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Speech Intelligibility of Pediatric Cochlear Implant Recipients With 7 Years of Device Experience

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Abstract

Speech intelligibility of 24 prelingually deaf pediatric cochlear implant (CI) recipients with 84 months of device experience was investigated. Each CI participant's speech samples were judged by a panel of 3 listeners. Intelligibility scores were calculated as the average of the 3 listeners' responses. The average write-down intelligibility score was 71.54% (*SD* = 29.89), and the average rating-scale intelligibility score was 3.03 points (*SD* = 1.01). Write-down and rating-scale intelligibility scores were highly correlated ($r = .91$, $p < .001$). Linear regression analyses revealed that both age at implantation and different speech-coding strategies contribute to the variability of CI participants' speech intelligibility. Implantation at a younger age and the use of the spectral-peak 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.

Keywords

cochlear implants; speech intelligibility; speech development; speech production

Acochlear implant (CI) is an auditory prosthesis that electrically stimulates the primary auditory nerve fibers to elicit sound perception in individuals with severe-to-profound sensorineural hearing impairments. A substantial number of studies have demonstrated that the use of CIs can facilitate the development of speech and language skills of children who are prelingually deaf (born deaf or become deaf before age 3; e.g., Blamey, Barry, & Jacq, 2001; Geers & Tobey, 1995; Serry & Blamey, 1999; Serry, Blamey, & Grogan, 1997; Spencer, Tye-Murray, & Tomblin, 1998; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000; Tobey, Geers, Brenner, Altuna, & Gabbert, 2003; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999; Tye-Murray & Kirk, 1993; Tye-Murray, Spencer, & Woodworth, 1995). Some investigators have also studied postimplant speech development by applying speech intelligibility measures (e.g., Chin, Finnegan, & Chung, 2001; Chin, Tsai, & Gao, 2003; Miyamoto, Kirk, Robbins, Todd, & Riley, 1996; Moog & Geers, 1999; Osberger, Robbins, Todd, & Riley, 1994; Svirsky & Chin, 2000; Tobey et al., 2003; Tobey & Hasenstab, 1991). The term "speech intelligibility" refers to the degree to which a speaker's intended message can be recovered by other listeners (Bunton, Kent, Kent, & Duffy, 2001). Speech intelligibility is a joint product of a speaker and a listener and can provide a close approximation of an individual's everyday communication status with regard to how well the individual can be understood by other listeners (Kent, Miolo, & Bloedel, 1994). For that

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reason, speech intelligibility measures tend to be relatively holistic and are distinct from many other clinical measures of speech production skills that intend to determine an individual's discreet phoneme accuracy.

Although individual intelligibility scores vary greatly from 0% to approximately 80% in the speech production of profoundly hearing-impaired individuals who did not receive a CI, the average speech intelligibility in this population is approximately 20% (Smith, 1975). Speech intelligibility measures have also been applied in examining pediatric CI recipients' postimplant speech development. Tye-Murray et al. (1995), for example, assessed the speech intelligibility in 28 prelingually deaf children who were users of total communication. Speech intelligibility scores were obtained by analyzing the correct percentages of words and of phonemes using imitative and spontaneous speech samples. The authors found that the intelligibility in their participants who had an average of 3 years of device experience remained low (i.e., 53% of phonemes and 22% of the words were produced correctly). In addition, children who received CIs before age 5 demonstrated greater improvement in their speech production skills than those who received CIs after that age.

Speech intelligibility, according to Tye-Murray et al. (1995), did not appear to be greatly improved in the first few years following implantation. This suggestion was further supported by Miyamoto et al. (1996), who examined speech intelligibility in pediatric CI recipients by deriving the percentage of accurately identified words by panels of listeners. Average intelligibility of the individuals with 4 years of device experience exceeded 40%. Furthermore, pediatric CI recipients' speech intelligibility improved over time and did not show a plateau with 5 years of device experience.

In another study, Osberger et al. (1994) compared speech intelligibility in CI recipients (N = 18) who used either oral communication (OC) or total communication (TC) via a write-down procedure from panels of listeners. Both groups were matched with regard to characteristics such as age at implantation (implanted by age 5) and length of device experience (2 years and above). Osberger and colleagues 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 did not reach a statistically significant level. The results showed that with 3.5 years of implant experience, children's average intelligibility was 48% in the OC group and 21% in the TC group. Moreover, there was a relatively wider range of individual scores in the OC group (14% to 93%) than in the TC group (4% to 59%).

In a more recent study, Tobey and colleagues reported that the average speech intelligibility of 181 children age 8 to 9 years, with an average of 5.5 years of CI experience, was 63.5% (Tobey et al., 2003). Performance was found to be associated with the variables of gender, nonverbal intelligence, communication mode, and educational setting. Age at implantation, however, was not found to be associated with participants' speech intelligibility. The authors attributed this unexpected result to the restricted range of their participants' age at implantation (1.7 to 5.3 years). Nevertheless, the study reported that pediatric CI recipients' speech intelligibility, though widely ranging, increased as length of device experience accumulated over time. Similarly, Chin et al. (2003) found that speech intelligibility in pediatric CI recipients with 6 years of device experience did not reach a plateau.

The authors in the above-mentioned studies have consistently reported improved speech intelligibility with prolonged device experience. However, there is a large amount of individual variability in CI recipients' postimplant spoken-language development (e.g., Miyamoto et al., 1994; Nikolopoulos, O'Donoghue, & Archbold, 1999). Factors contributing to individual variability include duration of deafness; age at onset of deafness; age at

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implantation; duration of CI use; physiological or device factors such as the number of surviving spiral ganglion cells, electrode placement and insertion depth, electrical dynamic range, and signal processing strategies; and other psychological, educational, and social factors such as the recipient's motivation or level of intelligence (for reviews, see Loizou, 1998; Waltzman, 2000). In the literature these factors are not weighted evenly because of the diverse nature or objectives of the studies. In the population of prelingually deaf CI recipients, the frequently considered factors include age at implantation, duration of CI use, and communication mode (e.g., Fryauf-Bertschy, Tyler, Kelsay, Gantz, & Woodworth, 1997; Nikolopoulos et al., 1999; Osberger & Fisher, 2000; Osberger et al., 1994). Most authors agree that postimplant speech and language advancements are positively associated with a younger age at implantation, duration of device use, and a reliance on OC. Connor, Hieber, Arts, and Zwolan (2000), however, reported that the speech (consonant) production skills of CI recipients using TC did not differ from those of children who used OC if they received their implants no later than age 5.

Taken together, despite several potential variables that may contribute to the great intersubject variability in speech intelligibility, these studies have consistently demonstrated that the use of CI devices can facilitate improved speech intelligibility in pediatric CI recipients. Additionally, improvement continues as device experience accumulates. Even with 5 to 6 years of device experience, there is no asymptotic pattern with regard to speech intelligibility (Chin et al., 2003; Tobey et al., 2003). Waltzman and colleagues, on the other hand, posited the possibility that the CI input may degrade over time, and the migration or extrusion of the inserted electrodes may occur in any growing child. It is unclear how CI devices or physiological characteristics may impact CI recipients' long-term speech and language performance (Waltzman, Cohen, Green, & Roland, 2002).

The present study aimed to examine the speech intelligibility in a group of 24 pediatric CI recipients who all had long-term device experience (i.e., 7 years). The study utilized two common speech intelligibility measures (i.e., write-down and rating procedures). We expected that, as a group, these participants would demonstrate greater speech intelligibility than that demonstrated in previous studies. Given that both procedures have their pros and cons (Cox, Alexander, & Rivera, 1991; Samar & Metz, 1988), a secondary purpose of the study was to examine the relation between the write-down intelligibility scores based on the obtained rating-scale intelligibility scores. Finally, with equivalent length of CI experience, regression models were derived based on CI participants' performance. Potential intersubject variables of age at implantation and device speech-coding strategies were also evaluated in the models. We hypothesized that better speech intelligibility would be associated with younger ages at implantation and more advanced speech-coding strategies.

Method

Participants

The CI participants were 24 prelingually deaf individuals whose average age was 147.5 months (*SD* = 25 months) with a range from 113.7 to 217.9 months. Their mean age at implantation was 61.3 months (*SD* = 24.5 months) with a range from 30.9 to 132.5 months. All participants received surgery and follow-up assessments at the University of Iowa Hospital and Clinics Department of Otolaryngology–Head and Neck Surgery and had been using their implants for 7 years. The speech recordings and relevant data were extracted from the database of the ongoing National Institutes of Health-funded Iowa Children's Cochlear Implant Project. All children received the Nucleus 22 device. Eighteen CI recipients employed the spectral-peak (SPEAK) speech-coding strategy, and 6 employed the multipeak (MPEAK) speech-coding strategy (Cochlear). All recipients but 1 used TC.

Participant CI-3 used OC. Background information for the 24 CI participants is summarized in Table 1.

In addition, 72 adult listeners (25 males and 47 females) were recruited on campus to participate. Their average age was 32.9 (*SD* = 14.9), with a range from 18 to 79 years. All were native speakers of English. Each of the listeners signed consent forms approved by the University of Iowa Institutional Review Board and was paid.

Prior to the listening task, each listener completed a questionnaire that was designed to obtain basic information from the listener. None of the listeners had significant experience with listening to the speech of the deaf or individuals with hearing impairments. In addition, none of the listeners reported having a hearing loss. However, to rule out the possibility that an undiagnosed hearing loss affected scoring in the more senior listeners, an examination of age and score assignment was completed (see Appendix). This examination revealed that scores of listeners above age 50 were consistent with scores of listeners younger than the age for any given CI participant. No pattern was found between any given listener's age and the participant's intelligibility score, compared to the scoring on the same CI participant from the other two listeners.

Speech Stimuli

The speech stimuli contained 14 sentences. The sentences were produced by each of the 24 CI participants following an examiner's simultaneous spoken and manual model at the 7-year postimplant testing session. Altogether, the resulting set consisted of a total of 336 imitatively produced sentences. The sentence stimuli were elicited using the long version of the Short-Long Sentence Test, which is part of the protocol used in the Iowa Children's Cochlear Implant Project. A detailed description of the test battery has been presented elsewhere (e.g., Tye-Murray, 1998; Tye-Murray et al., 1995). Mean length of each sentence was 7.43 words (*SD* = 1.22), with a range of 6 to 10 words. Sentences varied in their linguistic complexity and structures. In total, the modeled 14 sentences contained 104 words. Occasionally some participants produced variations of the model sentences, and therefore the actual produced sentences by each participant ranged from 99 to 106 words. All speech materials were extracted from videotapes and digitally edited at a sampling rate of 22050 Hz. The resulting sentences were stored in a 16-bit format using the sound-analysis software CoolEdit 2000 (Syntrillium Software Corp., 2000). Each sentence was normalized to maintain relatively constant sound levels across the recording of each sentence. All materials were then stored on the hard disk of a laptop (Sony VAIO PCGR505EL). Each CI participant's sound file was stored in a single directory and was randomly assigned to be played to each listener using Microsoft PowerPoint 2002.

Procedure

Each of the 72 listeners completed the listening tasks in a sound-treated booth. Before the listener arrived, the examiner randomly selected one set of sentences produced by 1 of the 24 CI participants. In this manner, each listener listened to only 1 CI participant's utterances, and each CI participant's speech samples were evaluated by three listeners. Each listener was instructed that she or he would listen to each sentence twice. She or he was to write down and rate the heard sentence on a 5-point rating scale, for which position 1 was labeled “not intelligible at all” and position 5 was labeled “totally intelligible.” Listeners were not allowed to change any responses on the answer sheets subsequent to completing a given sentence condition. An examiner (the first author) controlled presentation of the sentences, but each listener was not restricted in their response time in scoring the child's speech intelligibility. Two examples were provided before the formal listening task began. Sentences were presented binaurally through a Sennheiser (HD 25 SP) headphone at a comfortable listening level. Listeners were allowed to adjust the volume if desired during the practice. However, none of the listeners indicated that the volume was inappropriate (too loud or too soft).

Data Analysis

The write-down responses were tallied by counting the percentage of correctly perceived target words out of the total number of target words. The write-down and rating-scale intelligibility scores of each CI participant were calculated as the average of the panel of three listeners' responses. Responses from the first and the second listening conditions were kept separate.

Results

As a group, the average speech intelligibility score based on the first presentation of the sentences using the write-down procedure was 67.86% (*SD* = 30.56%), with a range of 5.5–100%. The average intelligibility score based on the second presentation of the sentences was 71.54% (*SD* = 29.89%), with a range of 5.83–100%. A significant positive correlation was found between the first and second presentations of the sentences, $r = .99$, $p < .001$. Paired *t* tests showed that the write-down intelligibility scores significantly increased with a repeated-sentence presentation, $t(23) = 4.82$, $p < .001$; the second presentation of the sentences contributed an increase of 3.68% in the write-down intelligibility scores.

As for the rating-scale results, the speech intelligibility score based on the first presentation ranged from 1.24 to 4.62 points, with a mean of 2.85 points (*SD* = 1.01 points). The scores based on the second hearing of the sentences ranged from 1.29 to 4.83 points, with a mean of 3.03 points (*SD* = 1.01 points). Again, a highly significant positive correlation was found between the ratings following the first and second presentations of the sentences, $r = .99$, $p < .001$. The effect of sentence repetition on the rating-scale intelligibility scores was statistically significant, $t(23) = 7.25$, $p < .001$. The second presentation of sentences contributed an increase of 0.18 points in the rating-scale intelligibility scores.

The effect of the repetition of sentence presentation is illustrated in the two panels of Figure 1, with a 45° line in each panel. Scatter plots of the data points for the first and second listening conditions are shown in Panel A and Panel B, respectively. Only one data point was below the 45° line for the first listening condition, and none of the data points were below the 45° line. There was virtually no difference between the first and second listening. Therefore, the subsequent analyses were conducted based on the data obtained from the second listening condition.

The relation between the write-down and rating-scale intelligibility scores is shown in Figure 2. The Pearson's correlation coefficient (*r*) between the write-down and the rating-scale scores was .91; the intelligibility levels using both measures were highly positively correlated ($p < .001$). The distribution of the rating and write-down intelligibility scores (SI) can be fitted reasonably well for all of the data points with a quadratic regression line, write-down SI = −95.92 + 90.26 * (rating SI) − 10.43 * (rating SI)^2, $R^2 = .95$, $F(2, 21) = 208.36$, $p < .001$.[1] According to this regression model, if a CI participant received a rating of 3 points, his or her corresponding write-down intelligibility score could be predicted to be 81%, and if

[1]Theoretically, the higher the rating-scale intelligibility score is, the higher the write-down intelligibility score should be, and vice versa. The pitfall of this quadratic regression model is that the fitted regression curve peaks at the rating score of 4.33 points. When the rating score is beyond 4.32 points, the predicted write-down score begins to decrease. This finding contradicts the aforementioned theoretical condition. A much more complicated model could be adopted to encompass this theoretical condition. Nevertheless, this quadratic regression model is presented because (a) it is simple and (b) it appropriately predicts the write-down score for midrange rating scores.

he or she received a rating of 4.5 points, his or her corresponding write-down intelligibility score could be predicted to be 99%.

Eighteen CI participants were fitted with the SPEAK speech-coding strategy, while the other 6 participants were fitted with the MPEAK speech-coding strategy. Because the two speech-coding strategies are essentially different and may contribute to some intersubject variability, the processor type should be considered when investigating the relation between scores and the age at implantation. A regression model that includes age at implantation and processor type as explanatory variables therefore was used. The distribution of the participants' write-down intelligibility scores (in percentages) as a function of age at implantation (“ImpAge” in months) and processor type is shown in Figure 3. Different processor types (MPEAK vs. SPEAK) are displayed as different symbols, and each of the two regression lines is associated with each of the two processor types. The fitted regression model was: SI = 44.74 – 0.46 * ImpAge +31.48 * processor type, where processor type = 1 if the participant was in the MPEAK group and processor type = 2 if the participant was in the SPEAK group; ImpAge: $t(21) = 2.24$, $p = .036$; processor: $t(21) = 2.76$, $p = .012$; model: $R^2 = .42$, $F(2, 21) = 7.54$, $p = .003$. Accordingly, the write-down intelligibility score for a SPEAK participant was, on average, 31.5% higher than an MPEAK participant's score, for each fixed age at implantation. Within either MPEAK or SPEAK group, a 1-year increase in age at implantation was associated with a 5.52% (0.46 * 12) decrease in the write-down intelligibility score.

The distribution of the participants' rating-scale intelligibility scores (in points) as a function of age at implantation (in months) and processor type is shown in Figure 4. Different processor types are shown as different symbols in the figure, and each of the two regression lines is associated with each of the two processor types. The fitted regression model was: SI = 2.08 – 0.0145 * ImpAge + 1.05 * processor type, where processor type = 1 if the participant was in the MPEAK group and processor type = 2 if the participant was in the SPEAK group; ImpAge: $t(21) = 2.03$, $p = .055$; processor: $t(21) = 2.64$, $p = .015$; model: $R^2 = .39$, $F(2, 21) = 6.61$, $p = .006$. Hence, the rating-scale intelligibility score for a SPEAK participant was, on average, 1.05 points higher than an MPEAK participant's score, for each fixed age at implantation. Within either MPEAK or SPEAK group, a 1-year increase in age at implantation was associated with a 0.174 point (0.0145 * 12) decrease in the rating-scale intelligibility score.

Discussion

The present study investigated the speech intelligibility scores of pediatric CI recipients with 7 years of device experience. Inexperienced listeners were able to understand approximately 68% (first listening) to 72% (second listening) of the words spoken by the pediatric CI recipients. The present CI participants, with 7 years of device experience, demonstrated improved speech intelligibility over previous reports (e.g., Chin et al., 2003; Miyamoto et al., 1996; Osberger et al., 1994; Tobey et al., 2003; Tye-Murray et al., 1995). Specifically, half of the CI participants ($n = 12$) achieved an 85% write-down intelligibility, and 8 of them exceeded 90% in both listening conditions. It has been reported that the average speech intelligibility score in profoundly hearing-impaired individuals who do not use CIs is about 20% (Smith, 1975). The speech intelligibility scores in the pediatric CI recipients with 7 years of device experience are remarkably higher. Moreover, the average write-down intelligibility score from the present study is 4% (first listening) to 8% (second listening) higher than that in Tobey et al. (2003), where a 64% intelligibility score was documented in 8–9-year-old children with an average of 5.5 years of CI experience.

These results also suggest that as a group, pediatric CI recipients' speech intelligibility scores continue to improve beyond 5 or 6 years of device use. Most participants (*n* = 23) in the present study were TC users. The speech intelligibility scores of pediatric CI recipients using OC have been shown to exceed the scores of pediatric CI recipients using TC (e.g., Osberger et al., 1994; Osberger, Zimmerman-Philips, & Koch, 2002); the speech intelligibility scores in the pediatric CI recipients who have prolonged device experience using OC could be expected to be at least comparable to the intelligibility scores in the ones using TC.

In the present study, each sentence was played twice to each listener, who was prompted to respond following each presentation. The present results show a statistically significant improvement in both write-down and rating-scale intelligibility scores with the repeated hearing of the same sentence. The present results are consistent with the results of Monsen (1983), in which repetition of sentence presentations was found to result in a significant increase in intelligibility levels. Repetition is one common form of communication strategy in daily conversation (e.g., Tye-Murray, 1998). Because repetition was successful in increasing the perceived intelligibility of CI participants, it can be a valid aural rehabilitation technique. The caveat of this finding is that the extent to which the effect can translate into a practical or conversational setting is unknown.

The present study incorporated both the write-down and rating-scale procedures in measuring speech intelligibility. The results reveal that the write-down and rating-scale intelligibility scores were highly correlated and compatible. In practice, both procedures have their pros and cons. For example, the write-down procedure lends itself to analysis of specific error patterns and can provide explicit assurance of the accuracy of the perceived speech materials. In addition, write-down intelligibility scores tend to be less sensitive to normal variations in breathiness or pitch register and, therefore, have clear face validity when measuring speech intelligibility for individuals with hearing impairments. The disadvantage of the write-down procedure is that it is rather time-consuming. The major advantage of the rating-scale procedure is that intelligibility scores can be obtained promptly, but it is difficult for the examiner to verify exactly what the listener understood. Rating-scale intelligibility scores, more than write-down scores, also tend to be affected by nonauditory factors such as listener expectations and personality traits (Cox et al., 1991; Samar & Metz, 1988).

All in all, compared to the write-down procedure, the rating-scale procedure is more efficient because it requires less time and effort to obtain an intelligibility score. Moreover, a strong relation was found between the write-down and rating-scale intelligibility scores. The quadratic regression model in which write-down intelligibility scores can be derived based on the rating-scale intelligibility scores can be clinically applied to predict the write-down intelligibility of any given pediatric CI recipients with long-term device experience.

Even though half of the CI participants achieved a write-down intelligibility score of 85% or above, some individuals' intelligibility scores remained low (6 out of 24 were below 50%). A variety of sources may contribute to this variability. In the present study, all CI participants had an equal length of CI experience at test time, and most of them were TC users. Regression models were derived based on CI participants' write-down and rating-scale intelligibility scores. Potential intersubject variables of age at implantation and device speech-coding strategies were evaluated in such models. For the regression model derived based on the write-down scores, the intelligibility score of a participant using the SPEAK speech-coding strategy was on average 31.5% higher than the intelligibility score of a participant using the MPEAK speech-coding strategy, with fixed age at implantation. Furthermore, 1 year earlier in age at implantation was associated with a 5.54% increase in

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the write-down intelligibility score. Similarly, the regression model derived from the rating-scale intelligibility scores revealed that intelligibility for the SPEAK strategy was on average 1.05 points higher than for the MPEAK strategy, with fixed age at implantation. Moreover, a 1-year increase in age at implantation was associated with a 0.174-point decrease in the rating-scale intelligibility score. Taken together, our present results are consistent with the expectation that greater speech intelligibility is associated with younger ages at implantation and with the use of the SPEAK speech-coding strategy. Because there is a trend for early implantation in infants as young as 12 months of age, and for the improved CI speech-coding strategies and associated technology, it remains unclear what long-term speech intelligibility will be like for the CI recipients in the current generation. It is likely that with younger ages at implantation and more advanced CI speech-coding strategies, these individuals will be able to achieve high speech intelligibility with a reasonable amount of device experience.

In summary, the results suggest 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 intelligibility over previous reports. Intelligibility scores obtained using the write-down and rating-scale procedures were highly associated. A pediatric CI recipient's write-down intelligibility can be reasonably predicted based on his or her rating-scale intelligibility score using a quadratic regression model. Finally, regression models derived based on CI participants' write-down and rating-scale intelligibility scores suggested that better speech intelligibility is associated with younger ages at implantation and more advanced speech-coding strategies.

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Appendix. Summary of each listener's age and the scoring of each CI recipient's second write-down and rating-scale speech intelligibility scores

	Listener		Speech intelligibility score	
Recipient ID	**ID**	**Age (years)**	**Write-down (%)**	**Rating (points)**
CI-1	1	22	29.70	1.79
	2	38	53.47	2.86
	3	53	59.41	2.57
CI-2	1	20	78.43	2.86
	2	22	81.37	3.14
	3	23	75.49	2.79
CI-3	1	48	96.55	3.29
	2	46	96.97	4.43

	Listener		Speech intelligibility score	
Recipient ID	**ID**	**Age (years)**	**Write-down (%)**	**Rating (points)**
	3	20	96.97	3.50
CI-4	1	22	43.27	2.21
	2	46	41.35	1.86
	3	23	26.92	2.64
CI-5	1	23	77.67	2.07
	2	23	82.52	3.14
	3	58	86.41	3.14
CI-6	1	64	98.08	4.43
	2	24	97.12	4.71
	3	30	99.04	4.00
CI-7	1	21	51.52	1.50
	2	21	45.45	1.86
	3	19	31.31	2.29
CI-8	1	35	98.97	4.36
	2	43	99.05	4.36
	3	59	100.00	4.36
CI-9	1	20	80.20	2.93
	2	38	94.06	3.50
	3	50	88.12	3.43
CI-10	1	24	67.00	2.29
	2	24	69.00	2.54
	3	21	63.00	2.43
CI-11	1	23	99.04	4.43
	2	36	99.04	3.77
	3	79	97.12	4.21
CI-12	1	46	91.43	3.79
	2	23	88.57	3.43
	3	26	81.90	3.38
CI-13	1	47	19.42	2.21
	2	26	14.56	1.29
	3	27	15.53	1.50
CI-14	1	51	8.74	1.14
	2	61	9.71	1.57
	3	20	9.71	1.43
CI-15	1	55	100.00	5.00
	2	18	100.00	4.50
	3	26	100.00	5.00
CI-16	1	23	96.12	4.21
	2	23	95.15	4.71
	3	28	97.09	4.71
CI-17	1	20	73.00	3.14

	Listener		Speech intelligibility score	
Recipient ID	**ID**	**Age (years)**	**Write-down (%)**	**Rating (points)**
	2	33	70.00	2.29
	3	23	66.00	2.00
CI-18	1	21	73.33	2.00
	2	26	61.90	2.38
	3	26	56.19	2.08
CI-19	1	21	7.77	1.43
	2	21	5.83	1.00
	3	25	3.88	1.43
CI-20	1	21	98.08	2.33
	2	23	92.31	4.07
	3	31	100.00	4.07
CI-21	1	48	95.15	2.64
	2	25	86.27	3.29
	3	55	92.16	3.79
CI-22	1	19	89.42	3.36
	2	59	86.54	3.50
	3	38	90.38	3.29
CI-23	1	24	96.15	3.43
	2	73	90.38	3.93
	3	24	87.50	3.43
CI-24	1	24	65.38	2.50
	2	24	59.62	1.89
	3	48	72.12	3.21

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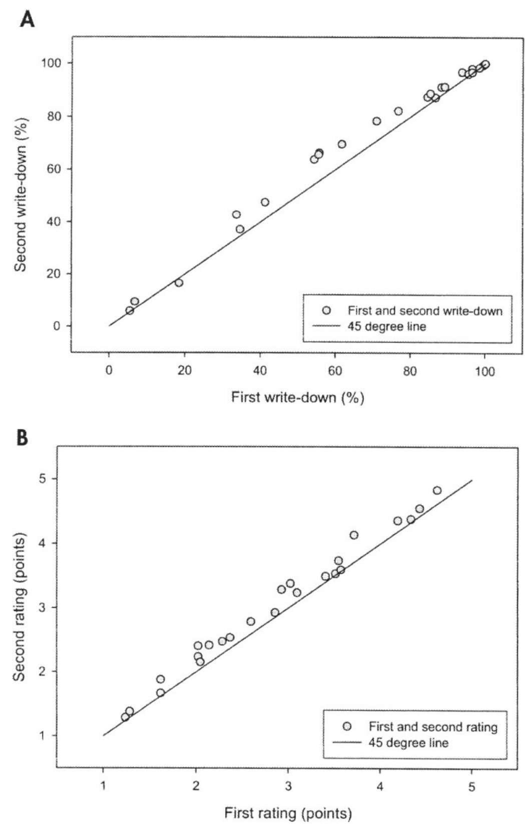

Figure 1.
Shown in Panels A and B are the scatter plots of the write-down and rating-scale intelligibility scores obtained from the first and second listening conditions, respectively. The first intelligibility scores are depicted on the x-axis, and the second intelligibility scores are represented on the y-axis. A 45° line is shown in each panel.

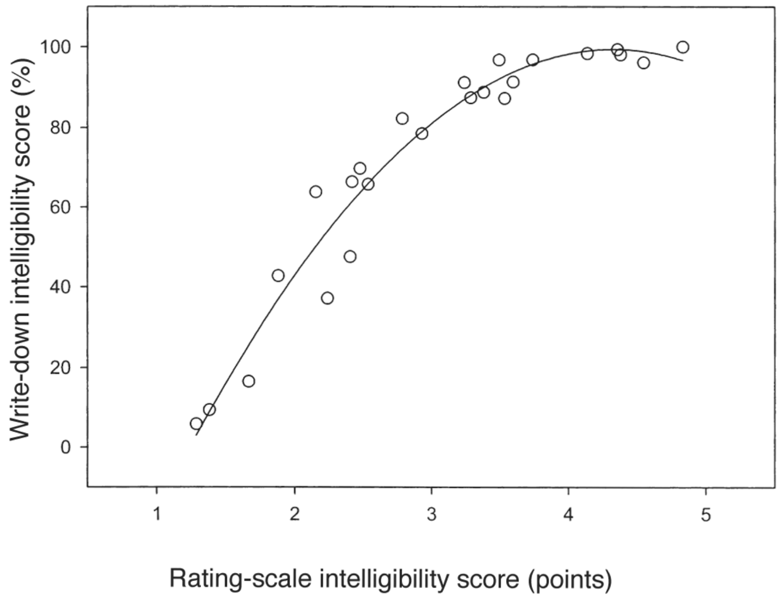

Figure 2.

The distribution of both rating-scale and write-down intelligibility scores are shown for each CI participant, along with the best-fitting quadratic regression line, which has been fit to all of the data points.

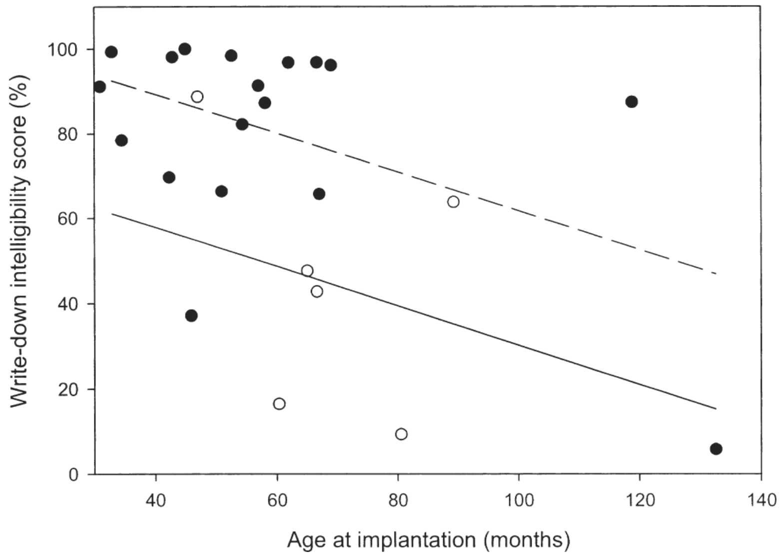

Figure 3.
The write-down intelligibility scores are shown as a function of age at implantation for the 24 CI recipients. The filled and open circles represent the scores of the CI participants in the SPEAK (n = 18) and the MPEAK (n = 6) groups, respectively. Fitted regression lines for the SPEAK and MPEAK groups are shown with the dashed and straight lines, respectively.

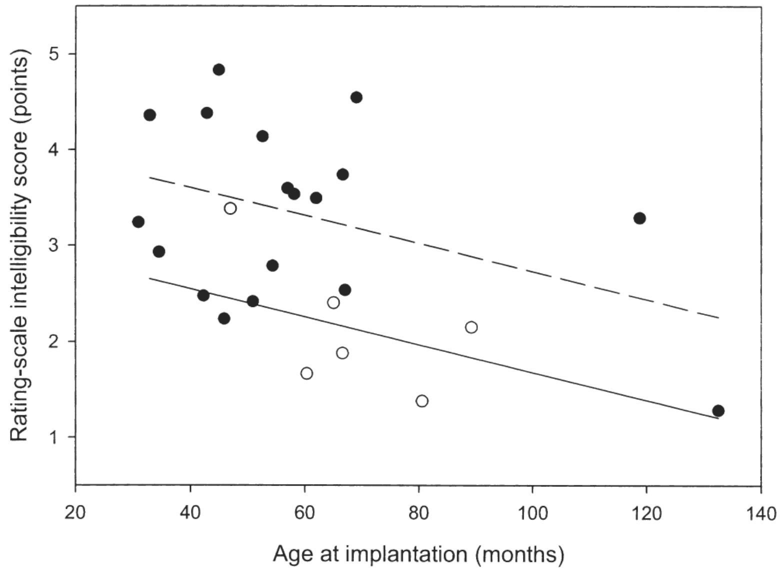

Figure 4.

The rating-scale intelligibility scores are shown as a function of age at implantation for the 24 CI recipients. The filled and open circles represent the scores of the CI participants in the SPEAK (*n* = 18) and the MPEAK (*n* = 6) groups, respectively. Fitted regression lines for the SPEAK and MPEAK groups are shown with the dashed and straight lines, respectively.

Table 1

Background information for the 24 CI recipients.

ID	Gender	Implanted ear	Age at implantation (months)	Age at testing (months)	Speech -coding strategy	Preimplant pure tone thresholds of the better ear (dB HL)			Comm. mode
						500 Hz	1000 Hz	2000 Hz	
CI-1	female	right	65.00	150.43	MPEAK	115	110	115	TC
CI-2	male	left	34.50	120.80	SPEAK	85	95	NR	TC
CI-3	male	right	66.60	149.40	SPEAK	90	110	NR	OC
CI-4	male	right	45.87	135.10	SPEAK	100	120	NR	TC
CI-5	male	left	54.30	142.13	SPEAK	100	105	NR	TC
CI-6	male	right	42.80	131.30	SPEAK	105	115	110	TC
CI-7	male	left	66.57	150.93	MPEAK	95	NR	NR	TC
CI-8	male	right	32.87	115.50	SPEAK	110	115	NR	TC
CI-9	female	right	118.77	202.43	SPEAK	105	90	115	TC
CI-10	female	right	50.87	136.37	SPEAK	95	105	NR	TC
CI-11	female	left	52.53	137.17	SPEAK	NR	NR	NR	TC
CI-12	female	right	58.07	146.53	SPEAK	100	110	100	TC
CI-13	female	right	60.30	151.00	MPEAK	110	NR	NR	TC
CI-14	female	right	80.53	170.00	MPEAK	75	110	NR	TC
CI-15	female	left	44.90	132.37	SPEAK	NR	NR	NR	TC
CI-16	female	left	68.97	152.93	SPEAK	100	110	NR	TC
CI-17	male	left	42.27	127.40	SPEAK	NR	NR	NR	TC
CI-18	female	left	89.23	181.67	MPEAK	90	110	NR	TC
CI-19	male	left	132.53	217.87	SPEAK	85	110	NR	TC
CI-20	female	left	61.93	147.50	SPEAK	115	NR	NR	TC
CI-21	male	right	30.93	113.67	SPEAK	90	105	100	TC
CI-22	male	right	46.93	129.80	MPEAK	90	NR	NR	TC
CI-23	male	left	56.93	141.60	SPEAK	100	NR	NR	TC
CI-24	male	left	67.00	156.77	SPEAK	110	NR	NR	TC

Note. NR = no response at the output limits (110 dB HL at 500 Hz, 115 dB HL at 1000 Hz, and 115 dB HL at 2000 Hz) of the pure-tone audiometer; OC = oral communication; TC = total communication.