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Speech Production Intelligibility of Early Implanted Pediatric Cochlear Implant Users

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Abstract

Objectives—To investigate the influence of age, and age at implantation, on speech production intelligibility in prelingually deaf pediatric cochlear implant recipients.

Methods—Forty prelingually, profoundly deaf children who received cochlear implants between 8 and 40 months of age. Their age at testing ranged between 2.5 – 18 years. Children were recorded repeating the ten sentences in the Beginner's Intelligibility Test. These recordings were played back to normal-hearing listeners who were unfamiliar with deaf speech and who were instructed to write down what they heard. They also rated each subject for the intelligibility of their speech production on a 5-point rating scale. The main outcome measures were the percentage of target words correctly transcribed, and the intelligibility ratings, in both cases averaged across three normal-hearing listeners.

Results—The data showed a strong effect of age at testing, with older children being more intelligible. This effect was particularly pronounced for children implanted in the first 24 months of life, all of whom had speech production intelligibility scores of 80% or higher when they were tested at age 5.5 years or older. This was true for only five out of nine children implanted at age 25 to 36 months.

Conclusions—Profoundly deaf children who receive cochlear implants in the first two years of life produce highly intelligible speech before age 6. This is also true for most, but not all children implanted in their third year.

Keywords

speech production; speech intelligibility; cochlear implants; age at implantation

Introduction

Speech production intelligibility can be defined as the accuracy with which a speaker can produce speech that is understandable by others. This is an important skill that is difficult or sometimes impossible to develop for children with congenital, profound-to-total deafness[1]. Fortunately, several studies in this population have shown that the use of cochlear implants

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(CIs) can be beneficial not only for speech perception[2] and language development3, but also for the development of speech production intelligibility4. In one study by Miyamoto et al.5, speech production intelligibility was assessed from recordings of the subjects' elicited speech and played to panels of normal hearing listeners. Intelligibility was scored in terms of percentage of words correctly understood by these listeners. The average scores for subjects who had used their CI for 4 years or more exceeded 40%. In another study, Osberger et al.6 compared speech production intelligibility in CI recipients who used oral communication (OC) or total communication (TC) via a write-down procedure from panels of listeners. They noted that the TC children had an earlier onset of deafness and received their implants at a slightly older age than the OC group, but the differences were not statistically significant. The results showed that speech production intelligibility was 48% in the OC group and 21% in the TC group, both with 3.5 years of implant experience. In 2003, Tobey et al.[7] investigated speech production outcomes and the factors influencing the outcomes in 181 children between the ages of 8 and 9 who had 4 to 6 yr of experience with a multichannel cochlear implant implanted before the age of 5. Results showed that performance for the key words in the speech production intelligibility measured averaged 63.5% for the group of children. Accuracy of phoneme production was higher for consonants (68.0%) than for vowels (61.6%) for the group. They noted that higher nonverbal intelligence, gender, longer use of the SPEAK processing strategy, a fully active electrode array, greater dynamic range, and greater growth of loudness were significant predictors of high levels of oral communication skills. The primary rehabilitative factors contributing to high levels of oral communication were an emphasis on oral-aural communication and classrooms that emphasized dependence on speech and listening. Factors previously thought to be major contributors to speech production performance, such as age at onset of deafness and age of implantation, did not appear to play significant roles in predicting levels of speech production performance.

In contrast, two studies did find an association between age at implantation and speech production intelligibility outcomes. Peng et al.[8] examined the speech production intelligibility of 24 prelingually deaf pediatric CI recipients with 84 months of device experience. The results suggested that approximately 70% of a particular set of utterances produced by pediatric CI recipients with 7 years of device experience could be understood by unfamiliar listeners. As a group, the CI participants demonstrated improved speech production intelligibility over previous reports. Intelligibility reports obtained using write-down and rating-scale procedures were highly associated. The write-down intelligibility score can be reasonably predicted based on the rating-scale score using a quadratic regression model. Finally, linear regression analyses revealed that both age at implantation and different speech-coding strategies contribute to the variability of CI participants' speech production intelligibility. Implantation at a younger age and the use of the SPEAK speech-coding strategy yielded higher intelligibility scores than implantation at an older age and the use of the Multipeak speech-coding strategy. These results serve as indices for clinical applications when long-term advancements in spoken-language development are considered for pediatric CI recipients. Svirsky et al.[9] also found that “earlier implantation had a positive and significant effect on the speech intelligibility of cochlear implant users” and their results suggested “that a gradual decline in the ability to acquire spoken language skills may occur over time”.

Fueled in part by numerous reports that earlier implantation results in better communicative outcomes, more parents are insisting on having their deaf children implanted within the first year of life, which is an “off-label” use of cochlear implants since these devices are currently approved by the FDA for use in patients who are at least 12 months of age. Because such early implantation may carry potential risks and benefits, it is very important to assess communicative outcomes in children implanted during their first year. The present study is the first one to examine speech production intelligibility in a group of children implanted in the first year of life, and compare it to the speech production intelligibility of children implanted

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between 13 to 24 months, and those implanted between 25 and 36 months. We hypothesized that the children who received implants in the first year of life would develop intelligible speech at a younger age than children who received implants later, in parallel with results observed in studies of speech perception and language development as a function of age at implant[10 11].

Methods

Participants

Cochlear Implant Users—The experimental group included 37 prelingually deaf children with cochlear implants whose age ranged between 2.5–18 years. The age of implantation ranged from 8 to 36 months; 11 subjects were implanted at 8 to 12 months, 16 subjects were implanted between the age of 13 and 24 months, and 10 subjects were implanted between the age of 25 and 36 months. The average age at implantation for the three groups was, respectively, 10.1, 17.1 and 29.3 months. Children were excluded from the study if they were known to have a co-existing handicapping condition that may influence speech production intelligibility such as mental retardation or speech motor problems. All subjects received surgery, follow-up assessments, and oral rehabilitation at the NYU Cochlear Implant Center. They all used oral communication at the time of testing. One child had used Total Communication (simultaneous use of signs and oral speech) in the past, but dropped the use of signs as he became more proficient with the CI. All children received cochlear implants manufactured by Cochlear Ltd. (Australia). Demographic information for the three groups is shown in Table 1. Written consent forms (approved by the NYU Institutional Review Board) were signed by the parent/guardian prior to the recording of the child's speech production of the BIT sentences.

Adult Listeners—Thirty adult listeners were recruited to participate in this study as listeners, to evaluate the intelligibility and quality of the children's speech. The age of these adult listeners ranged from 20 – 31 years. All were native speakers of English. Any individual with prior extensive exposure to deaf speakers was excluded, as were speech and hearing professionals. In addition, hearing loss in the listeners was ruled out in order to avoid inaccurate scoring. The listeners were paid for their participation in this study.

Materials and Procedures

Speech Stimuli—The Beginner's Intelligibility Test (Osberger et al., 1994) (see Appendix A) was used to assess the speech production intelligibility of young children with cochlear implants using a transcription (write-down) procedure. This test required three naïve listeners as auditors. Each administration of the BIT involved one out of the four available 10-sentence lists. Sentences contained words familiar to children and are syntactically simple; all words are 1 or 2 syllables long. Each sentence contained between 2 and 6 words. Lists contained 37 to 40 words.

BIT List Administration and Digitizing—One of the four BIT lists was administered to each cochlear implant subject. During the test administration, an examiner – either a medical student, a speech-language pathologist or an audiologist – would model the sentence, using objects and pictures to convey the target sentence to the child. The child was then prompted to reproduce the examiner's spoken model. The entire testing session was recorded in a quiet room onto high-quality digital recorders. The recordings were then digitized and normalized to maintain relatively constant sound levels across the recording of each sentence. The digitized samples were transfered into a .wav file, which consisted of two repetitions of the isolated reproduction of each sentence in the BIT list with inserted cues (e.g. "List 1, Sentence 1: ready, 'The baby falls.' – 4 second silence – "Sentence 2, again: 'The baby falls.'", with the underlined text indicating the part of the .wav file that was spoken by the child). The .wav files were then compiled and saved to USB drives for listening sessions.

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Listening Sessions—The listening sessions were conducted with the normal-hearing listeners described above. Each child's elicitations of the BIT lists were played back, in random order, to three normal-hearing, naïve adult listeners. The recordings were played back at 70 dB (+ 2 dB) to the listeners, who were seated approximately 4 ft (1.2m) from the speaker in a quiet room. Each listener transcribed 4 lists. Listeners did not hear the same list more than once nor did they listen to a list made by the same CI subject more than once. This was done to keep the speech production intelligibility scores from showing learning effects, which otherwise could have happened due to the listeners learning the content of a given list, or learning to understand a given child. Thus, each listener listened to only four sets of sentences and each CI participant's speech sample was evaluated by three listeners. Each listener was instructed to listen to each sentence twice. After the second recording, he or she was to write down what they have heard and to rate the sentence on a 5-point rating scale, where 1 is "not intelligible at all" and 5 is "totally intelligible." Listeners were not allowed to change their responses once completing the set. The examiner controlled presentation of the sentence set; however, listeners were not limited in their response time in assessing the child's speech production intelligibility.

Data Analysis—The write down responses were scored as the percent of target words correctly transcribed, averaged across the three listeners. All target words were scored, and all target words were weighted equally. The write-down and rating-scale intelligibility scores of each CI participant were calculated as the average of the panel of three listeners' responses.

A first analysis examined the strength of the correlation between rating-scale and write-down intelligibility scores. In a second analysis, nonlinear regressions for intelligibility scores as a function of age at testing were obtained separately for each age-at-implantation group using the formula

$$\text{Intelligibility} = y_0 + a(1 - e^{-b \times \text{age}})$$

The three regression curves (for children implanted at 8–12, 13–24, or 25–36 months) were visually compared to each other as well as to a normative data curve obtained from normal hearing listeners.

Multiple linear regression of intelligibility score as a function of age-at-implant, age at testing, number of implants (single or bilateral), bilingual/monolingual status, and residual hearing were carried out, both using age-at-implant as a continuous variable or as a binary variable indicating whether the children were implanted in the first two years or the third year of life. This analysis was then repeated for the subset of 27 children implanted up to 24 months of age. T-tests were used to compare speech intelligibility scores of children implanted at 8–24 months to those of children implanted at 25–36 months. This was done separately for data points obtained before or after 5.5 years of age, which is the age a child must be as of July 1st in order to enter first grade in the state of New York.

Results

Figure 1 shows a scatterplot of speech production intelligibility and speech quality ratings obtained from naïve listeners. The correlation was quite high (r=+0.79) and it was statistically significant ($p<0.001$). The adjusted R^2 was 0.609, indicating that 61% of the variance in speech quality can be explained by differences in speech intelligibility.

Figure 2 shows speech production intelligibility as a function of age at testing for the individuals in each group. The thick black line represents average data obtained from normal-hearing children. For all three subgroups, the data demonstrated a strong effect of age at testing, with older children being more intelligible. This effect was particularly pronounced for children implanted at 8 to 24 months of life, all of whom achieved intelligibility scores of 80% or higher when they were tested at 5.5 years or older. This was true for only five out of nine children implanted in their third year of life and tested at age 5.5 years or older. These observations are consistent with the statistical tests that compared children implanted earlier (8–24 months) or later in life (35–40 months). The data obtained after age 5.5 showed a significant advantage for earlier implanted children, who had a very high average intelligibility of 93% compared to only 80% for the later implanted children. This difference was statistically significant (t-test, $p=0.011$).

The multiple regression of the whole group of 37 children showed that older age at testing ($p<0.001$), younger age at implantation ($p<0.05$), and monolingual status ($p<0.01$) had a positive and statistically significant effect on the dependent variable. The sizes of the effects were increases of 0.44 percentage points for each additional month of age at testing; 1.0 percentage point for each month of earlier implantation, and 18 percentage points for monolingual vs. bilingual children. The children's amount of residual hearing (PTA), and whether they had a single CI or bilateral CI's did not have a statistically significant relation to the speech intelligibility scores. When age at implantation was encoded as a binary variable, the corresponding multiple regression showed an advantage of 18 percentage points of speech production intelligibility for the children implanted in the first two years with respect to those implanted in the third year of life. Results of the multiple regression that included only the 27 children implanted in the first 24 months were very similar to the results from the overall multiple regression, with one notable exception: age at implantation was not related to speech intelligibility scores within this subgroup.

Discussion

The correlation of 0.79 found between speech quality ratings and speech production intelligibility supports the concurrent validity of both measures. However, this correlation was less than perfect and it was lower than the 0.91 obtained by Peng et al.[8]. This result suggests that the speech production intelligibility scores obtained with the write down procedure we used do not measure exactly the same variable that is assessed by quality ratings. The former measures strictly the percentage of words that can be understood by a naïve listener, whereas the latter is a subjective measure of the quality of the speech. Both types of scores provide information that is useful to assess speech production in hearing impaired children

As expected, speech production intelligibility scores were higher for older children, and this was clear for all three age-at-implant groups. Age at implantation also affected intelligibility scores, with all children implanted at 8–24 months achieving 80% or higher after age 5.5 years. Results were less clear cut for children implanted at 25–36 months, who were on average 15 to 18 percentage points less intelligible than the earlier implanted groups when compared at the same age. Note that many children in the later age-at-implant group achieved scores that were comparable to those of the earlier age-at-implant group. In other words, implantation after 24 months does not necessarily imply that the child will be less intelligible than if he had been implanted earlier, but the likelihood of developing completely intelligible speech by 5.5 years is lower for the later implanted children. It is possible, of course, that the less intelligible children among those implanted at 25–36 months may catch up with their more intelligible peers at a later age, but the present dataset does not allow us to predict whether that will happen or not. On average, monolingual children were more intelligible than bilingual children, but even the latter achieved high levels of speech production intelligibility when they were implanted within the first two years of life.

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There were no apparent differences in scores between children implanted at 8–12 months and those implanted at 13–24 months. It is possible that the present study, which had 11 children in the first group and 16 in the second one, was not adequately powered to find relatively small differences in speech production intelligibility. However, based on the present data it seems unlikely that a large difference in speech production intelligibility may exist between the two groups.

It is interesting that three out of the 37 children in this study obtained intelligibility scores clearly above the normal hearing average. Two of these children were implanted at 8–12 months. In comparison, none of the 67 children tested by Svirsky et al.[9] achieved a similar result, even though 14 of them were implanted at 13–24 months. Taken together, the results obtained in the present study were higher than those obtained by children at the same age at testing and age at implantation in the Svirsky et al. study. Although the studies were conducted at different institutions, the methodology was identical. In order to ensure that the methods would be duplicated exactly, the person in charge of supervising data acquisition in the Svirsky et al. study was brought in as a consultant for the present study. The difference in speech production intelligibility between the two studies may be partly (but not entirely) due to differences in communication mode, as 20–25% of the children in Svirsky et al. (and none in the present study) used Total Communication, which has been associated with lower levels of speech production intelligibility. Another possible difference may be the amount of oral rehabilitation received by children in both studies, but this was not explicitly measured.

Conclusion

Taken together, these results show that congenitally deaf children with CI's can obtain high levels of speech production intelligibility by the time they reach school age, particularly if they are implanted before their second birthday. There were no apparent differences in scores between children implanted at 8–12 months and those implanted at 13–24 months. However, this is only one of the multiple factors parents and clinicians should consider when deciding the optimal age at implantation for any given child.

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Appendix A

The Beginner's Intelligibility Test Lists

List 1

1. The baby falls.
2. Mommy walks.
3. The duck swims.
4. The boy sits.
5. Grandma sleeps.
6. That is a little bed.
7. The boy walked to the table.
8. My car is blue.
9. He is brushing his teeth.
10. She is taking a bath.

List 2

1. Daddy runs,
2. The baby cries.
3. The dog eats.
4. The girl drinks.
5. The clown falls.
6. That is a big bed.

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7. The boy walked to the chair.
8. My van is green.
9. They are playing the drums.
10. She is talking on the phone.

List 3

1. Daddy walks.
2. The bunny drinks.
3. The dog sleeps.
4. The girl jumps.
5. Mommy reads.
6. That is a brown chair.
7. The boy is on the table.
8. My airplane is big.
9. He is tying his shoe.
10. She is brushing her hair.

List 4

1. The bear sleeps.
2. Mommy sits.
3. The rabbit hops.
4. The cowboy jumps
5. Grandma falls.
6. That is a black hat.
7. The boy is under the table.
8. My airplane is small.
9. He is painting the chair.
10. She is cooking dinner.

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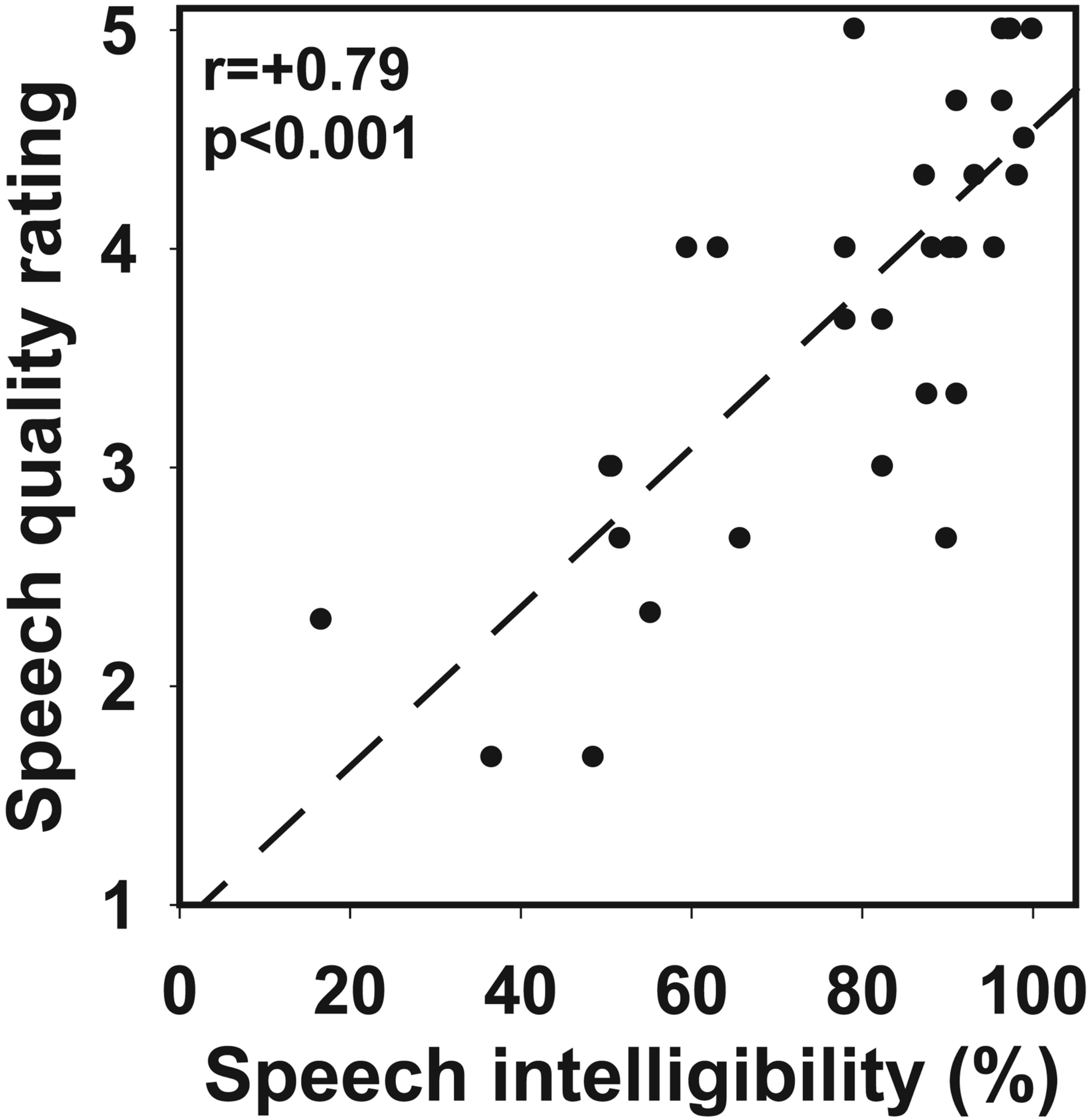

Figure 1.
Scatterplot of speech production intelligibility vs. speech quality ratings.

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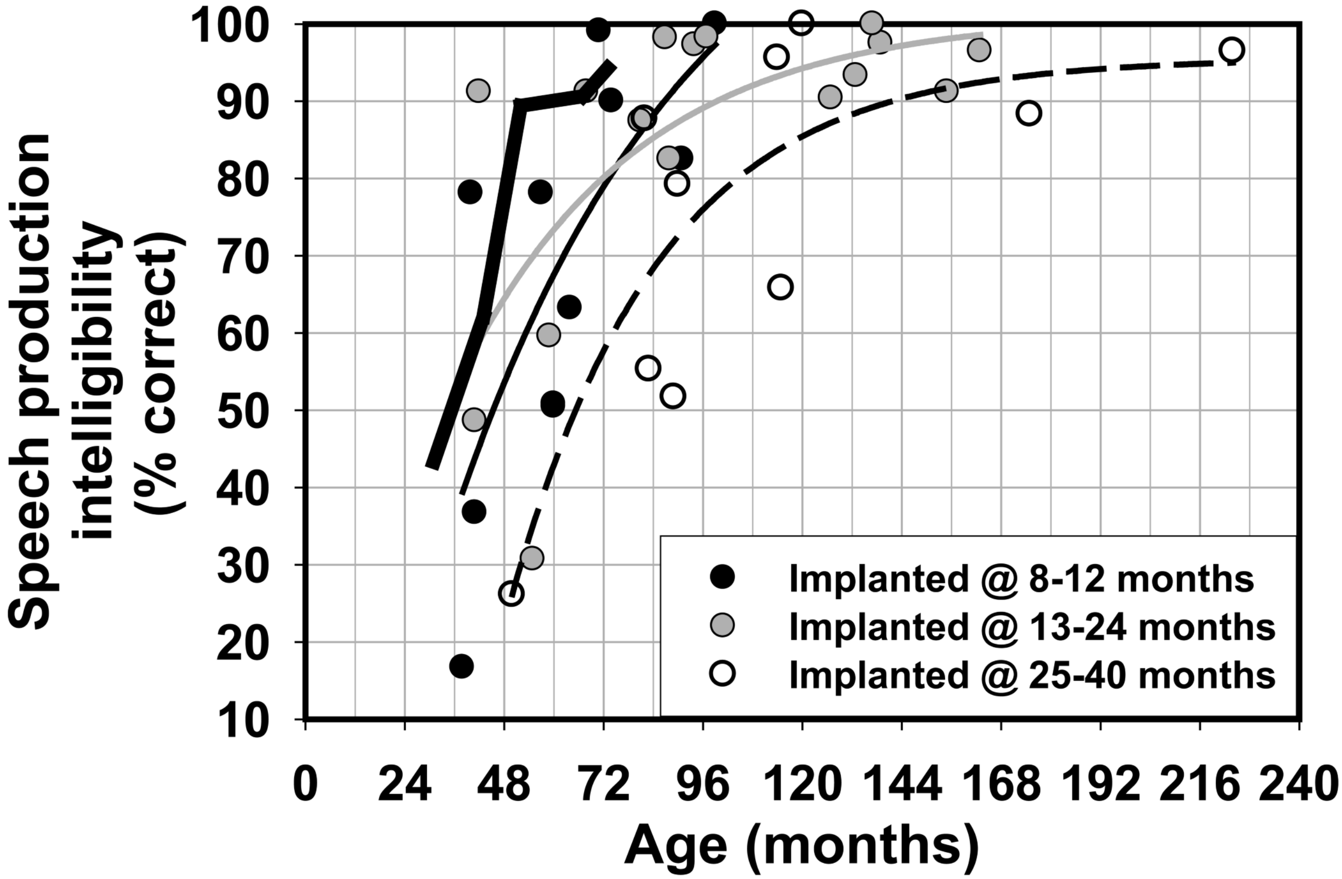

Figure 2.

Speech production intelligibility as a function of age at testing for the individuals in three age-at-implant groups: black circles for children implanted at 8–12 months, gray circles for those implanted at 13–24 months, and unfilled circles for those implanted at 25–40 months. Black, gray, and dashed thin lines, respectively, represent the results of the nonlinear regression used to fit the data for the three groups. The thick black line represents average data obtained from normal-hearing children.

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Table 1

Demographic characteristics of pediatric cochlear implant users in the study.

Range of age at implant (months)	Average age at implant (months)	Number of subjects	Number of bilateral CI users	Number of bilingual children	Stimulation strategies (X/Y indicates strategy X in one ear, Y in the other one)	Average PTA, better ear (dB HL)
8–12	10.1	11	8	6	All ACE	89
13–24	17.1	16	7	6	13 ACE, 1 SPEAK, 1 SPEAK/ACE	85
25–40	29.3	10	4	5	7 ACE, 1 SPEAK/ACE 1 MPEAK	76