Language Skills of Children with Early Cochlear Implantation

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Objective: **This study investigated factors contributing to the comprehension and production of English language by children with prelingual deafness after 4 to 7 yr of multichannel cochlear implant use. The analysis controlled for the effects of child and family characteristics so that educational factors most conducive to maximum implant benefit could be identified.**

Design: **A battery of language tests were administered to 181 8- and 9-yr-old children from across the United States and Canada who received a cochlear implant by age 5. Tests of comprehension, verbal reasoning, narrative ability and spontaneous language production were administered either in speech and sign or in the child's preferred communication mode. These constituted the Total Language measures. Spoken Language measures were derived from a speech-only language sample. Type and amount of educational intervention since implantation constituted the independent variables. Characteristics of the child and the family were considered intervening variables. A series of multiple regression analyses determined the amount of variance in Total Language and Spoken Language ability accounted for by the intervening variables and the amount of additional variance attributable to the independent variables.**

Results: **More than half of the children (with performance intelligence quotients in the average range) exhibited language skills that were similar to those of hearing 8 to 9 yr olds on measures of verbal reasoning, narrative ability, utterance length, and lexical diversity. Significant predictors of language ability were similar for Total and for Spoken Language outcomes and included greater nonverbal intelligence, smaller family size, higher socio-economic status and female gender. Age at receiving an implant did not affect language outcome. After the variance due to these variables was controlled, the primary rehabilitative factors associated with linguistic outcome were amount of mainstream class placement and an educational emphasis on speech and auditory skills.**

Conclusions: **Use of a cochlear implant has had a dramatic impact on the linguistic competence of profoundly hearing-impaired children. More than half of the children in this sample with average learning ability produced and understood English language at a level comparable with that of their hearing age mates. Such mature language outcomes were not typical of children with profound hearing loss who used hearing aids. Use of a visual (i.e., sign) language system did not provide the linguistic advantage that had been anticipated. Children educated without use of sign exhibited a significant advantage in their use of narratives, the breadth of their vocabulary, in their use of bound morphemes, in the length of their utterances and in the complexity of the syntax used in their spontaneous language. An oral educational focus provided a significant advantage for both spoken and total language skills.**

(Ear & Hearing 2003;24;46S–58S)

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DOI: 10.1097/01.AUD.0000051689.57380.1B

Development of age-appropriate linguistic competence is a goal of most, if not all, educational programs for children who are deaf or hard of hearing, and one of the most desirable potential outcomes of cochlear implantation. In addition to permitting children with hearing loss to function along side their hearing peers at school and eventually in the wider community, the role of language competence in the development of literacy is paramount. Geers and Moog (1989) studied literacy levels in 100 adolescents with profound hearing impairment and concluded that "the primary factors associated with the development of literacy in this orally educated sample are good use of residual hearing, early amplification and educational management, and—above all—oral English language ability, including vocabulary, syntax, and discourse skills." (p. 84). Similar findings with regard to the importance of English language skills to literacy development were reported by Moores and Sweet (1990) for 127 adolescents enrolled in total communication or sign-based educational programs.

The literature on language development in children after cochlear implantation has established that children who use cochlear implants develop language at a faster rate than children with similar degrees of hearing loss who use hearing aids (Svirsky, Robbins, Iler-Kirk, Pisoni, & Miyamoto, 2000). Furthermore, children who obtain greater auditory benefit from their implant achieve more normal language levels than children who have poor speech perception postimplant (Crosson & Geers, 2001). However, the amount of speech perception needed from any sensory aid for normal language development to occur has yet to be determined. The extent to which the language growth achieved resembles normal development and the amount of language delay exhibited by the deaf child after cochlear implantation continue to be examined. The role of communication modality in expediting language development postimplant is also the focus of considerable investigation with conflicting findings that may be at least partially related to the techniques used to measure language.

Cochlear Implants Compared with Hearing Aids

The impact of even a small amount of aided residual hearing on language development was apparent even before the advent of cochlear implants (Boothroyd, Geers, & Moog, 1991; Geers & Moog, 1988, 1992). Therefore, the dramatic increases in auditory speech perception afforded by the cochlear implant (Geers, Brenner, & Davidson, 2003) should make achievement of optimum language skills easier for profoundly hearing-impaired children. Tait and Lutman (1994) compared the preverbal conversational style of early-implanted children after 3 yr of device use with similar children who were proficient hearing aid users (unaided thresholds 87 to 110 dB HL) and those who were poor hearing aid users (113 to 120 dB HL). The implant users and the proficient hearing aid users exhibited a preverbal conversational style that was typically vocal and auditory. In a later study, these preverbal behaviors were found to be associated with the development of linguistic communication proficiency (Tait & Lutman, 1997).

Faster acquisition of language and communication skills has been documented in children using Nucleus 22-channel cochlear implants (early model speech processors) compared with those of matched groups of children who used hearing aids or tactile aids (Geers & Moog, 1994). After 36 mo of cochlear implant use, children implanted between 2 and 12 yr of age achieved significantly higher scores on both vocabulary and syntax measures than aided children with similar unaided hearing thresholds (PTA >100 dB HL). Although the language scores of the children with cochlear implants continued to lag behind those of their hearing age-mates, their language performance closely resembled that of children with hearing thresholds in the 90 to 100 dB HL range.

Blamey and colleagues (2001) compared language growth over time in children with Nucleus 22-channel implants with a more current processing strategy (SPEAK) with hearing aid users with PTA thresholds averaging 78 dB HL (range = 40 to 103 dB HL) and found that both groups, on average, were learning language at about half to two-thirds of the normal. A comparison of vocabulary growth rates from a number of studies of children with profound hearing loss by Dawson, Blamey, Dettman, Barker, and Clark (1995) indicated a faster rate for children using cochlear implants than for comparable groups of children using hearing aids. Tomblin, Spencer, Flock, Tyler, and Gantz (1999) compared performance by profoundly deaf hearing aid users on the IPSyn, a measure of productive syntax, with similar children who had 3 or more yr of experience with a cochlear implant. Chronological age was highly correlated with IPSyn levels for normal-hearing children and deaf children who used hearing aids. On the other hand, for children who used cochlear implants, length of implant experience rather than age was significantly correlated with IPSyn scores. This was interpreted to indicate that the length of linguistic experience afforded by the implant results in growth rates that are sufficiently great to overwhelm the association of language achievement and chronological age.

Robbins, Svirsky, and Kirk (1997) evaluated English-language skills in two groups of profoundly deaf children with the Reynell Developmental Language Scales, Revised. A group of 89 deaf children who had not received cochlear implants provided cross-sectional language data used to estimate the amount of language gains expected on the basis of maturation. A group of 23 subjects with implants demonstrated gains in receptive and expressive language skills after 12 mo of implant use that exceeded by 7 mo the predictions made on the basis of maturation alone. Moreover, the average language-development rate of the subjects with implants in the first year of device use was equivalent to that of children with normal hearing.

Age at Implant Effects

When cochlear implant users receive their implant, they typically already have a language delay with respect to normal-hearing children. On average, the implant keeps this delay from increasing further (Svirsky et al., 2000). This finding suggests that earlier implantation would result in smaller delays in language development. Analysis of language growth conducted by Connor, Hieber, Arts, and Zwolan (2000) indicated that, regardless of program type (oral or total communication), children who received the implant before the age of 5 achieved better outcomes over time, on average, than children who received their implants after the age of 5. Kirk, Miyamoto, Lento, Ying, O'Neill, and Fears (2002) reported longitudinal results on the Reynell Developmental Language Scales for 73 children from both oral and total communication settings who received a cochlear implant before 5 yr of age. The rate of receptive language development was significantly faster in both groups of children who were implanted before 3 yr of age than children implanted at 3 or 4 yr. Robbins, Bollard, and Green (1999) studied language growth from preimplant to 6 mo postimplant in 23 children who were implanted with the Clarion cochlear implant system between 2 and 5 yr of age. Although scores at both test intervals were significantly below those of their hearing age-mates, they progressed at a rate that exceeded that of normal-hearing children of the same language age. This result suggests the possibility of eventually achieving normal levels of linguistic competence.

These findings suggest that children who receive implants before 5 yr of age might be expected to achieve more age-appropriate linguistic competence than had been previously expected from deaf children. Moog and Geers (1999) studied the speech perception, speech production and language quotient scores of 22 children enrolled in intensive auditory-oral education. Children who achieved the best auditory skills were those who were implanted by 4.5 yr of age. Those children who achieved the best auditory skills developed language skills that equaled or exceeded those of their normal-hearing age mates.

Communication Mode Effects

Coerts and Mills (1995) examined spontaneous language samples from six children deafened at 2 or 3 yr of age and implanted between 4 and 6 yr of age. Four of the children were educated in predominately oral environments, and two of them were enrolled in total communication (TC) programs. All six children showed development in the morphology-syntax of their spoken language over an 18 mo period after implantation. The two TC children who became deaf at age 2 outperformed the two oral children with similar age at onset, but did not score better than the oral children deafened at age 3. The authors concluded that children who became deaf early appeared to profit most from a language environment in which signs are used. In fact, in a more in-depth analysis of the language samples of two of these children (Coerts, Baker, van den Broek, & Brokx, 1996) suggested that the knowledge of sign language had a positive influence on the process and rate of development of spoken language.

Connor et al. (2000) collected language scores from 147 children who had been implanted at the University of Michigan Medial Center between 1 and 10 yr of age. They compared postimplant language progress in 66 children who were consistently enrolled in oral communication (OC) programs with 81 children who were consistently enrolled in total communication (TC) settings. The two groups exhibited similar rates of growth in receptive spoken vocabulary, but the extrapolated vocabulary scores of the TC children who were implanted before age 5 were higher than those of the oral children implanted at the same early age. When expressive vocabulary scores (using either speech or sign) were compared for children who received their implant during preschool, the TC group exhibited a significantly greater growth rate over time as well as significantly higher extrapolated scores. It was concluded that the greatest vocabulary progress could be expected from children who were implanted before 5 yr of age and enrolled in TC programs.

Robbins et al. (1999) found no difference in the language performance of children who used oral versus total communication after 6 mo of Clarion cochlear implant use. In the Kirk et al. (2002) longitudinal study of children implanted under the age of 5, orally educated children exhibited significantly faster expressive language acquisition, and there was no difference between children from oral and total communication settings in their rate of acquiring receptive language skills.

Language Assessment

The use of sign in addition to speech in the assessment of language is most often associated with findings of an advantage for children enrolled in TC settings or no difference between OC and TC groups (Connor et al., 2000; Robbins et al., 1999). It is argued that the most appropriate method to assess language skills in children who use TC is with signs in addition to speech and audition, just as the language of children in OC programs is usually assessed with both lipreading and audition. The rationale is that these are the communication modes the children are exposed to in everyday situations and thus best reflect their overall language abilities (Robbins et al., 1999). On the other hand, it could also be argued that the benefit of a cochlear implant is best reflected in the child's ability to communicate using speech with the world at large in which sign language is not generally known. Even when they have the same language skills as their peers who use TC, children who use OC typically have more intelligible speech and higher levels of speech perception and are thus better oral communicators (Svirsky et al., 2000).

Spoken language appears to be an important outcome, even for children enrolled in programs that also include sign. Geers, Spehar, and Sedey (2002) studied language samples elicited from 27 8 and 9 yr olds who had received a Nucleus 22-channel cochlear implant before 5 yr of age and were enrolled in a total communication program for at least the first 3 yr after implantation. Samples were transcribed by mode of production (i.e., speech or sign) and scored for lexical diversity, syntax, utterance length and use of bound morphemes. Results revealed a wide range of mode preference, with some children using primarily speech, some primarily sign and some using both modes to varying extents. Not only did speech-users achieve higher auditory speech perception scores and speech intelligibility ratings, but they also demonstrated better comprehension and use of English syntax when considering both modes combined than children who used little or no speech.

Rationale

The study reported in this article documents the performance of a large sample of children implanted by 5 yr of age on a variety of language measures including comprehension, production, verbal reasoning and spoken language. Comparisons on each measure with hearing age-mates permits examination of the extent of language delay represented in this sample. The analysis sought to determine: 1) the extent to which children implanted at a young age achieved normal language levels after 4 to 6 yr of implant use; 2) the degree to which language development was affected by characteristics of the child, the implant and the family environment; and 3) the effect of educational intervention and classroom communication mode on language performance in spoken versus simultaneous communication.

METHOD

Participants

Characteristics of the 181 children with hearing loss who participated in this study are described in detail elsewhere in this supplement (Geers & Brenner, 2003) All participants were 8 or 9 yr old at the time the language tests were administered. All were deafened under 3 yr of age and were implanted by 5 1/2 yr of age (most under age 5). Although most of the children were reportedly deaf from birth, almost one-fourth of them had some known etiology of deafness after birth. Eighteen percent of the sample was deafened by meningitis and 13% were reported to have become deaf after experiencing a high fever or being administered an ototoxic drug. For the 140 children who were deaf from birth, the mean age at first hearing aid fit was 1 yr 3 mo.

Educational placement variables were quantified at the time of implant and each of 4 yr thereafter. These variables included type of school (public/private), type of classroom (mainstream/special education), amount of therapy, experience of therapist, parent participation in therapy, and classroom communication mode. Assessment of these variables is described in detail by Geers and Brenner (2003). Eighty-three percent of the children with cochlear implants were enrolled in mainstream classes with hearing children for at least part of each school day at the time of data collection. Children were about equally divided between oral ($N = 98$) and TC ($N = 83$) instructional modes at the time of testing. Ratings of classroom communication mode that were provided by the child's parents included three levels of TC programs (1-sign emphasis; 2-equal speech and sign emphasis; and 3-speech emphasis) and three levels of Oral programs (4-cued speech; 5-auditory/oral; and 6-auditory/verbal). Communication mode ratings were averaged for the preimplant and for each of the 4 yr after implantation were used to summarize this variable. A total of 89 children obtained average mode ratings between 1.0 and 3.9, indicating predominant placement in total communication classrooms. The remaining 92 children obtained average mode scores between 4.0 and 6.0, indicating predominant placement in oral classrooms. Although the average mode rating does not necessarily correspond with consistent use of a particular communication mode, it does reflect the overall degree of emphasis on speech and auditory skill development over a period of years.

For standardized measures, normative samples served as comparison groups. Data for nonstandardized measures were collected from two different groups of typically developing hearing children. Twenty-eight normal-hearing children between 8 yr 0 mo and 9 yr 11 mo served as a control group for the Narrative Ability task (Crosson & Geers, 2001). These children were enrolled in a local elementary school and were judged by their teachers to exhibit no speech or language problems and to be progressing well academically. Twenty-four 8 and 9 yr olds were administered the oral language sampling task. These children were recruited from a local private elementary school and also included children of staff members at Central Institute for the Deaf. Hearing

TABLE 1. Language measures.

Domain	Assessment Method		Dependent Variable
Language comprehension	TACL-R		Word classes
			Elaborated sentences
			Bound morphemes
Language production	Speech/sign interview	IPSyn	Noun phrase
			Verb phrase
			Question/negation
			Sentence structure
		Counts	Bound morphemes
			Lexical diversity
			Utterance length
	Narrative task	Story structure cohesion	Narrative ability score
Verbal reasoning	WISC-III Similarities subtest		Standard score
Spoken language production	Speech interview	IPSyn	Noun phrase
			Verb phrase
			Question/negation
			Sentence structure
		Counts	Bound morphemes
			Lexical diversity
			Utterance length

and language abilities were screened and fell within the average range.

Procedure

Each child was evaluated in five separate language assessment sessions: 1) a receptive language test; 2) a verbal reasoning test; 3) a narrative task 4) a speech-only language sample; and 5) a speech and sign language sample. Details of the assessment sessions are summarized in Table 1 and are described below.

Language Comprehension • The Test for Auditory Comprehension of Language-Revised (TACL-R) (Carrow, 1985) was administered to all children using Simultaneous Communication (i.e., speech and signed English) regardless of the child's regular mode of communication. In this way, any advantages that may accrue to children due to the iconicity of some signs would be available to all children tested. Children responded by selecting one of three pictures that best depicted the stimulus items in each of three subtests: Word Classes, Elaborated Sentences, and Bound Morphemes. Standard scores (mean = 50; SD = 10) and age equivalent scores were computed based on normative data for hearing children.

Verbal Reasoning • Each child was administered the Similarities subtest from the Verbal Scale of the Wechsler Intelligence Scale for Children–III (WISC-III) (Wechsler, 1991) to provide an estimate of verbal reasoning ability. The Similarities subtest consists of pairs of words representing common objects or concepts. The subtest was administered in the mode of communication used in each child's current educational setting. The stimulus words were also shown to the child in print. The child was credited with one or two points for correctly describing in speech, sign or both modes, the way(s) in which each pair of words are similar. Standard scores were computed based on the normative sample of age-appropriate hearing children (mean = 10; SD = 3). One child was not administered this subtest due to time limitations in the test setting.

Language Production • Each child was videotaped in two different interviews with an unfamiliar female adult. One interview was conducted in a speech-only mode and the other in total communication. The conversations averaged 24 minutes in length (SD = 2.72 minutes), but ranged from as short as 12 to 15 minutes for seven of the interviews when the child declined to converse any longer, to 30 minutes for three interviews when the child was particularly interactive. During the first half of each sample, the examiner used a set of pictures that contained sentence starters (e.g., It makes me mad when. . .) to initiate conversation. During the second half, sets of open-ended questions were used (e.g., What do you like to do in the summer/winter? What is your favorite movie/TV show?). Two similar sets of pictures and questions were created and the use of each set was counterbalanced across the two types of conversations. The children were randomly assigned to both the order of conversation type (speech-only or speech/sign) and the set of pictures/questions used.

Word-for-word transcriptions of the child's productions were created using the CHAT format as described by the CHILDES project (MacWhinney, 1995). After this step, a second transcriber watched the videotaped conversation and corrected the initial transcript where necessary. Linguistic analyses of the transcribed language samples were conducted using the CLAN programs (MacWhinney, 1995) and Computerized Profiling (Long, Fey, & Channell, 1999). The following variables were quantified using these programs:

1. Lexical Diversity. Lexical diversity was estimated from a count of the total number of different words produced in the session. This total was divided by the number of minutes in the conversation, yielding a "number of different words per minute" score. This measure reflects both the productivity and diversity of the subject's language, because children who produced more words per minute had a greater opportunity to exhibit a diverse vocabulary.
2. Bound Morphemes. Bound morphemes are word parts that modify the meaning of a root word (e.g., the plural marker "s" in the word "books"). In the transcription process, bound morphemes were set apart from the root word to be identified by the CLAN programs. Transcribers were given detailed lists (both English and ASL) of bound morphemes to be identified. If present, bound morphemes were transcribed whether or not they were used appropriately.
3. Utterance Length. Utterance length was defined as the mean number of words per utterance. An utterance was defined by the transcriber, using syntactic cues (i.e., a sentence), prosodic cues (e.g., pauses, falling intonation) and changes in conversational turn.
4. Syntactic Complexity. The Index of Productive Syntax (IPSyn) (Scarborough, 1990) scoring system was used to measure the syntactic complexity of the first 100 utterances in the transcript. To obtain the IPSyn score, first the transcript was submitted to Computerized Profiling (Long et al., 1999) to select candidate utterances for specific grammatical structures within the four IPSyn scoring categories: noun phrases, verb phrases, questions and negations, and sentence complexity. Then, an experienced linguist reviewed the selections and determined whether the child should be credited with zero, one or two points based on the number of appropriate exemplars of that structure. A quantitative index was determined by combining points earned in each category.

Speech/Sign Interview • These interviews were conducted by a clinician skilled in adapting to various sign systems based on the child's use. No limitations were imposed on the child's communication mode. The topics of conversation were controlled across the samples, although the specific content of the conversation was not. This procedure was followed regardless of whether the child had ever been exposed to sign language. Both signed and spoken productions were transcribed and the best of both modes was used in the analysis. For example, if the child said, "My team is called the" followed by a signed-only production of "Yankees," they received credit for producing "My team is called the Yankees." Both the transcriber and the verifier of samples from children who used total communication were experienced sign language interpreters. One child's total communication language sample was inadvertently taped over and has been excluded from the analysis.

Narrative Task • The children were asked to narrate events that occurred in an eight-picture-sequence story. No limitations were imposed on the child's communication mode. Each child was told to look at the pictures carefully because they had to tell a story. If the child produced little or nothing in response to the pictures, the examiner provided the child with neutral prompts, such as "tell me more." The narrative productions of the cochlear implant children were recorded on videotape and the hearing children were recorded on audio tape. Errors in video recording resulted in elimination of six cochlear implant children's narrative data, for a total N of 175. The children's narrative productions were transcribed by a teacher of the deaf and the transcriptions were verified by an experienced signer. The transcribed narratives were divided into theme units (T-units) for analysis (Hunt, 1965). A T-unit was defined as a unit of discourse capable of functioning as a sentence. Each T-unit consisted of one main clause and any subordinate clauses attached to it. Each T-unit was then coded for narrative structure and use of cohesive devices including referents and conjunctions. A Narrative Ability Score was obtained from these coded values using the procedure described by Crosson and Geers (2001).

Spoken Language Production • The second interview in which each of the children participated focused exclusively on their ability to converse with a person who did not know sign language. This measure was intended to represent the child's ability to combine speech perception, speech production and language skills to communicate orally.

Speech-Only Interview • These interviews were conducted by an oral teacher of the deaf, who used only spoken English. As in the Speech and Sign Interview, the child was free to use whatever communication method he or she chose, although only spoken productions were transcribed. Transcribers and verifiers were oral teachers of the deaf who did not know sign language but had extensive experi-

TABLE 2. Language scores on standardized measures.

	CI Mean	CI Standard Deviation	NH Mean	NH Standard Deviation
Language comprehension				
TACL word classes	44.2	18.8	50	10
TACL morphemes	17.1	43.0	50	10
TACL sentences	20.5	30.9	50	10
TACL total score	17.5	35.1	50	10
Language production				
Narrative ability score	7.3	3.4	11	1.8
Verbal reasoning				
WISC similarities (N = 180)	6.9	3.9	10	3

Normal hearing means and standard deviations are based on the normative data provided by the respective test authors.

ence listening to the speech of deaf children. A normally hearing comparison group, comprised of 24 children from a local private elementary school were engaged in the same conversational paradigm. They were of the same chronological age as the children with hearing loss and of approximately equal gender distribution.

Results

Average standard scores obtained on the language comprehension and verbal reasoning measures and raw scores on the narrative ability measure are summarized for 181 subjects in Table 2 along with means and standard deviations for hearing 8 and 9 yr olds. Narrative ability scores for normal-hearing 8 and 9 yr olds were derived from data reported by Crosson and Geers (2001). Mean standard scores of the cochlear implant group were 3 or more SDs below the average scores of hearing age mates on all subtests of the TACL except for the Word Classes subtest. Average age equivalent scores on the TACL ranged from 77 mo for Elaborated Sentences to 96.5 for Word Classes (average chronological age = 107 mo).

Linguistic measures obtained from the two types of language samples (speech-only and speech/sign) are summarized in Table 3 for the cochlear implant (CI) and normal hearing (NH) subject groups. One-way ANOVAS were conducted to compare mean scores between the two types of interviews. Significant interview effects were found for all linguistic variables except for IPSyn questions/negatives.

Post hoc comparison of means using Sheffe tests with Bonferroni adjustment to an alpha of 0.05/8 = 0.006 revealed significant differences between interviews for the children with hearing loss only for utterance length and lexical diversity. On average, CI children produced more words per utterance ($p < 0.0001$) and more different words per minute ($p < 0.003$) in the speech/sign interview than in the speech-only interview. For all other measures, communication

TABLE 3. Language scores based on spontaneous language samples.

	Group	Interview	Mean	Standard Deviation	Minimum	Maximum	F(2,382)
Utterance length (words/utterance)	CI*	Sp/Sign	4.9	2.0	1	11	25.58**
	CI	Sp Only	4.0	1.8	1	10	
	NH*+	Sp Only	6.5	1.3	4	9	
Lexical diversity (different words/min)	CI*	Sp/Sign	12.5	3.7	2.2	23.3	30.60**
	CI	Sp Only	11.2	4.6	0	21.1	
	NH*+	Sp Only	18.2	3.3	11	26	
Bound morphemes (per word)	CI	Sp/Sign	0.07	0.04	0.01	0.15	25.00**
	CI	Sp Only	0.07	0.03	0	0.15	
	NH*+	Sp Only	0.12	0.02	0.10	0.16	
IPSyn noun phrases	CI	Sp/Sign	18.4	3.0	6	22	6.82**
	CI	Sp Only	17.7	4.5	0	22	
	NH*+	Sp Only	20.5	1.2	18	22	
IPSyn verb phrases	CI	Sp/Sign	19.3	6.4	4	31	11.41**
	CI	Sp Only	19	7.1	0	30	
	NH*+	Sp Only	25.8	1.9	23	29	
IPSyn questions/negatives	CI	Sp/Sign	7.4	3.5	0	17	0.43
	CI	Sp Only	7.6	3.8	0	16	
	NH	Sp Only	8.0	2.7	6	15	
IPSyn sentence structure	CI	Sp/Sign	22.1	5.7	2	32	13.30**
	CI	Sp Only	20.4	6.8	0	31	
	NH*+	Sp Only	27.0	1.7	24	31	
IPSyn total score	CI	Sp/Sign	67.1	16.1	13	93	9.14**
	CI	Sp Only	64.8	20.1	1	92	
	NH*+	Sp Only	81.2	3.7	75	91	**$p < 0.0001$

* *Mean score greater than CI group in SpOnly interview, $p < 0.001$.*
+ *Mean score greater than CI group in Sp/sign interview, $p < 0.001$.*

TABLE 4. Percent of children scoring at or above hearing age-mates.

	% at Normal Levels Speech and Sign Interview	Speech Interview
Utterance length (words/utterance)	65	51
Lexical diversity (different words/min)	72	62
Bound morphemes (per word)	27	22
IPSyn—index of productive syntax	47	42
TACL—language comprehension	30	—
WISC similarities	64	—
Narrative ability score	67	—

mode used by the examiners in the interview did not affect linguistic scores of the CI group. Significant differences were obtained between linguistic scores of hearing comparison subjects and the cochlear implant group, regardless of the interview mode, on all but the IPSyn category of Questions/Negatives, where the overall effect of interview was not significant.

Further analyses addressed the following questions:

What proportion of children implanted by 5 yr of age achieved English language skills that were comparable with those of hearing age-mates?

Although at sample selection, all children were reported to have normal intelligence, when the WISC-III Performance Scale was administered, 24 of the children achieved IQ scores below 85 (more than 1 SD below average). Because this factor could contribute to poorer than expected English language development, for this analysis these children were eliminated, bringing the total N to 157. Table 4 summarizes the percentage of these children who scored within the average range for hearing age-mates, either in comparison with the normative standardization sample (≥ -1 SD on the TACL and WISC Similarities) or above the minimum score obtained by the comparison samples of hearing 8 to 9 yr olds tested for this study. Over half of the children in the cochlear implant group scored within the average range for utterance length, lexical diversity (different words/minute), verbal reasoning (WISC-Similarities) and narrative ability. Fewer than 50% of the CI children achieved normal levels on their use of bound morphemes and in their overall language comprehension scores on the TACL.

Does the addition of sign language input provide an advantage over speech-only input in the development of English language competence?

Table 5 presents the average language test scores of children divided according to their average instructional mode rating (Oral or Total Communication) over a 5-yr period. Unpaired *t*-tests were conducted comparing means for the two communication mode groups. There were no significant differences in language comprehension or verbal reasoning between the scores of children who spent more of their postimplant years in oral classroom settings and children whose programs used total communication. However, children in the oral group exhibited higher narrative ability scores [t (1,173) = 3.39; $p <$ 0.0009].

Table 6 summarizes the performance of each of these groups in the two interviews, speech/sign and speech-only. ANOVAs were conducted for each measure to examine the effects of communication mode group and interview type. It was anticipated that children whose classroom communication mode for the past 5 yr was primarily total communication would exhibit superior performance in the speech and sign interview compared with the speech-only interview and would outperform children whose classroom communication mode was primarily oral in the speech and sign interview. It was predicted that children whose classroom communication mode for the past 5 yr was primarily oral would outperform children from total communication programs in the speech-only interview. Significant results are discussed for each measure.

Utterance Length: Significant differences were found between mode groups [F (1,357) = 34.96; $p <$ 0.0001] and interview types [F (1,357) = 25.65; $p <$ 0.0001) with no significant interaction. Although utterances were longer for both groups in the speech and sign interview, children in the oral communica-

TABLE 5. Language scores for children grouped by classroom communication mode

	Subject Group	Mean	Standard Deviation	Minimum	Maximum	*N*
TACL—language comprehension	TC	15.5	37.0	−94	66	89
	OR	19.4	33.3	−110	60	92
WISC similarities	TC	6.4	3.8	1	15	88
	OR	7.4	4.0	1	18	92
Narrative ability score	TC	6.4	3.7	0	13	86
	OR*	8.1	2.9	0	13	89

* $p < 0.0009$.

TABLE 6. Language scores in speech interviews and speech and sign interviews for oral and TC classroom communication mode groups.

	Mode Group	Interview	Mean	Standard Deviation	F Test Interview	F Test Mode	F Test Int × Mode
Utterance length (words/utterance)	TC	Sp & Sign	4.4	1.8	25.6**	35.0**	0.26
	TC	Sp Only	3.3	1.6			
	OR	Sp & Sign	5.4	2.2			
	OR	Sp Only	4.6	1.7			
Lexical diversity (different words/min)	TC	Sp & Sign	12.0	3.6	8.67*	17.0**	6.15*
	TC	Sp Only	9.6	5.0			
	OR	Sp & Sign	13.0	3.8			
	OR	Sp Only	12.8	3.7			
Bound morphemes (per word)	TC	Sp & Sign	0.05	0.03	0.04	84.1**	0.34
	TC	Sp Only	0.05	0.03			
	OR	Sp & Sign	0.08	0.03			
	OR	Sp Only	0.08	0.03			
IPSyn total score	TC	Sp & Sign	61.4	17.4	1.6	52.4**	1.0
	TC	Sp Only	57.3	24.0			
	OR	Sp & Sign	72.5	12.8			
	OR	Sp Only	72.1	11.6			

* $p < 0.02$.
** $p < 0.0001$.

tion mode group produced significantly longer utterances regardless of interview type.

Lexical Diversity: There was a significant effect of mode group [F (1,357) = 17.04; $p < 0.0001$], and interview type [F (1, 357) = 8.67; $p < 0.003$] and a significant interaction between mode group and interview type [F (1,357) = 6.15; $p < 0.01$]. Children from oral communication classrooms produced a greater number of different words than children from total communication classrooms in both the speech and the speech/sign interview.

Bound Morpheme: There was a significant effect for mode group [F (1,357) = 84.06; $p < 0.0001$] but not for interview type, and there was no significant interaction. Children from oral communication classrooms used more bound morphemes in both speech and speech and sign interviews.

Syntax: IPSYN total scores showed a significant effect of mode group [F (1,357) = 52.37; $p < 0.0001$] but not of interview type. There was no significant interaction. Children from oral communication classrooms produced more syntactically complex structures in both the speech and the speech and sign interviews than did children from total communication classrooms.

Are scores on measures of comprehension, production and verbal reasoning highly interrelated in this group of children?

Table 7 contains the intercorrelation matrix summarizing the relations among the language measures. All coefficients were significant at $p < 0.001$. The relatively high correlation coefficients obtained among the measures suggests that the language variable could be reduced to a single standardized score using principal components analysis. Principal components analysis forms this summary score by

TABLE 7. Intercorrelations among language scores.

	Speech Interview				Speech/Sign Interview					
	IPSyn	WPU	BndM	DiffWPM	IPSyn	WPU	BndM	DiffWPM	TACL	WISC Sim
Sp IPSyn	1.00									
Sp WPU	0.80	1.00								
Sp BndM	0.65	0.57	1.00							
Sp Diff WPM	0.89	0.89	0.62	1.00						
Sp/S IPSyn	0.87	0.78	0.63	0.85	1.00					
Sp/S WPU	0.70	0.87	0.51	0.79	0.79	1.00				
Sp/S BndM	0.60	0.62	0.78	0.65	0.60	0.52	1.00			
Sp/S Diff WPM	0.67	0.74	0.52	0.79	0.72	0.80	0.46	1.00		
TACL T-Score	0.62	0.56	0.47	0.62	0.64	0.56	0.47	0.55	1.00	
WISC similarities	0.57	0.61	0.40	0.65	0.66	0.68	0.41	0.68	0.64	1.00
Narrative ability	0.69	0.68	0.49	0.69	0.74	0.67	0.50	0.65	0.57	0.65

All correlations are significant at $p < 0.0001$. Correlations are based on 181 observations except for those involving the speech and sign (Sp/S) interview (obs = 180), WISC similarities (obs = 180), and narrative ability (obs = 175).

TABLE 8. Principal components factor loadings.

Total language	
Number of words/utterance	0.89
IPSYN—verb phrase	0.89
IPSYN—sentence structure	0.89
Number of different words	0.85
Narrative ability score	0.83
Number of bound morphemes	0.82
WISC-similarities	0.79
IPSYN—noun phrase	0.79
TACL—elaborated sentences	0.77
TACL—morphemes	0.62
TACL—word classes	0.56
IPSyn—question/negative	0.52
Spoken language	
Number of different words	0.96
IPSyn—verb phrase	0.95
IPSyn—sentence structure	0.93
Number of words per utterance	0.89
IPSyn—noun phrase	0.87
Number of bound morphemes	0.83
IPSyn—question/negative	0.67

creating a weighted linear combination of the original variables. Because it was anticipated that spoken language would be particularly affected by cochlear implantation, two component scores were created. A Spoken Language component score was a weighted combination of scores obtained from the speech-only interview. A Total Language component score was a weighted combination of scores obtained from the speech/sign interview and all measures administered in the child's preferred communication mode (TACL, Narrative Ability, WISC-Similarities).

The component loadings of each measure are listed in Table 8. The principal components scores accounted for 63% of the variance in the Total Language measures and 73% of the variance in the Spoken Language measures.

To what extent is the variance in language outcome postimplant determined by pre-existing characteristics of the child and the family? The two dependent measures, Spoken Language component score and Total Language component, were entered into multiple regression analyses with seven child and family characteristics entered as predictors: the child's age at test, at implant and at onset of deafness, the Performance IQ on the WISC-III (Wechsler, 1991), the number of family members, the family socio-economic status (SES) represented by a standardized sum of the ratings for parents' income and education, and the child's gender (1 = female; 2 = male). Measurement of these variables is described in detail in Geers and Brenner (2003). Results are presented in Table 9. Together child and family variables accounted for 23% of the variance in Spoken Language component score and 27% of variance in Total Language component score. Children with higher performance intelligence quotients, smaller family sizes, higher socio-economic status and female gender developed greater language competence regardless of modality. Children with later age at onset scored higher in Total Language, but not Spoken Language competence.

What educational variables are most important for language development? Six educational variables were entered as predictors of Total Language and Spoken Language component scores after variance due to child and family characteristics had been removed: number of hours of individual therapy (per year averaged over 4 yr postimplant), the number of deaf and implanted children in the clinician's prior experience, parent report of their participation in therapy, public versus private school setting (rating between 1 and 3 averaged over 5 yr), special education versus mainstream class placement (rating between 1 and 3 averaged over 5 yr) and communication mode (rating between 1 and 6 averaged over 5 yr). Measurement of these variables is described in detail in Geers and Brenner (2003). Results are presented in Table 10. Together the educational variables accounted for 7% of added variance in Total Language and 12% of added variance in Spoken Language component scores. The educational variables that

TABLE 9. Child and family factors predictive of language competence.

	Spoken Language			Total Language		
	Std. Coeff.	F-ratio	*p*	Std. Coeff.	F-ratio	*p*
Child and family factors						
Age	−0.02	0.03	NS	0.02	0.02	NS
Age at implant	−0.12	1.65	NS	−0.10	1.20	NS
Age at onset	0.01	1.71	NS	0.02	8.55	0.004
Performance IQ	0.01	7.91	0.005	0.01	10.99	0.001
Family size	−0.21	10.80	0.001	−0.20	10.87	0.001
Socio-economic status	0.06	10.90	0.001	0.07	15.04	0.0001
Gender	−0.23	9.67	0.001	−0.20	9.75	0.002
Explained variance	23%		df = (1,173)	27%		df = (1,171)

TABLE 10. Factors contributing added variance (after child and family variables are removed) to predicting language outcome.

	Spoken Language			Total Language		
	Std. Coeff.	F-ratio	*p*	Std. Coeff.	F-ratio	*p*
Educational factors						
Hours of therapy	0.00	0.97	NS	0.001	1.50	NS
Therapist experience	−0.01	0.04	NS	−0.02	0.33	NS
Parent participation	0.06	0.15	NS	0.06	0.12	NS
Public/private school	−0.10	1.16	NS	−0.11	1.51	NS
Special ed/mainstream	0.27	6.44	0.01	0.27	6.49	0.01
Communication mode	0.22	19.53	0.0001	0.12	5.72	0.02
Added variance	12%		df = (1,167)	7%		df = (1,165)
Total variance explained	35%			34%		
Speech and hearing factors						
Speech perception	0.15	5.31	0.02	0.08	0.68	NS
Speech production	0.76	127.01	0.0001	0.67	44.97	0.0001
Added variance	63%		df = (1,171)	42%		df = (1,169)
Total variance explained	86%			69%		

made a significant independent contribution were class placement (mainstreamed children had better language) and communication mode (children with more oral emphasis had better language). It is interesting that the benefits of an educational emphasis on spoken language in an auditory/oral classroom environment were present whether or not the outcome language measures included sign or were restricted to only spoken language productions. Some of the educational variables that did not reach significance when all of them were considered together were significant when considered individually. In particular, number of hours of therapy was a significant independent predictor of Spoken Language competence when no other educational variables were entered into the analysis. However, the effects of classroom type and communication mode on language outcome overcame the effects of therapy when all predictors were included.

What are the effects of auditory speech perception and speech production skills on language development?

An analysis was conducted to examine the contribution of speech perception (see Geers et al., 2003) and speech production (see Tobey, Geers, Brenner, Altuna, & Gabbert, 2003) component scores to Total Language and Spoken Language competence. After variance due to child and family characteristics was removed, these factors accounted for 63% of added variance in Spoken Language component score and 42% of added variance in Total Language component score. Although speech production ability was important to both types of outcome measures, speech perception ability (presumably a measure of implant benefit) was a significant predictor of Spoken Language, but not Total Language score.

CONCLUSIONS

Children with average learning ability who receive a cochlear implant at or before 5 yr of age have the potential to produce and understand English language at a level comparable with that of their hearing age mates. Over half of the children in this sample with intelligence at or above average exhibited verbal reasoning and narrative ability and used utterance length and lexical diversity in their spontaneous conversation that was comparable with hearing 8 to 9 yr olds. This proportion of profoundly deaf children scoring within the range of hearing age-mates far exceeds those reported in previous studies of similar children who used hearing aids (Boothroyd et al., 1991; Geers & Moog, 1978; Geers, Moog, & Schick, 1984; Moog & Geers, 1985). Factors that predispose children to higher levels of language development include higher nonverbal intelligence, smaller family size, higher family socio-economic status (i.e., parent education and income) and female gender. Onset of deafness after birth, even within the prelingual period, also provides an advantage for Total Language development.

Receiving an implant at 2 or 3 yr of age did not appear to provide any significant linguistic advantage over receiving it at age 4 or 5. This result is contrary to that reported by Kirk et al. (2002) who reported a significant advantage for children implanted under 3 compared with 3 to 4 yr of age. It is possible that the early-implant group reported by Kirk et al. contained more children implanted under the age of two. Implantation at 2 yr may not be young enough to show the advantage of early input. Furthermore, the data presented by Kirk et al. were collected when most of the very early implanted children were below 6 yr of age. There may be an advantage for early implantation (i.e., under 3 yr) that is no longer apparent by 8 to 9 yr of age, when the current sample was tested.

After the variance in language outcome due to characteristics of the child and the family had been accounted for, the impact of educational variables on linguistic competence were examined. As expected, children with longer experience in mainstream classrooms tended to have better language. This may well be a result rather than a cause of good linguistic performance. The only other variable that predicted significant added variance was the amount of emphasis on speech and auditory skill development in the child's classroom. Educational use of oral language was a significant predictor not only of spoken language competence, but also of total language development when speech and sign were both assessed. When language measures were examined separately for expressive and receptive tasks, this study indicated no difference between oral and TC students on the receptive syntax measure (the TACL), but a significant expressive language advantage for children from oral communication settings. This result is consistent with that reported by Kirk et al. (2002) on the Reynell Developmental Language Scale.

Use of a visual language system did not provide the receptive advantage that had been anticipated in this group of profoundly deaf children. Use of sign language was expected to facilitate comprehension in those children who had been exposed to it in their classrooms. Not only did children educated without use of sign comprehend language just as well, they also exhibited a significant expressive advantage in the breadth of their vocabulary, in their use of bound morphemes, in the length and complexity of their utterances and in their use of the narrative form. These advantages were apparent whether or not the children were credited with signed productions in addition to spoken language. It appears from these data that linguistic competence was associated with placement in educational environments that emphasized the development of speech and auditory skills.

This result appears to contradict results reported by Connor et al. (2000) for 147 prelingually deafened children who had used an implant for between 6 mo and 10 yr. The Connor et al. study compared spoken vocabulary development of implanted children enrolled in OC or TC settings throughout Michigan and parts of Ohio and Indiana. Relatively greater vocabulary growth was observed for the TC group, even when stimuli were presented using only speech. Differences between the current study and the Conner et al. results may be related to the samples studied and the types of language measures employed. Unlike the present study, the number of children followed for 4 to 6 yr after implantation in the Connor et al. study was small (<30) and included even fewer children implanted under the age of 5. It is possible that there is a linguistic advantage for children in total communication settings at the beginning of their implant experience that diminishes as oral children gain experience with the device. The group in the present study was much more homogeneous in chronological age and duration of implant use and heterogeneous in the geographical distribution of educational programs sampled and in the breadth of measures used to assess language abilities. Furthermore, in the present study, the language outcome was heavily weighted for English Syntax. In contrast, the findings of the Conner et al. study were based primarily on single-word vocabulary.

Achievement of age-appropriate linguistic competence, even in a speech-only mode, is now exhibited by larger numbers of profoundly deaf children than ever before. Continuing advances in speech processor technology and, possibly, earlier ages at implantation, are likely to even further increase the proportion of deaf children who attain age-appropriate language abilities.

Acknowledgments:

This study was supported by Grant Number DC03100 from the National Institute on Deafness and other Communication Disorders (NIDCD) of the National Institutes of Health to Central Institute for the Deaf (CID). Language tests were administered by Julia Biedenstein from the Moog Center for Deaf Education, Allison Sedey from the University of Colorado at Boulder, Debbie Carter, LaShawn Cole, Monica Rapp, Brent Spehar and Pam Zacher from CID, and Abbie Sterling from the Special School District of St. Louis County. Language transcription and verification was conducted by Sarah Fessenden, Heidi Geers, Julie Otto and Brent Spehar from CID and Allison Sedey from the University of Colorado at Boulder. Language sample analysis was conducted by Christine Brenner and Gina Torretta from CID. Judy Baek from the Massachusetts Institute of Technology verified and finalized the IPSYN linguistic scoring. Narrative transcription and coding was conducted by Jillian Crosson and Shari Epstein from CID.

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Accepted August 28, 2002

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