home and educational environments used simultaneous communication, and they were all educated within local public school programs. Participants HA-1 through HA-12 received CIs subsequent to their participation as HA users and also participated later as Participants CI-1 through CI-12. An additional subgroup of 7 children received CIs within 1 year after participation; however, these children did not participate as part of the CI group because they had less than 1 year of experience and had not yet returned for their annual speech and language evaluation. We also caution that, although we are naming this group the “HA group,” this does not mean that all the children in this group wore their hearing aids consistently or gained maximal benefit from their hearing aids. We did not assess hearing-aid fit or use during this study. The children in the HA group were considered to be candidates to receive a cochlear implant. This indicates that the benefit they received from their hearing aids was minimal.

Procedures

All participants were individually evaluated in a quiet room. A Panasonic VHS professional/industrial video camera with a Realistic tie-pin microphone input was used to record each participant’s productions. The camera angle was adjusted such that all hand and facial movements could be recorded.

To assure that the two groups did not differ significantly with respect to the families’ socioeconomic status, the educational level for each participant’s mother was documented. A scoring system was used based on the mother's highest level of education. The system was as follows: 1.0 was assigned for a 9th–12th-grade education, 2.0 for a high-school diploma, 3.0 for some college but no degree, 4.0 for a college degree, and 5.0 for a graduate degree. The CI group had a mean score of 2.9 (*SD* = .9), and the HA group had a mean score of 2.7 (*SD* = 1.0). A *t* test indicated that the difference between groups was not significant, *t* = .232.

Expressive Language Sampling

Samples of expressive sentence usage were obtained from all children using a story retell protocol (Tye-Murray, Spencer, & Woodworth, 1995). This protocol comprised six short stories. Each story was presented to the child using simultaneous communication by the examiner, along with pictures that depicted the events in the story. The child was then asked to retell the story and was permitted to use both speech and sign during the retelling. The child's responses were videotaped.

The stories were presented and transcribed by the same examiner. The examiner (the second author) was a speech pathologist with extensive experience transcribing the speech of deaf and hearing-impaired children. She was also a fluent signer of Signed English with 14 years of signing experience. The stories were presented in voice and sign, as read from a script. All grammatical morphemes were consistently included in the presentations. The videotape of the child retelling the story was reviewed and transcribed. The transcriptions were a combination of the child's signed and spoken output. For example, if the child signed "The dad fix the truck" but spoke "The dad will fix the truck," the sample was transcribed as "The dad will fix the truck," and the word "will" was coded as "voiced only." Transcriber reliability was completed via a second transcriber, an educational interpreter who holds an associate degree from an interpreter training program, an interpreter's license, and a Quality-Assurance Level 2 from the state of Wisconsin. Mean word-for-word agreement was .96 between the two transcribers before consensus was achieved.

The transcriptions were then analyzed using the Index of Productive Syntax (IPSyn) scoring system (Scarborough, 1990). The completed transcriptions were presented in written format to the scorers. The scorers were not given information about the mode of communication presented. An example of the transcription presented to the scorer is as follows:

> The boy was getting dressed. He put his socks on first, then he put on his shirt. Last he put on his pants. He had a cowboy hat and cowboy boots. He looked like a cowboy.

This system provided for a quantitative index of the developmental levels of four domains of sentences in the language corpus, including noun phrases, verb phrases, questions, and negations, as well as simple and complex sentence forms. Each of these grammatical domain scores was combined to form a Total IPSyn score. The IPSyn protocol scored each grammatical domain with respect to the occurrence of 0, 1, or 2 tokens of a particular grammatical type, such as the use of a copula (*to be* verb functions as a main verb) or nouns with plural marking. A maximum of two points for each grammatical domain were assigned. Points accrued as the child used more types type of tokens within a domain.

This approach to scoring was sensitive to the number of opportunities for the use of a form. Scarborough controlled for number of opportunities by using 100 utterances as the standard for IPSyn scoring because her samples were derived from conversational samples. In this study, the number of utterances was not constrained, but the number of opportunities for production of any form was controlled by the use of a fixed story elicitation method. This method does confound grammatical performance with narrative performance to some degree. Children who retold longer stories were more likely to obtain higher IPSyn scores because they had more opportunities to use new grammatical tokens and types. This confound was not viewed as serious given that the primary objective of the study was to examine the relationship between CI use and language development. A confound of discourse achievement with grammatical achievement should not invalidate this objective.

Transcripts from each child were scored using the method described by Scarborough (1990). Two scorers independently scored each transcript. Each scorer was trained on IPSyn scoring procedures using sample story transcriptions. The results of these independent scores were then compared, and discrepancies were reconciled. Interscorer reliability was .94, and intrascorer reliability for Scorer 1 was .99 and for Scorer 2 was .99.

Sentence Comprehension

Although the primary measure of language development in this study was the IPSyn, we also included a measure of sentence comprehension to provide an additional hearing-aid comparison group. Thus, all children in the CI group were also administered the Rhode Island Test of Language Structure (RITLS; Engen & Engen, 1983), which is a test of sentence comprehension. The HA group was not administered this test. The norms provided by the test were used instead to represent performance by non-implanted deaf children. This test consisted of a sentence that was presented in signed English and voice. The child then chose the one picture from a set of three that best represented the meaning of the sentence presented. The final score was the total number of sentences chosen in error. This test was normed for children who are deaf. These norms were developed prior to the time children who were deaf received CIs, and they therefore provided a means of comparing experienced CI users to children without CI experience who were deaf. The RITLS was administered only once to the CI users during the most recent visit; thus, unlike the IPSyn, longitudinal data were not available for this measure.

Results

Sentence Usage Achievement Levels in CI and Non-CI Children Who Are Deaf

Sentence Comprehension

The RITLS scores for the children with CI experience are shown in Figure 1. Participant CI-13 was not given this test because of a schedule conflict on his date of testing; thus there were 28 children for this measure. Figure 1 shows the percentile scores on the RITLS plotted against the child's age. A mean percentile rank of 92.2 (*SD* = 15.74) was obtained for these children. Because the mean percentile for the normative groups was 50, each score was subtracted from this value to test the hypothesis that the difference between the obtained scores and this reference value was 0. A mean difference score of 42.2 (*SD* = 15.7) was significant ($t = 14.19$, $df = 27$, $p < .0001$). Although these children were age appropriate for this test and had hearing levels prior to implantation that were similar to the normative group for this test, the data in Figure 1 show that many of them were at or approaching the ceiling of this test. Nearly all these children with CIs were no longer linguistically comparable to deaf children using HAs. This high level of performance, however, was not found in 1 child who was 5 years 9 months old at the time of testing and had 3 years of CI experience. As shown in Figure 1, this child was below the 20th percentile.

IPSyn Performance

The IPSyn provided subscale scores and a total score. The subscale scores are shown in Figure 2. These data show that the children with CIs had higher scores than the HA group on all subscales. The low rate of questions and negatives for both groups reflects the fact that the language samples were obtained from a story retell in which questions and negation were not required. Because the performance patterns were similar across the subscales, our analysis focused on the total score. The IPSyn scores for the children using HAs were examined in order to describe the developmental levels obtained by children with severe to profound hearing losses who were HA users. Figure 3 displays the total IPSyn score for each child plotted against the child's chronological age. It can be seen that the scores ranged from 12 to 67 (*M* = 40.69, *SD* = 17.41) and that the scores increased with advances in age. Also shown in Figure 3 is a linear regression line representing the regression of age onto IPSyn score, as well as the 95% confidence interval for the prediction of new observations based on chronological age. This regression function and the 95% prediction interval provided a means to compare the performance of the children using HAs with the children using CIs.

In order to address whether one group had a tendency to generate longer stories, the mean number of utterances per sample was computed for each group.

Figure 1. Achievement levels by the children with cochlear implants on the Rhode Island Test of Language Structure expressed as percentile ranks for children of the same chronological age who are deaf.

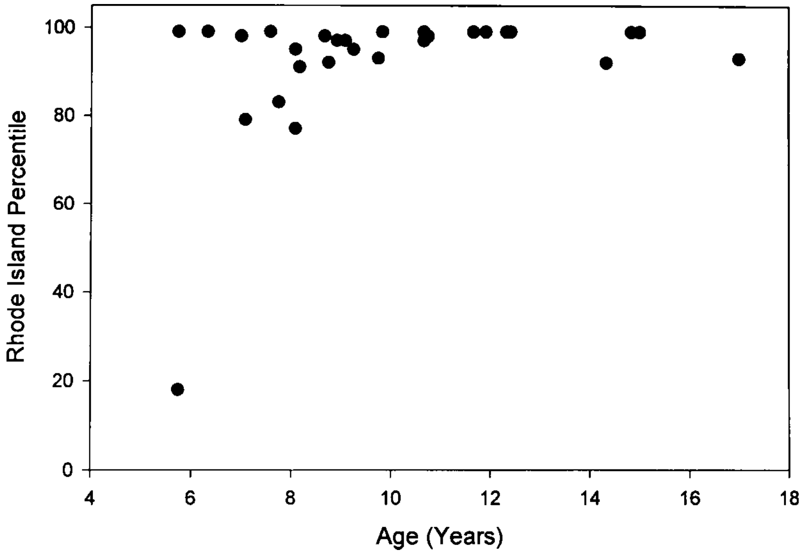


Figure 2. IPSyn subscale scores for children using cochlear implants (CI) and children who have used only hearing aids (HA).

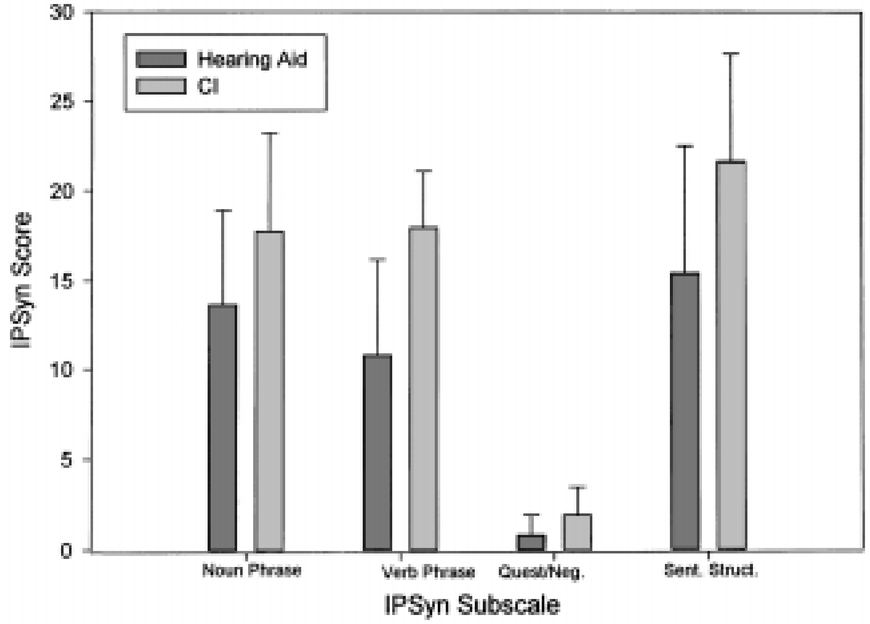
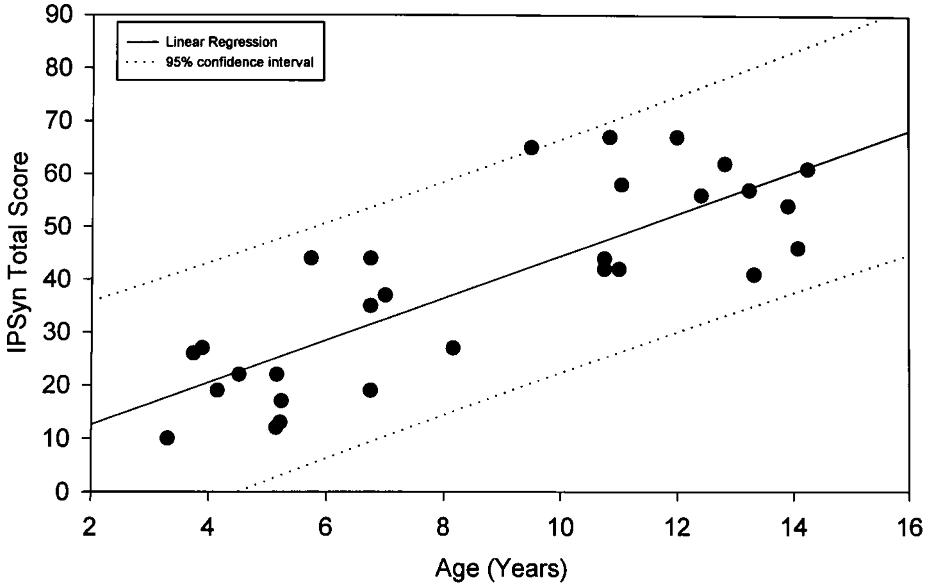


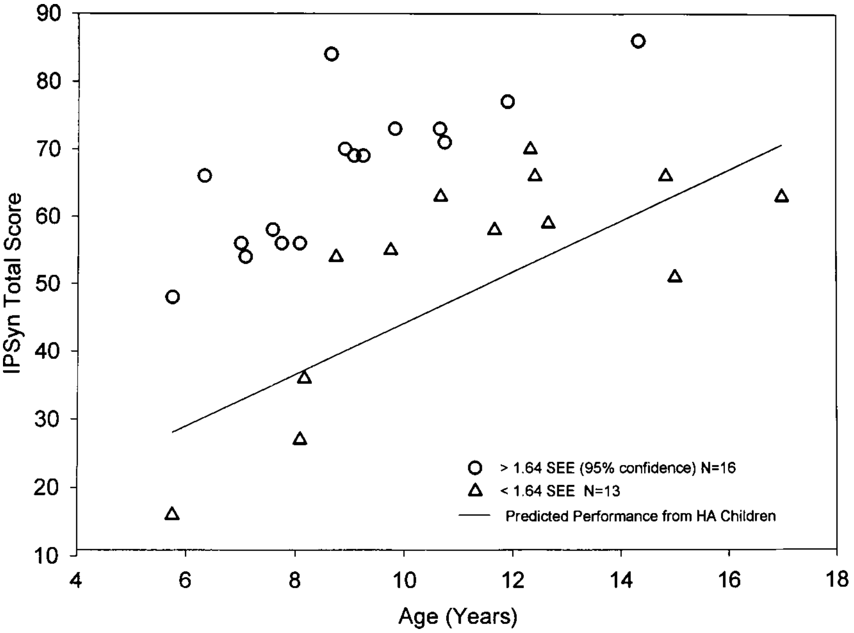
Figure 3. Total IPSyn scores obtained by children only using hearing aids as a function of chronological age. The regression of age onto IPSyn scores and the 95% confidence prediction interval are show by the solid and dashed lines, respectively.



Children in the HA group had a mean story sample length of 32 .4 utterances, (*SD* = 9.6), whereas children in the CI group had a mean story sample length of 27.24 utterances (*SD* = 7.2). This difference was not significant.

Figure 4 displays the IPSyn total scores for each of the children using CIs plotted against their chronological age at the time of their last visit. The mean IPSyn score for these children was 60.34 (*SD* = 15.19), which was 20 points higher and more than 1 standard deviation above the mean for the children using HAs. Recall that at their most recent visit, the children using CIs were on average 1 year older than the children using HAs. The difference between the mean IPSyn scores for the two groups was tested using a mixed model analysis of variance procedure. This analysis allowed for a comparison of two groups where some of the participants

Figure 4. Total IPSyn scores obtained by children with cochlear implants as a function of chronological age. The solid line represents the obtained regression of age onto IPSyn performance obtained with the children using hearing aids represented in Figure 3. The circles represent scores that exceed the 95% prediction interval based on standard error of estimate (SEE) for the child's age. Triangles represent scores falling inside the 95% prediction interval.



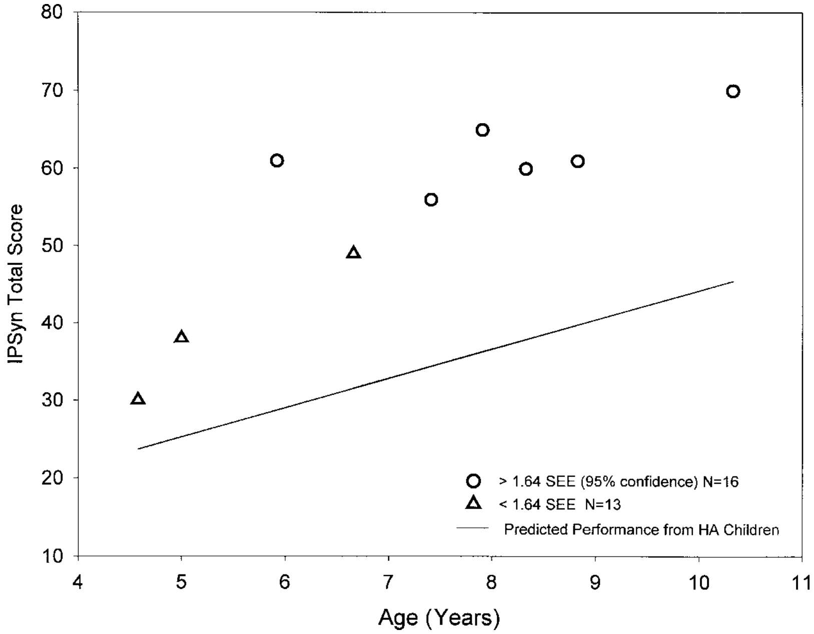
were in each group (within subjects) and others were only in one group (between subjects). Furthermore, it allowed for the inclusion of age as a covariate, which was viewed as desirable because the two groups were not fully matched on age. This test resulted in a significant difference, $F(1, 10) = 24.07$, $p < .0006$, between the CI users and the HA users. Figure 4 also displays the regression line predicting IPSyn scores from age, based on the HA group. All but 5 children using CIs fell above this line. Furthermore, the 17 children represented by open circles (55%) were those whose IPSyn scores exceeded the 95% confidence interval for the prediction of new values based on the performance of the HA group. Thus, more than half of the children using CIs were significantly above their predicted IPSyn score based on age expectations found among HA users. This 95% confidence interval was used as an estimate of the 95th percentile for HA users, and fewer than 5% of those children were expected to be at this level. In contrast, more than half the children using CIs exceeded this level of performance.

The comparison of the HA and CI groups above on IPSyn achievement may have been biased by the fact that the children from the CI groups received this protocol on each visit and, therefore, on return visits may have become increasingly familiar with the story retell task. In contrast, the HA group were only given the story retell task once and, consequently, did not have this advantage. Nine of the children from the CI group did not begin their participation in the story retell protocol until they had 2 or more years of implant experience. The IPSyn scores obtained for these children on their first visit were compared to the predictions based on the HA group to determine if similar improvements associated with CI experience could be found in the absence of repeated participation in the protocol. These results are shown in Figure 5. It can be seen that 66% of these children were above the 95% prediction interval. Thus, this subgroup, which had no prior experience with the story retell, were very similar to the total CI group, when observed after several visits; therefore, it is unlikely that practice effects are responsible for these findings.

Use of Communication Mode During Story Retell Task

The use of communication mode was assessed during the story retell task for the HA group and for the most recent visit of the CI group. Although all children (with the exception of CI-25) participated in educational programs that used Signed English as the primary communication during their school day, we wanted to ascertain what communication mode was used during this testing protocol to see if there were differences between the two groups. The first 100 words of each story were coded for mode of expression. A word produced with voice

Figure 5. Total IPSyn score obtained on the first examination by 9 children using cochlear implants. The circles represent scores that exceed the 95% prediction interval based on the standard error of estimate (SEE) for the child's age. Triangles represent scores falling inside the 95% prediction interval.



only was coded as [vo], a word produced with sign and no speech was coded [so], and a word produced with voice and in sign was coded [vs]. We found that, on average, over 70% of the words in the story retell task were produced using both speech and sign. Table 1 provides information on communication mode. Children in the CI group tended to produce an average of 23% of their words with voice only and 6% of their words with sign only. Conversely, children in the HA group tended to produce 5% of their words with voice only and 23% of the words with sign only.

IPSyn Achievement as a Function of Chronological Age and Length of Implant Experience

The data in Figure 3 display the association between IPSyn achievement and chronological age for the HA group. This association was tested and found to be very strong and significant ($r = .80$, $p < .0001$). Figure 4 shows the same relationship between IPSyn performance and age for the CI group. When this relationship was tested, a much lower and nonsignificant correlation ($r = .42$, $p < .03$) was found. Figure 6 shows the relationship between IPSyn achievement levels plotted against months of implant experience for this group. A test of this association showed a moderate correlation ($r = .64$, $p < .0001$) between years of CI experience and IPSyn score for those children receiving a CI. This association remained at a similar level ($r = .57$, $p < .001$) even when chronological age was partialed out of years of CI experience. Thus, length of experience with a CI, rather than chronological age, was the principal factor in accounting for the IPSyn achievement levels of children with CIs.

Table 1. Communication mode used during story retell task.

	Percent of words produced		
Group	Sign only mode	Voice only mode	Sign and voice mode
CI Group	6.07 (*SD* = 15.6)	22.7 (*SD* = 40.7)	71.2 (*SD* = 40.3)
HA Group	23.0 (*SD* = 25.0)	4.7 (*SD* = 15.0)	71.8 (*SD* = 30.8)

When Does Implant Experience Become Evident?

The data examined above concern the IPSyn achievement levels of the children with CIs during their most recent visit, which averaged more than 4 years after receipt of the implant. The results above showed that by the last visit, those children with CIs were significantly more advanced in expressive language development than children who had not received CIs. Furthermore, the fact that this growth was associated with the amount of CI experience suggested that a pattern of divergence between those with and without CIs should be expected. Thus, the IPSyn scores at each annual examination following implantation were compared with predicted

Figure 6. Total IPSyn scores plotted as a function of length of post-implant experience in months.

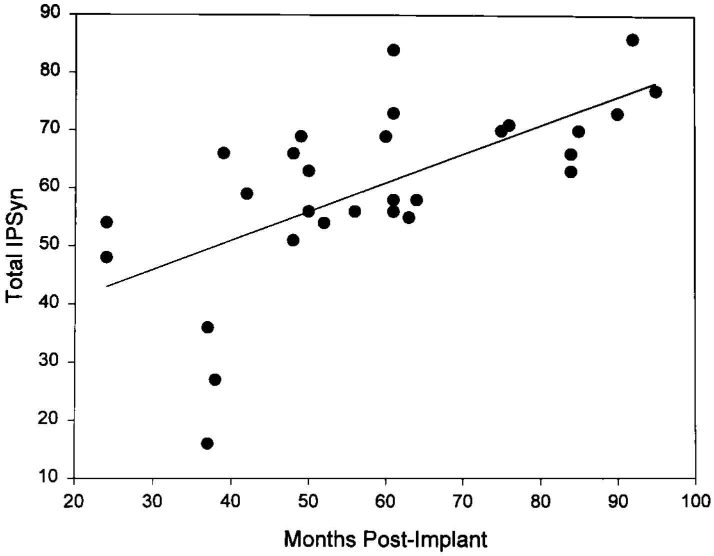
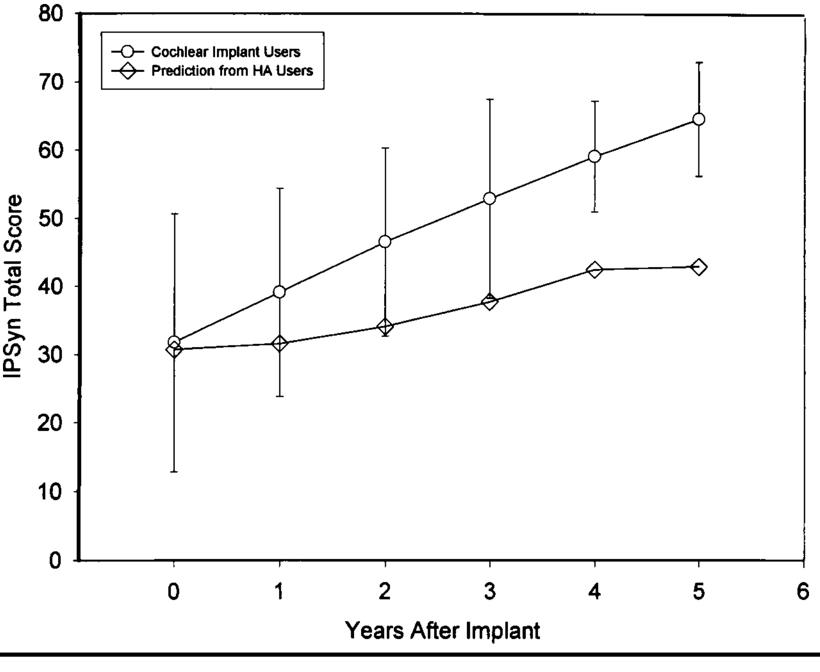


Figure 7. Mean IPSyn performance for children receiving cochlear implants at each annual visit. Error bars represent standard deviations.



IPSyn scores for these children given their age at that interval. This prediction was based on the regression of age onto the IPSyn scores from the HA users employed in the other analyses. These data are shown in Figure 7. A clear pattern of divergence between obtained scores for the CI users and the predictions based on the HA group are shown. At 1 year post-implantation, 28% of the CI users exceeded the 95% prediction interval; however, by 5 years post-implantation, 64% of the children were above this interval.

The data shown in Figure 7 show evidence of systematic growth for the children using CIs across the follow-up intervals. These data were also inspected to determine the degree to which the children's relative performance at one interval was associated with subsequent relative performance levels. Table 2 provides a correlation matrix for the IPSyn scores between each interval. These data show a strong and significant correlation between pre-implant IPSyn levels and the 1-year follow-up interval. Subsequently, however, this

Table 2. Correlations between IPSyn total scores across post-implant follow-up intervals.

	1 year post	2 years post	3 years post	4 years post
Pre-implant	*r* = .87 *p* = .002 *n* = 9	*r* = .52 *p* = .08 *n* = 12	*r* = .65 *p* = .03 *n* = 17	*r* = .05 *p* = .9 *n* = 8
1 year post		*r* = .75 *p* = .0005 *n* = 17	*r* = .76 *p* = .0009 *n* = 15	*r* = .45 *p* = .22 *n* = 9
2 years post			*r* = .83 *p* = .0001 *n* = 23	*r* = .55 *p* = .02 *n* = 17
3 years post				*r* = .80 *p* = .0001 *n* = 19

correlation declines and is no longer significant for later follow-up intervals. Strong and significant correlations were found between the 1-year performance and the following 2 years (2 and 3 years post-implant).

Achievement levels at 3 and 4 years post-implant were likewise strongly associated with relative IPSyn achievement levels in the subsequent years. These results indicate that there are rather stable patterns of language achievement occurring across the intervals subsequent to implantation. The only exceptions to this are those contrasts involving the association of performance at 4 years post-implantation with performance levels at 1 and 2 years post-implantation. However, these results are likely to be due to the limited number of children providing data for these contrasts. The strong correlations, ranging from .75 to .87 for the adjacent observation intervals, also provide evidence of very good test-retest reliability for the IPSyn measure, particularly considering that the retest interval was 1 year.

Discussion

This study examined the influence that the receipt of a CI had on the English language achievement levels of children who were implanted between 2;9 and 13 years of age. Language achievement in these children was measured for receptive and expressive sentence usage and a comparison in achievement levels was made with two groups of children with hearing impairment. One comparison group used for receptive language comparisons consisted of those children who contributed to the norms of the RITLS, who were described as having a range of hearing loss, and who were students at the Rhode Island School for the Deaf. The other comparison group comprised children using HAs who were similar to the children using CIs with respect to the CI users' pre-implant hearing status and educational background. These children were used as the comparison group for the IPSyn measure representing expressive language usage. Both comparisons showed statistically significant and probably functionally demonstrable differences in English language achievement levels favoring the children using CIs.

The results from the IPSyn also extend the findings of Spencer, Tye-Murray, and Tomblin (1998) concerning the influence of CI experience on expressive grammatical development. Several of the children in the current study were also participants in the Spencer et al. study that provided evidence that CI experience resulted in gains in the use of English grammatical morphemes. The results from this study using the IPSyn provided a broader measure of grammatical performance and also contained a comparison group of HA users. These results are also consistent with the small number of previous studies of language development in children with CIs. Geers and Moog (1994) and Miyamoto et al. (1997) provided the only other data in which children with CIs were compared with a group of HA users. These authors did not report data on individual achievement levels, but did show that the mean performance of children with CIs equaled or exceeded the levels attained by both the HA comparison group and the children in the Rhode Island norm group. In this study, it was found that the majority of children using CIs exceeded the achievement levels of 95% of those children who contributed to the norms. Furthermore, all but one child using a CI were above the 80th percentile. The RITLS was designed to measure English language achievement in deaf children up to 17 years of age. Children with CIs were clearly at the ceiling of this test by age 9 however, on average.

One striking feature of the data in this study pertains to the relationship between IPSyn scores and chronological age. Scarborough, Rescorla, Tager-Flusberg, and Fowler (1991) have shown that IPSyn scores are strongly associated with growth in mean length of utterance (MLU) for typically developing preschool children. Miller and Chapman (1981) have shown that MLU is strongly associated with chronological age, and, therefore, IPSyn scores should be correlated with chronological age. Likewise, a significant correlation between age and IPSyn scores was obtained for the children who were HA users. Such a correlation between chronological age and language achievement is expected for children who are still developing language; however, this relationship was not found among the children with CIs. Rather than chronological age accounting for the variance in IPSyn achievement among these children, it was the length of time elapsing since receipt of their implant (implant age) that accounted for a significant amount of the variance in their IPSyn achievement levels. Little of the overall variance in language achievement for the children using CIs was due to chronological age, as demonstrated by the partial correlation of implant age with chronological age removed. A significant amount of this variance was associated with duration of implant use. These results show that the length of linguistic experience afforded by the implant results in growth rates among implant users that are sufficiently great to overwhelm the association of language achievement and chronological age. These findings further support the contention that the differences in achievement levels between the children with CI experience and those without CI experience can be attributed to the CI experience. That is, deaf children with CI experience have higher English grammatical achievement than those without CI experience. In addition, children with more CI experience do better than those with less experience.

Because the amount of CI experience has been shown to have an important influence on grammatical development, this study also explored how long it took before these effects appeared in the language development of the CI children. Using longitudinal results, the data showed that, by 2 years post-implantation, more than 50% of the children using CIs exceeded the 95% prediction interval for their IPSyn scores. This contrasted with 28% at 1 year. Further gains at intervals after 2 years were smaller; however, this may be a result of ceiling effects in the language measures. Also, correlations computed between follow-up intervals revealed that relative IPSyn achievement among these children was quite consistent, particularly between the 2nd and 3rd years post-implantation. We may conclude that those children who receive implants can be evaluated with respect to their language development early in their implant experience. The children who are failing to benefit from the implant experience can also be identified early, and additional efforts directed toward language development may be implemented.

The results of the current study also reveal that there continue to be individual differences in language achievement resulting from CI experience. These individual differences were more noticeable for the expressive language measure than the receptive measure. This is likely to be due to a ceiling effect present for the RITLS. Individual differences in language development are to be expected, but it now becomes important to determine whether these individual differences among children receiving CIs are due to the same factors that contribute to individual differences among all language learners or whether some of these differences can be traced to factors that are unique to children who use CIs. Recently, Fryauf-Bertschy, Tyler, Kelsay, Gantz, and Woodworth (1997) reported that the amount of daily use of the CI explained much of the variability of speech perception among children using CIs. Several of the participants in the Fryauf-Bertschy et al. study were also participants in this study; thus, we might anticipate that amount of daily use may explain some of the variance in the language outcome data as well. Another factor often claimed to influence communication benefits among those using CIs is the type of language/aural rehabilitation program provided to the children. With the exception of the 3 children noted in the methods section, all the children in this study remained in programs that were described as employing simultaneous communication systems. Thus, the sample of children studied did not provide a range of programming alternatives that could be used to account for these differences. However, all these children were being served in their home communities, and the implementation of their educational and rehabilitation programs was determined and conducted by parents, the personnel in these local school systems, and local clinicians and clinics. As a result, there was likely to have been considerable variation in the amount and specific type of spoken language, sign language, and aural rehabilitation approaches used within these programs. The fact that the educational and rehabilitation programming was not controlled in this sample limits our ability to identify specific programming sources that may have influenced the language outcomes of these children. This limitation, however, also points out that the gains in language achievement in these children were obtained in ordinary service delivery systems rather than intensive or optimized programs.

The use of CIs with children who are profoundly deaf continues to be controversial. Those from the Deaf culture have expressed concerns over the linguistic and social consequences of cochlear implantation as a treatment for these children (Crouch, 1997; Lane & Grodin, 1997). Lane has questioned whether the improvements in speech perception shown in the research literature will result in sufficient improvements in spoken language and communication to permit these children to be fully participating members of the hearing community. The data from this study, in association with the previous studies, show that prelingually deaf children are better able to acquire English when provided with CIs than when provided with HAs. Thus, the CI experience can be viewed as beneficial to language development, as long as one assumes that acquisition of English and affiliation with the hearing community is the desired outcome.

The existing data showing gains in English acquisition associated with the CI experience do not address the more fundamental concerns voiced by Lane and Grodin and by Crouch. Specifically, it has yet to be shown that the levels of improvement in English language development permit these children to fully participate in the hearing society. The data required to address this issue will need to be discourse and pragmatic evidence. Additionally, sociolingustic and quality-of-life outcome data that demonstrate the full functional acceptability of the linguistic gains documented thus far will also be needed.

A fundamental question in this research remains. How does the implant experience influence a child's ability to be successful in the hearing community? Data provided here indicates that in this group of children who primarily use simultaneous communication, there continues to be a reliance on the part of CI users to utilize both speech production and signed English to communicate in this type of testing situation. We do not know if these children would be more successful affiliating with the Deaf community if they had not been given implants. The answers to these questions may be ideological and, thus, unanswerable by science. Despite the fact that these data do not resolve the controversy concerning the use of CIs with congenitally deaf children, they do demonstrate that these devices are providing the gains in linguistic development promised by the previously demonstrated improvements in audibility, speech perception, and speech production.

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References

Bellugi, U. (1988). The acquisition of a spatial language. In F. Kessel (Ed.), *The development of language and language researchers, essays in honor of Roger Brown* (pp. 153–185). Hillsdale, NJ: Erlbaum Associates.

Coerts, J., & Mills, A. (1995). Spontaneous language development of young deaf children with a cochlear implant. *Annals of Otology, Rhinology and Laryngology, 166,* (Suppl.) 385–387.

Crouch, R. A. (1997). Letting the deaf be deaf: Reconsidering the use of cochlear implants in prelingually deaf children. *Hastings Center Report, 27*(4), 14–21.

Dawson, P. W., Blamey, P. J., Dettman, S. J., Barker, E. J., & Clark, G. M. (1995). A clinical report on receptive vocabulary skills in cochlear implant users. *Ear & Hearing, 16*(3), 287–294.

Engen, E., & Engen, T. (1983). *Rhode Island Test of Language Structure.* Baltimore: University Park Press.

Erber, N., & Alencewicz, C. (1972). Audiologic evaluation of deaf children. *Journal of Speech and Hearing Disorders, 41,* 256–267.

Fryauf-Bertschy, H., Tyler, R. S., Kelsay, D. M., & Gantz, B. J. (1992). Performance over time of congenitally deaf and postlingually deafened children using a multichannel cochlear implant. *Journal of Speech and Hearing Research, 35*(4), 913–920.

Fryauf-Bertschy, H., Tyler, R., Kelsay, D., Gantz, B., & Woodworth, G. (1997). Cochlear implant use by prelingually deafened children: The influences of age at implant and length of device use. *Journal of Speech, Language, and Hearing Research, 40,* 183–199.

Geers, A. E., & Moog, J. (1990). *Early Speech Perception Test Battery*. St. Louis: Central Institute for the Deaf.

Geers, A. E., & Moog, J. (1994). Spoken language results: Vocabulary, syntax, and communication. *The Volta Review, 96,* 131–148.

Geers, A. E., & Toby, E. (1992). Effects of cochlear implants and tactile aids on the development of speech production skills in children with profound hearing impairment. *The Volta Review, 94,* 135–163.

Hasenstab, M. S., & Tobey, E. (1991). Language development in children receiving nucleus multichannel cochlear implants. *Ear and Hearing, 12,* 55–64.

Haskins, H. A. (1949). *A phonetically balanced test of speech discrimination for children.* Unpublished master's thesis, Northwestern University, Evanston, IL.

Lane, H. (1992). *The mask of benevolence.* New York: Alfred A. Knopf.

Lane, H., & Grodin, M. (1997). Ethical issues in cochlear implant surgery: An exploration into disease, disability, and the best interests of the child. *Kennedy Institute of Ethics Journal, 7*(3), 231–251.

Littell, R., Milliken, G., Wolfinger, R. (1996). *SAS systems for mixed models.* Cary, NC: SAS Institute Inc.

McConkey-Robbins, A., Osberger, M. J., Miyamoto, R. T., & Kessler, K. S. (1995). Language development in young children with cochlear implants. In A. S. Uziel & M. Mondain (Eds.), *Cochlear implants in children* (pp. 160–166). Basel: Karger.

Miller, J., & Chapman, R. (1981). The relation between age and mean length of utterance in morphemes. *Journal of Speech and Hearing Research, 24,* 154–161.

Miyamoto, R. T., Svirsky, M. A., & Robbins, A. M. (1997). Enhancement of expressive language in prelingually deaf children with cochlear implants. *Acta Oto-Laryngologica, 117*(2), 154–157.

National Institutes of Health. (1995). Cochlear implants in adults and children. *NIH Consensus Statement, 13*(2), 1–30.

Nelson, K., Loncke, F., & Camarata, S. (1993). Implications of research on deaf and hearing children's language learning. In M. Marschark & D. Clark (Eds.), *Psychological perspectives on deafness* (pp. 123–151). Hillsdale, NJ: Lawrence Erlbaum.

Osberger, M. J. (1986). Language and learning skills of the hearing-impaired: Summary and implications for research and educational management (ASHA Monograph No. 23, pp. 92–98). Rockville, MD, American Speech-Language-Hearing Association.

Osberger, M. J., Robbins, A. M., Berry, S. W., Todd, S. L., Hesketh, L. J., & Sedey, A. (1991). Analysis of the spontaneous speech samples of children with cochlear implants or tactile aids. *The American Journal of Otology, 12,* 151–164.

Quigley, S., Power, D., & Steinkamp, M. (1977). The language structure of deaf children. *The Volta Review, 79*, 73–83.

Reynell, J. K., & Huntley, M. (1985). *Reynell Developmental Language Scales* (Rev. Ed. 2). Windsor: NFER Publishing.

Scarborough, H. S. (1990). Index of Productive Syntax. *Applied Psycholinguistics, 11*, 1–22.

Scarborough, H. S., Rescorla, L., Tager-Flusberg, H., & Fowler, A. E. (1991). The relation of utterance length to grammatical complexity in normal and language-disordered groups. *Applied Psycholinguistics, 12*, 23–45.

Spencer, L., Tye-Murray, N., & Tomblin, J. B. (1998). The production of English inflectional morphology, speech production and listening performance in children with cochlear implants. *Ear and Hearing, 19*(4), 310–318.

Tobey, E., Geers, A., & Brenner, C. (1994). Speech production results: Speech feature acquisition. *The Volta Review, 96*, 109–129.

Tye-Murray, N., & Kirk, K. I. (1993). Vowel and diphthong production by young users of cochlear implants and the relationship between the phonetic level evaluation and spontaneous speech. *Journal of Speech and Hearing Research, 36*(3) 488–502.

Tye-Murray, N., Spencer, L., & Woodworth, G. (1995). Acquisition of speech by children with prolonged cochlear implant experience. *Journal of Speech and Hearing Research 38*(2), 327–337.

Tyler, R., Davis, J., & Lansing, C. (1987). Cochlear implants in young children. *Asha, 29*(4), 41–49.

Tyler, R., Fryauf-Bertschy, H., & Kelsay, D. (1991). *Children's Vowel Perception Test*. Iowa City: University of Iowa.

Tyler, R. S. (1993). Cochlear implants and the Deaf culture. *American Journal of Audiology, 2*, 26–32.

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Appendix.

Table A1. Demographic information for cochlear implant participants.

Participant	Connection age years;months	Etiology	Most recent educational program	User status at most recent testing
CI-1	5;02	Unknown	SC/MS	Minimal
CI-2	5;02	Meningitis	SSD	Non
CI-3	4;01	Meningitis	MS	Full Time
CI-4	5;03	Unknown	SC	Full Time
CI-5	13;02	Hereditary	MS	Full Time
CI-6	4;07	Unknown	MS	Full Time
CI-7	11;00	Hereditary	MS	Full Time
CI-8	10;10	Meningitis	MS	Minimal
CI-9	5;08	Unknown	MS	Full Time
CI-10	5;02	Meningitis	MS	Full Time
CI-11	3;08	Cytomegalovirus	MS	Full Time
CI-12	3;11	Unknown	SC/MS	Full Time
CI-13	9;07	Meningitis	MS	Non
CI-14	3;04	Unknown	MS	Full Time
CI-15	2;09	Hereditary	SC/MS	Full Time
CI-16	2;09	Unknown	MS	Full Time
CI-17	6;09	Unknown	MS	Full Time
CI-18	4;08	Unknown	MS	Minimal
CI-19	4;04	Unknown	MS	Full Time
CI-20	4;10	Unknown	MS	Full Time
CI-21	4;02	Meningitis	MS	Full Time
CI-22	5;07	Unknown	MS	Minimal
CI-23	4;09	Unknown	MS	Minimal
CI-24	2;06	Meningitis	MS	Full Time
CI-25	3;01	Unknown	SC/OP	Full Time
CI-26	7;04	Unknown	MS	Full Time
CI-27	5;05	Unknown	MS	Full Time
CI-28	5;00	Unknown	SSD	Minimal
CI-29	3;11	Unknown	MS	Full Time

Note. User status is indicated as follows: *Non* indicates no use, *Minimal* indicates use during the school day, and *Full Time* indicates use during all waking hours. Educational programs are indicated by the following: MS = mainstreamed with interpreter; SC/MS = self-contained program and mainstreamed for some subjects; SC/OP = self-contained oral program for the deaf; SSD = State school for the deaf.

Table A2. Demographic information for hearing-aid participants.

Participant	Age at test years;months	Etiology	Most recent educational program	Participant	Age at test years;months	Etiology	Most recent educational program
HA-1	5;02	Unknown	SC/MS	HA-16	8;04	Ototoxic	MS
HA-2	5;02	Meningitis	SSD	HA-17	11;01	Cytomegalovirus	SC
HA-3	4;01	Meningitis	MS	HA-18	9;00	Cytomegalovirus	SC/MS
HA-4	5;03	Unknown	SC	HA-19	11;06	Unknown	MS
HA-5	13;02	Hereditary	MS	HA-20	13;11	Premature	MS
HA-6	4;07	Unknown	MS	HA-21	13;03	Unknown	MS
HA-7	11;00	Hereditary	MS	HA-22	14;05	Meningitis	MS
HA-8	10;10	Meningitis	MS	HA-23	14;01	Unknown	SC/MS
HA-9	5;08	Unknown	MS	HA-24	12;05	Unknown	MS
HA-10	5;02	Meningitis	MS	HA-25	10;05	Hereditary	SC/MS
HA-11	3;08	Cytomegalovirus	MS	HA-26	6;08	Hereditary	MS
HA-12	3;11	Unknown	SC/MS	HA-27	6;09	Unknown	SC/MS
HA-13	9;11	Meningitis	MS	HA-28	7;00	Unknown	SC/MS
HA-14	10;09	Unknown	SC	HA-29	7;08	Hereditary	SC/MS
HA-15	12;00	Meningitis	MS				

Note. Educational programs are indicated by the following: MS = mainstreamed with interpreter; SC/MS = self-contained program and mainstreamed for some subjects; SC/OP = self-contained oral program for the deaf; SSD = State school for the deaf.

Table A3. Pre-implant thresholds for cochlear implant participants and post-implant visit information.

	Pre-implant hearing thresholds (dB)						Months post-implant at successive annual visits								
	500 HZ		1000 HZ		2000 HZ										
Participant	RE	LE	RE	LE	RE	LE	0	1	2	3	4	5	6	7	8
CI-1	NR	NR	NR	NR	NR	NR	0	12	32						
CI-2	115	NR	NR	NR	NR	NR	0	14	27						
CI-3	100	NR	NR	NR	NR	NR	0	12	26	40	59				
CI-4	100	115	110	NR	115	NR	0	11	25	37					
CI-5	115	115	120	115	120	105	0	10	27	37	50	62			
CI-6	90	90	NR	NR	NR	NR	0	10	26	39	52				
CI-7	85	90	110	115	NR	NR	0	11	25	38	48				
CI-8	90	100	115	NR	NR	NR	0	9	23	35	48				
CI-9	100	105	110	110	NR	NR	0	12	22	36	47	61			
CI-10	115	NR	NR	NR	NR	NR	0	11	24	37	49				
CI-11	NR	NR	NR	NR	NR	NR	0	10	24	36	48	61			
CI-12	90	NR	NR	NR	NR	NR	0		24	37	49	61			
CI-13	90	NR	NR	NR	NR	NR		10	29	42					
CI-14	110	105	NR	NR	NR	NR		15	26	39					
CI-15	100	110	115	120	NR	NR		12	24	36					
CI-16	85	95	95	NR	NR	NR		14	31	37					
CI-17	90	95	110	110	NR	NR		14	26	39	48	64			
CI-18	NR	NR	NR	NR	NR	NR		13	24	36	50	63			
CI-19	110	NR	120	NR	NR	NR		12	24	37	49	60	72		
CI-20	100	110	110	115	110	110		13	26	39	50	62	76		
CI-21	100	105	NR	NR	NR	NR			25	37	48		75		
CI-22	100	105	110	110	NR	NR			25	37	49	59	71		
CI-23	NR	NR	NR	NR	NR	NR			24	36	48	60	72		
CI-24	90	95	105	100	115	NR			24	36	50	61			
CI-25	100	100	115	110	NR	NR			24	38	50				
CI-26	90	95	110	110	NR	NR				41	52	69	78	92	
CI-27	95	95	NR	NR	NR	NR				37	47	59	72	85	
CI-28	110	NR	NR	NR	NR	NR				38	49		75	90	
CI-29	90	NR	NR	NR	NR	NR					47	59	71	83	95

Aggregate pure-tone average (PTA) for right ear: 111.9 dB, *SD* = 5.48
Aggregate pure-tone average (PTA) for left ear: 114.8 dB, *SD* = 4.80

Note. Thresholds were obtained in the sound field without hearing aids. NR = no response because of the upper limits of the audiometer. For average value, 120 was substituted for NR value.

Table A4. Thresholds for hearing-aid participants.

	Pre-implant hearing thresholds (dB)					
	500 HZ		1000 HZ		2000 HZ	
Participant	RE	LE	RE	LE	RE	LE
HA-1	NR	NR	NR	NR	NR	NR
HA-2	115	NR	NR	NR	NR	NR
HA-3	100	105	NR	NR	NR	NR
HA-4	100	115	110	NR	115	NR
HA-5	115	115	120	115	120	105
HA-6	90	90	NR	NR	NR	NR
HA-7	85	90	110	115	NR	NR
HA-8	90	100	115	NR	NR	NR
HA-9	100	105	110	110	NR	NR
HA-10	115	NR	NR	NR	NR	NR
HA-11	NR	NR	NR	NR	NR	NR
HA-12	90	NR	NR	NR	NR	NR
HA-13	90	NR	NR	NR	NR	NR
HA-14	115	120	115	115	NR	115
HA-15	115	120	NR	NR	NR	NR
HA-16	100	105	100	115	110	120
HA-17	NR	110	115	110	NR	105
HA-18	90	95	105	105	120	120
HA-19	105	105	NR	105	NR	120
HA-20	90	85	95	95	110	110
HA-21	85	90	105	105	NR	NR
HA-22	100	110	NR	105	NR	NR
HA-23	90	100	90	90	90	95
HA-24	100	95	105	100	NR	NR
HA-25	100	90	100	90	NR	NR
HA-26	85	95	105	105	110	105
HA-27	110	105	NR	NR	NR	110
HA-28	100	90	NR	NR	NR	NR
HA-29	105	80	100	90	105	100

Aggregate pure-tone average (PTA) for right ear: 110.3 dB, *SD* = 7.3
Aggregate pure-tone average (PTA) for left ear: 110.7 dB, *SD* = 8.2

Note. Thresholds obtained in the sound field without hearing aids. NR = no response because of the upper limits of the audiometer. For average value, 120 was substituted for NR value.