RESEARCH ON SPOKEN LANGUAGE PROCESSING
Progress Report No. 25 (2001-2002)
Indiana University

Speech Intelligibility of Children with Cochlear Implants and Children with Normal Hearing: A Preliminary Report[1]

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[1] This work was supported by grants from the National Institute on Deafness and Other Communication Disorders to Indiana University (R01DC00423 and T32DC00012). We are grateful to Susan T. Sehgal, Cara Lento Kaiser, Tara E. O'Neill, and Shelly P. Godar for assistance with data collection; to Theresa S. Kerr for database analysis; to Michael S. Vitevitch, Karen Iler Kirk, and Derek M. Houston for comments and suggestions; and to Luis R. Hernández and Jeffrey D. Karpicke for assistance with manuscript formatting. Finally, we very much appreciate the assistance and cooperation of the children who participated and their parents, as well as of the staff and administration of the Center for Young Children at Indiana University–Purdue University Indianapolis, in particular its director, Beth Jeglum.

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Abstract. The objectives of the study reported here were (a) to assess the convergent validity of the Beginners' Intelligibility Test with respect to other measures of speech intelligibility in children, (b) to assess the development of speech intelligibility in children with normal hearing between the ages of 2 and 6 years, and (c) to compare the development of speech intelligibility in children with normal hearing and children with cochlear implants. The Beginners' Intelligibility Test, a sentence-repetition task, was administered to 50 children with normal hearing and 34 age-matched children who used cochlear implants. Responses were audiotape-recorded and presented to naïve adult listeners for transcription. Percent correct scores were compared for the effects of chronological age and hearing status. Consistent with previous studies of intelligibility, children with normal hearing achieved adult-like or near-adult-like speech intelligibility by around 4 years of age or shortly thereafter. Children with cochlear implants were considerably less intelligible than their chronological-age peers with normal hearing at all ages, although the intelligibility of children with cochlear implants did increase with chronological age through the latest age examined. Results from this study have important implications for the socialization and education of children with cochlear implants, particularly with respect to on-time placement in mainstream educational environments with same-age peers.

Introduction

Since the early 1990s, cochlear implantation has become a widely used treatment in cases of profound deafness in the pediatric population. Numerous studies have attested to the beneficial effects of cochlear implantation on the communicative abilities of children who use them. Insofar as spoken communication involves the transfer of information and knowledge, of paramount importance in assessing the effects of cochlear implantation is the connected speech intelligibility of the user of a cochlear implant, intelligibility referring here to "the degree to which the speaker's intended message is recovered by the listener" (Kent, Weismer, Kent, & Rosenbeck, 1989, p. 483) or "the comprehensibility of the specifically linguistic information encoded by a speaker's utterances" (Samar & Metz, 1991, p. 699).

A number of studies of the connected speech intelligibility of children who use cochlear implants dating from the early 1990s to approximately 1998 have been reviewed by Svirsky and Chin (2000), and the main results from previous research are (a) children's speech intelligibility improves from before implantation to after implantation and then further improves with increased use of a cochlear implant (e.g., Dawson et al., 1995; Mondain et al., 1997; Tobey, Angelette et al., 1991; Tobey & Hasenstab, 1991), and (b) cochlear implants support the development of speech production intelligibility at least as well as conventional hearing aids (depending on such factors as length of device use, age at device fitting, and amount of residual hearing; e.g., Miyamoto, Kirk, Robbins, Todd, & Riley, 1996; Miyamoto, Kirk et al., 1997; Miyamoto, Svirsky et al., 1997; Osberger, Maso, & Sam, 1993; Osberger, Robbins, Todd, Riley, & Miyamoto, 1994; Svirsky, 2000; Svirsky, Sloan, Caldwell, & Miyamoto, 2000). Other studies have examined the effect of communication mode on connected speech intelligibility (e.g., Tobey et al., 2000; Vieu et al., 1998) and the relationships between connected speech intelligibility and other communicative abilities (e.g., Chin, Finnegan, & Chung, 2001; O'Donoghue, Nikolopoulos, Archbold, & Tait, 1999). With the notable exception of several studies from University Hospital at the Queen's

Medical Center in Nottingham, United Kingdom (e.g., Allen, Nikolopoulos, Dyar, & O'Donoghue, 2001; Allen, Nikolopoulos, & O'Donoghue, 1998; O'Donoghue et al., 1999), which used rating scales, most studies of the intelligibility of children who use cochlear implants have used write-down (transcription) procedures. Speech materials used for the assessment of the connected speech intelligibility of children with cochlear implants have included sentences developed by McGarr (1983; e.g., Tobey et al., 1991); by Monsen (1983; e.g., Osberger et al., 1993); and by Osberger, Robbins, Todd, and Riley (1994). Materials from McGarr (1983) and Monsen (1983) were developed for assessing the intelligibility of children with hearing impairments and from Osberger et al. (1994) specifically for children who use cochlear implants (see also Svirsky & Chin, 2000; Svirsky, Chin, & Miyamoto, in press).

Previous research indicates that cochlear implantation for children supports the development of connected speech intelligibility at least as well as the use of conventional hearing aids. However, a variety of factors, including improved hardware and software, younger ages at implantation, and improvements in habilitation, have raised expectations to the point that language acquisition and development on a par with that of children with normal hearing is no longer considered unrealistic. With respect to connected speech intelligibility, however, it is not yet known how children who use implants compare to children who have normal hearing.

In comparing the connected speech intelligibility of children who use cochlear implants to that of children with normal hearing, one factor to consider is that although there is an obvious difference between children who use cochlear implants and children with normal hearing (the presence vs. absence of deafness), children with normal hearing do not in fact form a homogeneous population with respect to the production of speech and language. For the most part, research on connected speech intelligibility in children has been clinical, rather than theoretical. In addition to the extensive literature on the speech intelligibility of children with hearing impairments, the bulk of research on the speech intelligibility among children with normal hearing has been devoted to those children with such conditions as Down's syndrome (e.g., Chapman, Seung, Schwartz, & Kay-Raining Bird, 1998; Kumin, 1994), cerebral palsy (e.g., Clarke & Hoops, 1980), CNS lesions (e.g., Jerger, 1987), cleft palate (e.g., Keuning, Wineke, & Dejonckere, 1999), and autism (e.g., Koegel, Camarata, Koegel, Ben-Tall, & Smith, 1998). However, for children developing language in the absence of frank organically-based difficulties (including deafness), as recently as 2000, Gordon-Brannan & Hodson (2000) observed that "intelligibility data for young children with typical as well as disordered phonologies are generally lacking even though critical clinical decisions often depend on intelligibility" (p. 142).

The lack of definitive data can be traced in part to a lack of consensus regarding how to measure intelligibility and how to interpret the resulting data. In a review of evaluation procedures for intelligibility, Kent, Miolo, and Bloedel (1994) note that "although many would agree with Subtelney's (1977) comment that 'Intelligibility is considered the most practical single index to apply in assessing competence in oral communication' (p. 183), consensus withers when it comes to deciding how intelligibility should be measured and assessed" (p. 81). Additionally, most researchers regard connected speech intelligibility not as a monolithic sui generis factor, but rather as a factor dependent on, or at least related to, a variety of linguistic and extralinguistic characteristics. Weston and Shriberg (1992), for example, examined the influence of contextual and linguistic factors on intelligibility, finding that intelligibility outcomes were associated with utterance length, word position, the intelligibility of adjacent words, phonological complexity, grammatical form, and syllabic structure. Kent et al. (1994) further suggested that a number of factors affect speech intelligibility. Besides the basic competence of the speaker, these include the nature of the spoken material, the context of communication, the listener's familiarity with the speaker, contextual support for the message to be transmitted, clarity of the visual and acoustic signals of speech, and other environmental and linguistic factors.

In spite of the difficulties inherent in assessing connected speech intelligibility in young children and in interpreting results, a handful of studies have addressed the identification of benchmarks in the development of intelligibility in children. Weiss (1982), cited by Gordon-Brannan (1994), reported expectations for ranges of intelligibility for young children: 26% to 50% intelligible by age 2, 51% to 70% intelligible by age 2;6, 71% to 80% intelligible by age 3;0, 81% to 90% intelligible by age 3;6, and 100% intelligible by age 4;0. Gordon-Brannan (1994) points out, however, that the procedures for obtaining these data were not made clear.

In a study of 235 children, Coplan and Gleason (1988) asked parents to respond to the question "How clear is your child's speech? That is, how much of your child's speech can a stranger understand: (1) less than half, (2) about half, (3) three quarters, or (4) all or almost all?" Smoothed curves for age of emergence of 50%, 75%, and 100% intelligibility were derived, and cutoff ages were determined at which 90% of respondents ascribed each level of intelligibility to their child. The cutoff age for 50% intelligibility was 22 months, for 75% intelligibility 37 months, and for 100% intelligibility 47 months. As a comparison, Coplan and Gleason further cited anecdotal evidence from Weiss and Lillywhite (1976): 50% by age 2, 75% by age 3, and 100% by age 4.

Gordon-Brannan and Hodson (2000) examined intelligibility in 48 prekindergarten children with normal hearing ranging in age from 4;0 to 5;6 (mean = 4;7), dividing them into four groups based on the percentage of words transcribed correctly from a connected speech sample by unfamiliar listeners. Intelligibility scores for a "severe" group (the group with the lowest intelligibility scores) ranged from 16% to 63%. For the other three groups (moderate, mild, and adult-like), scores ranged from 68% to 100%, with a mean of 85%. Gordon-Brannan and Hodson suggested that for a child of 4 years or older, a score of less than 66% (2 standard deviations below the mean) might be a potential indicator of speech difficulty.

Despite variations in methodology, these studies appear to concur that children with normal hearing become fully intelligible by approximately age 4. The present study addresses two questions. First, does use of the Beginners' Intelligibility Test (BIT; Osberger et al., 1994), developed for assessing connected speech intelligibility in children with cochlear implants, replicate the results obtained with other measures with respect to full intelligibility in children with normal hearing by approximately age 4 years? That is, can convergent validity be established for the BIT with respect to other tests of intelligibility? Second, using the BIT, how intelligible are children who use cochlear implants in comparison to children of the same age with normal hearing?

The latter research question ignores for the time being the fact that children who use cochlear implants may have identical chronological ages but different lengths of experience with the implant. Previous research has determined that communication abilities increase with increased length of use of a cochlear implant, but children may be fitted with a cochlear implant at different chronological ages. Comparisons of children with like chronological ages may thus be confounded by the differences in length of experience with a cochlear implant. However, with increasingly higher expectations of benefits from cochlear implantation and increasing pressure toward educational mainstreaming and placement with same-age peers, it is important to know whether the communicative abilities of a child with a cochlear implant are age appropriate, that is, to know whether a child with a cochlear implant who looks and walks like an x-year-old also talks like an x-year-old.

To address this question, we administered the Beginners' Intelligibility Test (BIT; Osberger et al., 1994) to a group of children with normal hearing between the ages of 2 and 11 to determine approximate age-level performance on this assessment of connected speech intelligibility. These scores were then compared to archival data from the same task administered to an age-matched group of young children with profound deafness and cochlear implants. This comparison provides a context for the assessment of speech intelligibility in children who use cochlear implants that is different from contexts previously reported and has implications for expectations regarding outcomes of pediatric cochlear implantation, for educational placement and services, and for remediation.

Method

Participants

Participants were children with normal hearing, children with profound deafness and cochlear implants, and adults with normal hearing acting as listener judges of intelligibility.

Children with Normal Hearing

Connected speech intelligibility data were collected from a group of children who attended the Center for Young Children, a day-care facility on the campus of Indiana University–Purdue University Indianapolis. Children were recruited by letters to parents or guardians requesting their children's participation as members of a comparison group in a study examining the "development of speech" of children with hearing impairments. Speech data were collected from all children whose parents accepted the invitation to participate. However, based on responses on a demographic questionnaire, only data from children who met the following inclusionary criteria were analyzed: (a) no known speech or hearing problems, and (b) English as a native language. Data from children who lived in a home where a second language also was spoken were not excluded from analysis.

Using the foregoing inclusion criteria, data from 50 children were analyzed for Study 1 and from 34 children (a subset of the 50) for Study 2. For the group of 50 children in Study 1, age at time of testing ranged from 2;6 to 11;1 (*M* = 4;10, *SD* = 1;7; median = 4;7). For the group of 34 children for Study 2, age at time of testing ranged from 3;1 to 6;9 (*M* = 4;8, *SD* = 0;11; median = 4;7).

Children with Cochlear Implants

Connected speech intelligibility data from pediatric cochlear implant users were extracted from the database maintained in the DeVault Otologic Research Laboratory of the Department of Otolaryngology–Head and Neck Surgery at the Indiana University School of Medicine. These data had been collected prior to inception of the comparison study with normal-hearing children as part of a larger NIH-supported research project examining the speech and language development of children with cochlear implants.

Demographic information for each of the 34 children who used cochlear implants is included in the appendix. Children's age at onset of deafness ranged from 0;0 to 2;1 (*M* = 0;1, *SD* = 0;5), and their age at the time of receiving a cochlear implant ranged from 1;4 to 5;3 (*M* = 3;1, *SD* = 1;0). Unaided pure-tone average thresholds in the better ear before implantation ranged from 90 to 120.07 dB HL (*M* = 110.53, *SD* = 7.33; median = 111.69). Age at time of testing ranged from 3;1 to 6;9 (*M* = 4;8, *SD* = 0;11; median = 4;7), and length of cochlear implant use ranged from 0.50 years to 3.90 years (*M* = 1.63 years, *SD* = 0.88 years; median = 1.5 years).

All of the children used currently provided processing strategies. Three of the children used the advanced combination encoding (ACE) speech coding strategy with a Nucleus CI24M cochlear implant, four used the continuous interleaved sampling (CIS) strategy with a Clarion implant, and 27 used the spectral peak (SPEAK) strategy (25 with a Nucleus-22 device and 2 with a Nucleus CI24M); see Wilson

(2000) for a review of cochlear implant speech processing strategies. Nineteen of the children used oral-only communication, and 15 used total communication (a combination of spoken and signed language).

Listener Judges

Listener judges of the connected speech intelligibility of the children with cochlear implants and the children with normal hearing were adults between the ages of 18 and 40 who reported normal speech and hearing, as well as English as their native language. Potential judges of the speech of children with cochlear implants were excluded if they had more than minimal experience with speech produced by persons with hearing impairment. Listeners were recruited by means of two mail lists on the campus of Indiana University–Purdue University Indianapolis, one distributed to all students, faculty, and staff, and the other distributed specifically to medical students. Listeners were paid for their participation.

Materials

Connected speech intelligibility data were collected from all children participating in this study using the Beginners' Intelligibility Test (BIT; Osberger et al., 1994; see also Miyamoto, Kirk et al., 1997; Miyamoto, Svirsky et al., 1997). The BIT uses small objects and pictures to convey the context of the target sentence, and the child is instructed to produce an imitative response to the examiner's spoken model. Sentences in the test contain words that would be familiar to young children, simple syntactic structure is used in all sentences, and none of the words used in the sentences is more than two syllables long. Sentences range in length from 2 to 6 words (M = 3.8 words) and from 3 to 7 syllables (M = 4.5 syllables). Each of the four lists of 10 sentences contains between 37 and 40 total words (M = 38.3 words).

Procedures

Elicitation and Recording

Each child was administered one 10-sentence list from the BIT. Administration for children with cochlear implants was conducted in small testing rooms in the DeVault Otologic Laboratory at the Indiana University Medical Center in Indianapolis. Administration for children with normal hearing was conducted in small meeting rooms or empty classrooms at the Center for Young Children on the campus of Indiana University–Purdue University Indianapolis. All sessions with children were audio-recorded onto high-quality cassette tapes using lavalière microphones and a Marantz PMD430 recorder.

Listener-tape Preparation

Sentence productions from children who used cochlear implants were digitized using CSpeechSP (Milenkovic & Read, 1997) with a 22-kHz sampling rate, 16 bits per sample. The digitized sentences were then edited to remove extraneous material (e.g., examiners' models). Sentence productions from children with normal hearing were similarly digitized and edited using CoolEdit 2000 software. In addition, a small amount of background noise on a few tapes resulting from nonoptimal siting of testing rooms was digitally filtered and removed. For each child, a batch file was created consisting of two repetitions of each of the 10 sentences, along with stimulus cues ("Number X: ready" and "Number X again: ready"). ISIs were 2 seconds between repetitions of the same sentence and 4 seconds between different sentences.

Listener tapes were produced by recording the output of the digital batch files to high-quality cassette audiotapes using a Nakamichi BX-3000 discrete-head cassette deck. One tape was created for each panel of listeners, so each tape contained up to four BIT lists and no more than one recitation of each of the four BIT lists.

Listener Judgments

The speech intelligibility of each child was judged by three adult listeners with normal hearing. Stimuli were presented in a sound field at 65 to 70 dB HL to the listeners, who were seated in a sound-attenuated booth. Listeners were supplied with paper and pencil and instructed to write down everything that they heard the children say. Each panel of listeners heard either only children with cochlear implants or only children with normal hearing. Scores for individual children were calculated as the mean number of whole words understood correctly across the three listeners and converted to percent words correct.

Analysis

For Study 1, data from the group of 50 children with normal hearing were analyzed to determine the correlation between age at testing and BIT score. Additionally, differences in BIT scores between nominal age groups (e.g., age group 2 included children between 2;0 and 2;11) were analyzed by ANOVA. Study 2 was a comparison of children with normal hearing and an age-matched group of children who used cochlear implants. For each child with normal hearing, data from a child of the same chronological age were selected from the archival database of children who used cochlear implants. Selection was blind with respect to the recorded BIT score, and no child using a cochlear implant contributed more than one data point. Matching was possible in only 34 cases, so that Study 2 analyzed data from 34 children with normal hearing and 34 children with cochlear implants. The analyses in Study 2 were similar to those in Study 1, that is, correlational analyses of age and BIT score and comparison of mean BIT scores for different age groups using ANOVA. Additionally, mean BIT scores across like age groups for the two groups of children were compared.

Results

Study 1: Children with Normal Hearing

Scores on the BIT ranged from 13.5% to 100% correct (M = 87.2%, SD = 19%), with a median score of 94.7% correct. The scatterplot and regression line in Figure 1 show the distribution of BIT scores by ages of the children. For the children with normal hearing included in Figure 1, there was a moderate significant correlation between age at time of testing and BIT score ($r = .504$, $p < .00001$).

Descriptive statistics for BIT scores of nominal age groups (e.g., 2 = 2;0 to 2;11) of the 50 children with normal hearing are shown in Table 1. The data in Table 1 indicate that both mean and median scores on the BIT tended to increase as the age group increased. This was true for age groups 2 through 6, although the mean and median scores showed a slight decline from age group 6 to age group 7+.

Figure 1. Scatterplot and regression line for ages in years (x-axis) and BIT percent correct scores for 50 children with normal hearing

Age Group (Median age)	N	BIT Score (percent correct)				
		Min	Max	Mean	SD	Median
2 (2;7)	3	13.5	79.8	53.9	35.5	68.4
3 (3;7)	13	34.2	100	71.8	21.9	72.8
4 (4;4)	13	86.8	100	95.2	3.75	96.5
5 (5;7)	14	89.2	100	96.2	3.15	97.0
6 (6;1)	4	97.4	100	99.1	1.24	99.6
7+ (10;2)	3	92.5	100	95.7	3.87	94.6

Table 1. Descriptive statistics for BIT scores of 50 children with normal hearing

To test for significant differences in BIT score means of the different age groups, a one-way analysis of variance with age group as the between-groups factor was conducted. The ANOVA revealed a significant effect of age, $F(5, 44) = 9.39$, $p < .001$. Post hoc multiple comparisons (Student-Newman-Keuls method) to determine which pairs of age groups were significantly different indicated that the mean score for age group 2 differed significantly from the means for age group 4 ($q = 6.514$, $p < .001$), age group 5 ($q = 6.726$, $p < .001$), age group 6 ($q = 5.987$, $p < .01$), and age group 7 ($q = 5.176$, $p < .01$). Similarly, the mean score for age group 3 differed significantly from the means for age group 4 ($q = 6.038$, $p < .001$), age group 5 ($q = 6.524$, $p < .001$), age group 6 ($q = 4.843$, $p < .05$), and age group 7 ($q = 3.782$, $p < .05$). Conversely, there was no significant difference between means for age groups 2 and 3, nor were there significant differences between pairs of means for age groups 4, 5, 6, and 7. These results thus indicated a threshold of speech intelligibility for children with normal hearing occurring between ages 3 and 4 years.

Study 2: Comparison of Children with Normal Hearing and Children with Cochlear Implants

Children with Normal Hearing

The group of 34 children with normal hearing was a subset of the larger group of 50. Comparison by *t* tests indicated no significant differences between the mean age of each age group in the 34 children and the corresponding age group in the larger group of 50. For the 34 children with normal hearing, scores on the BIT ranged from 43.3% to 100% correct (*M* = 90.1%, *SD* = 15.0%), with a median score of 96.4%. Descriptive statistics for the BIT scores of nominal age groups (e.g., 2 = 2;0 to 2;11) of the 34 children with normal hearing are shown in Table 2.

Age Group (Median age)	N	BIT Score (percent correct)				
		Min	Max	Mean	SD	Median
3 (3;8)	9	43.3	100	73.9	22.0	72.8
4 (4;4)	11	86.8	100	95.0	4.1	96.5
5 (5;7)	11	89.2	100	96.1	3.51	97.3
6 (6;2)	3	97.4	100	98.8	.3	99.1

Table 2. Descriptive statistics for BIT scores of 34 children with normal hearing

The data in Table 2 indicate that both mean and median scores on the BIT tended to increase as the age group increased. This is further illustrated by the scatterplot and regression line in Figure 2. For the children with normal hearing included in Figure 2, there was a modest but significant correlation between age at time of testing and BIT score ($r = .586$, $p < .001$).

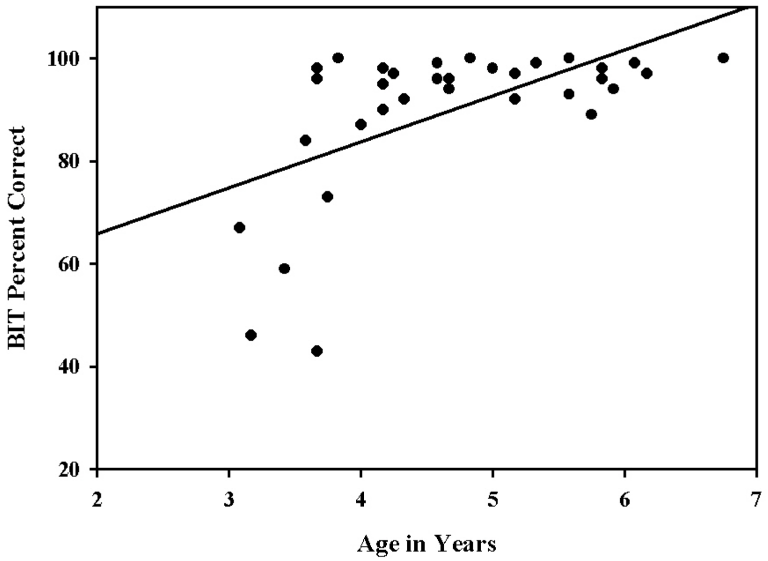

Figure 2. Scatterplot and regression line for ages in years (x-axis) and BIT percent correct scores for 34 children with normal hearing

To test for significant differences in BIT score means of the different age groups, a one-way analysis of variance with age group as the between-groups factor was conducted. As with the larger group of 50, there was a significant effect of age group on BIT scores for the smaller group of 34 children with normal hearing, $F(3, 30) = 7.83$, $p < .001$. Post hoc multiple comparisons (Student-Newman-Keuls method) indicated that the mean BIT score for age group 3 differed significantly from those of age group 4 ($q = 5.463$, $p < .001$), age group 5 ($q = 5.938$, $p < .001$), and age group 6 ($q = 4.492$, $p < .05$). On the other hand, there were no significant pairwise differences in BIT scores for age groups 4, 5, and 6.

Children with Cochlear Implants

Mean length of cochlear implant use for the nominal age groups (e.g., age group 3 = 3;0 to 3;11) were as follows: age group 3: 1.24 years (*SD* = 0.58); age group 4: 1.40 years (*SD* = 0.45 years); age group 5: 2.03 years (*SD* = 1.07 years); age group 6: 2.13 years (*SD* = 1.58).

For all 34 users of cochlear implants, scores on the BIT ranged from 0% to 85% correct (*M* = 15.3%, *SD* = 23.1%), with a median score of 7% correct. The scatterplot and regression line in Figure 3 show the distribution of BIT scores by ages of the children. For the children with cochlear implants included in Figure 3, there was no significant correlation between age at time of testing and BIT score ($r = .235$, $p = .182$ [n.s.]).

Descriptive statistics for the BIT scores of nominal age groups of the 34 children who used cochlear implants are shown in Table 3. Table 3 shows that mean BIT scores increased as age group increased from 3 through 6. Median scores, however, did not exhibit a similar monotonic increase. To test for significant differences in BIT score means of the different age groups, a one-way analysis of variance with age group as the between- groups factor was conducted. The ANOVA showed that for the group of 34 children with cochlear implants, age group was not a significant factor in differences between BIT scores.

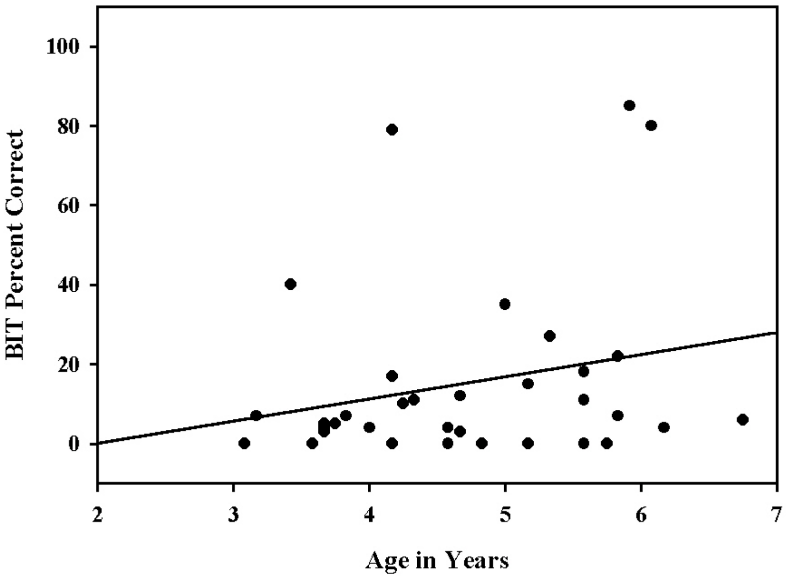

Figure 3. Scatterplot and regression line for ages in years (x-axis) and BIT percent correct scores for 34 children with cochlear implants

Age Group (Median age)	N	BIT Score (percent correct)				
		Min	Max	Mean	SD	Median
3 (3;8)	9	0.0	40.0	7.9	12.3	5.0
4 (4;4)	11	0.0	79.0	12.7	22.3	4.0
5 (5;7)	11	0.0	85.0	20.0	24.5	15.0
6 (6;2)	3	4.0	80.0	30.0	43.3	6.0

Table 3. Descriptive statistics for BIT scores of 34 children with cochlear implants

Comparison: Children with Normal Hearing and Children with Cochlear Implants

Table 4 shows mean BIT scores and standard deviations for the four age groups (3 to 6) for both children with normal hearing (left) and children with cochlear implants (right).

Age Group	Children with Normal Hearing		Children with Cochlear Implants	
	Mean	**SD**	**Mean**	**SD**
3	73.9	22.0	7.9	12.3
4	95.0	4.1	12.7	22.3
5	96.1	3.5	20.0	24.5
6	98.8	0.3	30.0	43.3
All	90.1	15.0	15.3	23.1

Table 4. Percent correct BIT scores for 34 children with normal hearing and 34 children with cochlear implants

To examine the effects of hearing status and age group on BIT scores, a 2 x 4 factoral ANOVA was conducted with hearing status (normal-hearing vs. cochlear implant) and age group (3 vs. 4 vs. 5 vs. 6) as between-groups factors. Results indicated main effects of both hearing status, $F(1, 60) = 203.53$, $p < .001$, and age group, $F(3, 60) = 3.94$, $p < .05$, but no interaction effect of hearing status and age group.

The plot in Figure 4 shows mean BIT scores by age group for both children with normal hearing (filled circles) and children with cochlear implants (open circles); the lines in this figure are included as a visual aid and not to imply linear increases in scores from circle to circle. As this figure shows, scores for children with normal hearing were consistently higher than scores for children with cochlear implants across all four age groups examined. The difference between percent correct scores for age group 3 was 66.0%; this increased at age group 4 (82.3%) but then decreased through age group 5 (76.1%) and age group 6 (68.8%).

Discussion

Consistent with previous studies (e.g., Coplan & Gleason, 1988; Gordon-Brannan & Hodson, 2000; Weiss, 1982; Weiss & Lillywhite, 1976), the children with normal hearing in Study 1 reached ceiling or near-ceiling around the age of 4 years. BIT scores for children 4;0 and older ranged from 86.8% to 100%, with a mean score of 96.1% (*SD* = .03%) and a median score of 97.0%. By contrast, scores for children with normal hearing below the age of 4;0 were considerably lower and more variable, ranging from 13.5% to 100%, with a mean score of 68.4% (*SD* = 24.6%) and a median score of 70.6%. Further evidence for an intelligibility threshold at age 4 is that there were significant differences in mean scores between ages 3 and 4 (and between ages 2 and 4) but no differences between age 4 and ages 5, 6, and 7+. In spite of the lack of significant differences in mean scores above age 4, there is nevertheless a significant correlation between age and BIT score across the range of ages tested. These generalizations also hold for the smaller group of 34 children with normal hearing analyzed in Study 2. With the group of 34 children who use cochlear implants from Study 2, the results indicate a somewhat different picture. There was no significant correlation between age and BIT score, and there were no significant differences in mean scores between any of the nominal age groups. Consequently, there was no obvious threshold of connected speech intelligibility among the children who used cochlear implants of the kind found for children with normal hearing.

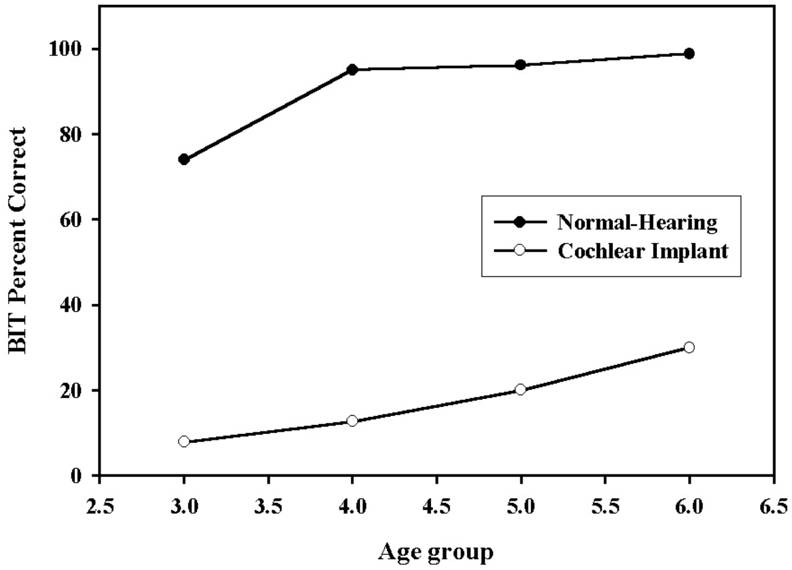

Figure 4. Mean percent correct BIT scores for age groups 3, 4, 5, and 6 for children with normal hearing and children with cochlear implants

The major difference between the children who use cochlear implants and the children with normal hearing, however, is that BIT scores for children with cochlear implants were significantly lower than for children with normal hearing. The 34 children with normal hearing had a mean BIT score of 90.1% (*SD* = 15.0%, median = 96.4%), whereas the age-matched group of 34 children with cochlear implants had a mean BIT score of 15.3% (*SD* = 23.1%, median = .07%). For the four nominal age groups, the difference in mean percent correct scores on the BIT ranged between 66.0% and 82.3%. The difference between the children with normal hearing and those with cochlear implants was lowest for age group 3 and highest for age group 4, indicating a large increase in scores for the children with normal hearing between ages 3 and 4 that was not present for the children with cochlear implants. From the large difference at age 4, the difference in scores then decreased through ages 5 and 6. This was due almost solely to increases in mean scores for the children with cochlear implants, the children with normal hearing having already achieved ceiling or near-ceiling scores.

The present study compares the connected speech intelligibility of children with normal hearing and children with cochlear implants solely on the basis of their chronological age. As the demographic data in the appendix show, the children who use cochlear implants examined here do not form a homogeneous group with regard to such characteristics as age at implantation, length of cochlear implant use, processing strategy, or communication mode. However, we believe that this very diversity serves the primary purpose of this study, namely to determine how different the speech intelligibility of children who use cochlear implants is from that of children with normal hearing of the same chronological age. As children with cochlear implants enter society and its institutions, a major factor affecting how well they will integrate is whether or not their speech intelligibility is consistent with other people's expectations based on experience with children of similar age with normal hearing. Using a different type of task, Monsen (1981) asserted that with intelligibility below 59%, "listeners are confronted with overwhelming difficulty in understanding what was said" (p. 850). In the present study, all but three children with cochlear implants had BIT scores below 59%, even up to the age of 6;9 (see Figure 3).

The results obtained in the present study, which specifically addresses the *age-appropriateness* of intelligibility before age 7, should not be construed to mean that children with cochlear implants cannot become intelligible. Figure 3 shows that some children with cochlear implants have relatively high speech intelligibility before age 7: 79% for SMY at age 4;2, 85% for SMC at age 5;11, and 80% for SKT at age 6;1. Furthermore, both SMC and SKT had durations of implant use that were considerably above the mean for this group (3.0 years and 3.9 years, respectively, vs. a mean of 1.63 years), and for this group of children, BIT scores were correlated significantly with length of device use ($r = .64$, $p < .0001$). Thus, although the majority of the children with cochlear implants in the present study had speech intelligibility scores well below the scores of same-aged children with normal hearing, there was still a tendency for scores to increase with age and a signficant correlation between scores and duration of use. Finally, the youngest age at implantation in this group was 1;4, but recent increases in the number of children given implants before age 1;0 will almost certainly result in higher speech intelligibility scores at ages 2 through 6 than those reported here.

Conclusions

This study allows us to draw a number of conclusions regarding the speech intelligibility of both children with normal hearing and children with cochlear implants. First, on the Beginners' Intelligibility Test, children with normal hearing younger than age 4 years are quite variable in their speech intelligibility, but at age 4 or shortly thereafter, they achieve adult-like or near-adult-like intelligibility. This is consistent with the few previous studies that have contributed normative data on the development of intelligibility. Second, children with cochlear implants between ages 3 and 6 years are *on average* considerably less intelligent than their chronological-age peers with normal hearing. Third, however, at least up to age 6, the speech intelligibility of children with cochlear implants does increase with age and increased duration of device use. It will be the task of future research to determine if and when children with cochlear implants are able to achieve the same level of connected speech intelligibility that children with normal hearing achieve around the age of 4 years.

References

Allen, C., Nikolopoulos, T.P., Dyar, D., & O'Donoghue, G.M. (2001). Reliability of a rating scale for measuring speech intelligibility after pediatric cochlear implantation. *Otology & Neurology, 22,* 631-633.

Allen, M.C., Nikolopoulos, T.P., & O'Donoghue, G.M. (1998). Speech intelligibility in children after cochlear implantation. *American Journal of Otology, 19,* 742-746.

Chapman, R.S., Seung, H.K., Schwartz, S.E., & Kay-Raining Bird, E. (1998). Language skills of children and adolescents with Down syndrome: II. Production deficits. *Journal of Speech, Language, and Hearing Research, 41,* 861-873.

Chin, S.B., Finnegan, K.R., & Chung, B.A. (2001). Relationships among types of speech intelligibility in pediatric users of cochlear implants. *Journal of Communication Disorders, 34,* 187-205.

Clarke, W.M., & Hoops, H.R. (1980). Predictive measures of speech proficiency in cerebral palsied speakers. *Journal of Communication Disorders, 13,* 385-394.

Coplan, J., & Gleason, J.R. (1988). Unclear speech: Recognition and significance of unintelligible speech in preschool children. *Pediatrics, 82,* 447-452.

Dawson, P.W., Blamey, P.J., Dettman, S.J., Rowland, L.C., Barker, E.J., Tobey, E.A., Busby, P.A., Cowan, R.C., & Clark, G.M. (1995). A clinical report on speech production of cochlear implant users. *Ear and Hearing, 16,* 551-561.

Gordon-Brannan, M. (1994). Assessing intelligibility: Children's expressive phonologies. *Topics in Language Disorders, 14*(2), 17-25.

Gordon-Brannan M., & Hodson, B.W. (2000). Intelligibility/severity measurements of prekindergarten children's speech. *American Journal of Speech-Language Pathology, 9,* 141-150.

Jerger, S. (1987). Validation of the pediatric speech intelligibility test in children with central nervous system lesions. *Audiology, 26,* 298-311.

Kent, R.D., Miolo, G., & Bloedel, S. (1994). The intelligibility of children's speech: A review of evaluation procedures. *American Journal of Speech-Language Pathology, 3,* 81-95.

Kent, R.D., Weismer, G., Kent, J.F., & Rosenbek, J.C. (1989). Toward phonetic intelligibility testing of dysarthria. *Journal of Speech and Hearing Disorders, 54,* 482-499.

Keuning, K.H., Wieneke, G.H., & Dejonckere, P.H. (1999). The intrajudge reliability of the perceptual rating of cleft palate speech before and after pharyngeal flap surgery: The effect of judges and speech samples. *Cleft Palate-Craniofacial Journal, 36,* 328-333.

Koegel, R.L., Camarata, S., Koegel, L.K., Ben-Tall, A., & Smith, A.E. (1998). Increasing speech intelligibility in children with autism. *Journal of Autism & Developmental Disorders, 28,* 241-251.

Kumin, L. (1994). Intelligibility of speech in children with Down syndrome in natural settings: Parents' perspective. *Perceptual & Motor Skills, 78,* 307-313.

McGarr, N.S. (1983). The intelligibility of deaf speech to experienced and inexperienced listeners. *Journal of Speech and Hearing Research, 26,* 451-458.

Milenkovic, P.H., & Read, C. (1997). *CSpeechSP user's manual*. Madison, WI: Author.

Miyamoto, R.T., Kirk, K.I., Robbins, A.M., Todd, S., & Riley, A. (1996). Speech perception and speech production skills of children with multichannel cochlear implants. *Acta Otolaryngologica (Stockholm), 116,* 240-243.

Miyamoto, R.T., Kirk, K.I., Robbins, A.M., Todd, S., Riley, A., & Pisoni, D.B. (1997). Speech perception and speech intelligibility in children with multichannel cochlear implants. *Advances in Otorhinolaryngology, 52,* 198-203.

Miyamoto, R.T., Svirsky, M.A., Kirk, K.I., Robbins, A.M., Todd, S., & Riley, A.I. (1997). Speech intelligibility of children with multichannel cochlear implants. *Annals of Otology, Rhinology, & Laryngology, 106,* 35-36.

Mondain M., Sillon, M., Vieu, A., Lanvin, M., Reuillard-Artieres, F., Tobey, E., & Uziel, A. (1997). Speech perception skills and speech production intelligibility in French children with prelingual deafness and cochlear implants. *Archives of Otolaryngology–Head and Neck Surgery, 123,* 181-184.

Monsen, R.B. (1981). A usable test for the speech intelligibility of deaf talkers. *American Annals of the Deaf, 126,* 845-852.

Monsen, R.B. (1983). The oral speech intelligibility of hearing-impaired talkers. *Journal of Speech and Hearing Disorders, 48,* 286-296.

O'Donoghue, G.M., Nikolopoulos, T.P., Archbold, S.M., & Tait, M. (1999). Cochlear implants in young children: The relationship between speech perception and speech intelligibility. *Ear and Hearing, 20,* 419-425.

Osberger, M.J., Maso, M., & Sam, L.K. (1993). Speech intelligibility of children with cochlear implants, tactile aids, or hearing aids. *Journal of Speech and Hearing Research, 36,* 186-203.

Osberger, M.J., Robbins, A.M., Todd, S.L., & Riley, A.I. (1994). Speech intelligibility of children with cochlear implants. *Volta Review, 96,* 169-180.

Osberger, M.J., Robbins, A.M., Todd, S.L., Riley, A.I., & Miyamoto, R.T. (1994). Speech production skills of children with multichannel cochlear implants. In I.J. Hochmair-Desoyer & E.S. Hochmair (Eds.), *Advances in cochlear implants* (pp. 503-508). Vienna: Manz.

Samar, V.J., & Metz, D.E. (1991). [Reply:] Scaling and transcription measures of intelligibility for populations with disordered speech: Where's the beef? *Journal of Speech and Hearing Research, 34,* 699-704.

Subtelney, J. (1977). Assessment of speech with implications for training. In F. Bess (Ed.), *Childhood deafness* (pp. 183-194). New York: Grune & Stratton.

Svirsky, M.A. (2000). Speech intelligibility of pediatric cochlear implant users and hearing aid users. In S. B. Waltzman & N. L. Cohen (Eds.), *Cochlear implants* (pp. 312-314). New York: Thieme.

Svirsky M.A., & Chin, S.B. (2000). Speech production. In S.B. Waltzman & N.L. Cohen (Eds.), *Cochlear implants* (pp. 293-309). New York: Thieme.

Svirsky, M.A., Chin, S.B., & Miyamoto, R.T. (in press). Speech intelligibility of profoundly deaf pediatric hearing aid users. *The Volta Review*.

Svirsky, M.A., Sloan, R.B., Caldwell, M., & Miyamoto, R.T. (2000). Speech intelligibility of prelingually deaf children with multichannel cochlear implants. *Annals of Otology, Rhinology & Laryngology, 109*(12, Pt. 2), 123-125.

Tobey, E.A., Angelette, S., Murchison, C., Nicosia, J., Sprague, S., Staller, S.J., Brimacombe, J.A., & Beiter, A.L. (1991). Speech production performance in children with multichannel cochlear implants. *American Journal of Otology, 12(Suppl.),* 165-173.

Tobey, E.A., Geers, A.E., Douek, B.M., Perrin, J., Skellett, R., Brenner, C., & Toretta, G. (2000). Factors associated with speech intelligibility in children with cochlear implants. *Annals of Otology, Rhinology, & Laryngology, 109*(12, Pt. 2), 28-30.

Tobey, E.A., & Hasenstab, S. (1991). Effects of a Nucleus multichannel cochlear implant upon speech production in children. *Ear and Hearing, 12(Suppl.),* 48S-54S.

Vieu, A., Mondain, M., Blanchard, K., Sillon, M., Reuillard-Artieres, F., Tobey, E., Uziel, A., & Piron, J. P. (1998). Influence of communication mode on speech intelligibility and syntactic structure of sentences in profoundly hearing impaired French children implanted between 5 and 9 years of age. *International Journal of Pediatric Otorhinolaryngology, 44,* 15-22.

Weiss, C.E. (1982). *Weiss Intelligibility Test*. Tigard, OR: CC Publications.

Weiss, C.E., & Lillywhite, H.S. (1976). *Communicative disorders*. St. Louis: C. V. Mosby Co.

Weston, A.D., & Shriberg, L.W. (1992). Contextual and linguistic correlates of intelligibility in children with developmental phonological disorders. *Journal of Speech and Hearing Research, 35,* 1316-1332.

Wilson, B.S. (2000). Strategies for representing speech information with cochlear implants. In J. Niparko, K.I. Kirk, N.K. Mellon, A.M. Robbins, D.L. Tucci, & B.S. Wilson (Eds.), *Cochlear implants: Principles and practices* (pp. 129-170). Philadelphia: Lippincott Williams & Wilkins.

Appendix

Demographic information for 34 pediatric users of cochlear implants

Code[a]	PTA[b]	Age at Onset of Deafness	Age at Implantation	Age at Test	Length of CI Use (years)	Strategy[c]	Mode[d]
SIV	111.70	0;0	2;7	3;1	0.5	CIS	TC
SLF	103.37	0;0	2;4	3;2	0.8	SPEAK	OC
SHJ	116.67	0;0	1;4	3;5	2.0	SPEAK	OC
SHV	116.73	0;0	3;0	3;7	0.6	ACE	TC
SKZ	118.40	2;1	2;9	3;8	0.9	SPEAK	OC
SMD	118.37	0;0	2;6	3;8	1.2	SPEAK	TC
SMH	118.43	0;0	2;2	3;8	1.5	SPEAK	OC
SLH	111.70	0;0	2;1	3;9	1.7	CIS	OC
SWJ	105.03	0;0	1;9	3;10	2.0	SPEAK	OC
SLD	103.33	0;0	3;3	4;0	0.7	CIS	OC
SWC	98.33	0;0	2;1	4;2	2.1	SPEAK	OC
SMT	108.33	0;0	3;2	4;2	1.0	SPEAK	TC
SMY	106.67	0;0	2;2	4;2	2.0	SPEAK	OC
SMR	111.70	0;0	2;9	4;3	1.5	SPEAK	OC
SNA	120.07	0;0	2;9	4;4	1.5	SPEAK	TC
SNS	118.43	0;4	3;0	4;7	1.6	ACE	TC
SMK	105.33	0;0	3;7	4;7	1.0	SPEAK	OC
SGD	111.67	0;4	3;9	4;8	0.9	SPEAK	OC
SMI	115.03	0;0	3;1	4;8	1.6	SPEAK	OC
SIO	115.07	0;0	3;3	4;10	1.5	SPEAK	TC
SIU	118.43	1;6	2;0	5;0	3.0	SPEAK	TC
SMO	110.00	0;0	4;8	5;2	0.5	SPEAK	TC
SMJ	110.07	0;0	3;7	5;2	1.6	SPEAK	TC
SMB	103.33	0;0	2;2	5;4	3.1	SPEAK	OC
SIY	118.43	0;0	2;7	5;7	3.0	SPEAK	TC
SND	110.00	0;0	3;6	5;7	2.1	SPEAK	OC
SHL	90.00	0;0	4;8	5;7	0.9	ACE	TC
SIC	118.40	0;0	5;3	5;9	0.5	SPEAK	TC
SLE	103.33	0;0	4;3	5;10	1.5	CIS	OC
SKN	103.33	0;0	2;9	5;10	3.0	SPEAK	OC
SMC	120.00	0;0	2;9	5;11	3.1	SPEAK	TC
SKT	106.67	0;0	2;2	6;1	3.9	SPEAK	OC
SKR	111.70	0;0	5;3	6;2	0.9	SPEAK	OC
SIN	100.00	0;0	5;2	6;9	1.6	SPEAK	TC

[a]Arbitrary triliteral code name (i.e., not participant initials); [b]Pure-tone average threshold in dB HL; [c]Speech processing strategy: SPEAK = spectral peak, CIS = continuous interleaved sampling, ACE = advanced combination encoder (see Wilson, 2000); [d]Communication mode: OC = oral-only communication, TC = total communication (combined spoken and signed communication)