

## Clinical Forum

# Factors Affecting the Development of Speech, Language, and Literacy in Children With Early Cochlear Implantation

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**T**he advent of cochlear implants has had a dramatic effect on the achievements of young profoundly deaf children. Spoken language competence is now attainable by many children who previously depended primarily on sign language for communication. Children who receive an implant early in life, followed by a period of appropriate rehabilitation, typically achieve speech intelligibility and conversational fluency that exceeds levels observed in profoundly deaf children with hearing aids. However, there continues to be considerable variability and large individual differences in the performance outcomes of groups of children (Pisoni, Cleary,

Geers, & Tobey, 2000). Fryauf-Bertschy, Tyler, Kelsay, Gantz, and Woodworth (1997) reported that most children demonstrated some improvement in speech perception after receiving a cochlear implant: Some children demonstrated dramatic improvement, and some children obtained only limited perceptual gains even after 3–4 years of cochlear implant use. Ten out of the 16 children in this study who had been implanted before the age of 5 achieved greater than 50% recognition of words in an open-set list (Phonetically Balanced Kindergarten Words). However, the 9 minimal and eventual nonusers in this study all scored less than 32% open-set word recognition. Possible reasons for

**ABSTRACT: Purpose:** This study investigated factors contributing to auditory, speech, language, and reading outcomes in children with prelingual deafness after 4–6 years of multichannel cochlear implant use. The analysis controlled for the effects of child, family, and implant characteristics so that educational factors most conducive to maximum implant benefit could be identified.

**Method:** The sample included 136 8- and 9-year-old children from across the United States and Canada who were implanted by age 5 with the Nucleus 22-channel implant. Type and amount of educational intervention since implantation constituted the independent variables. The dependent variable was performance on a battery of tests of speech perception, speech production, language, and reading administered 4–6 years postimplant. Characteristics of the child, the family, and the implant itself constituted interven-

ing variables. A series of multiple regression analyses determined the amount of variance in each outcome accounted for by the intervening variables and the amount of additional variance attributable to independent variables.

**Results:** Characteristics of the child and the family (primarily nonverbal IQ) accounted for approximately 20% of the variance in postimplant outcome. An additional 24% was accounted for by implant characteristics and 12% by educational variables, particularly oral communication mode.

**Clinical Implications:** Auditory, speech, language, and reading skills achieved 4–6 years after cochlear implantation were most strongly associated with nonverbal IQ, implant functioning, and use of an oral communication mode.

**KEY WORDS:** deaf, cochlear implant, deaf education, communication mode

poor performance included inadequate device fitting, insufficient cognitive skills, poor motivation, educational and social environment emphasizing manual communication, and limited parental support.

Implant benefit has been examined in relation to a number of demographic variables. Onset of deafness at a later age and shorter length of auditory deprivation have been associated with greater speech perception scores (Osberger, Todd, Berry, Robbins, & Miyamoto, 1991; Staller, Beiter, Brimacombe, Mecklenburg, & Arndt, 1991). A younger age at implantation and longer duration of implant use (Fryauf-Bertschy et al, 1997; Waltzman & Cohen, 1998) have also been associated with better speech perception scores. Other factors contributing to variability include preimplant residual hearing (Osberger & Fisher, 2000) and the type of processor used (Parkinson, Parkinson, Tyler, Lowder, & Gantz, 1998). Communication mode used in the child's educational setting has also been found to play an important role in postimplant outcome. Miyamoto et al. (1994) used multiple regression techniques to predict postimplant speech perception scores for 61 children who used a Nucleus cochlear implant. Age at onset of hearing loss, duration of deafness, processor type, and communication mode were all significant predictors, but the length of device use accounted for the largest amount of variance in speech perception scores postimplant.

Whereas establishing the effects of preexisting child and implant characteristics on postimplant performance is useful for addressing candidacy issues and establishing post-implant expectations, parents and educators are interested in determining which educational choices will maximize their child's ability to benefit from implantation. Educational choices for children with hearing impairments include factors such as mainstream or special education class placement; public or private school programs; speech, sign, or equal communication mode emphasis; amount of individual speech and language therapy provided; and characteristics of the clinicians providing the therapy.

One educational variable that is frequently examined in relation to implant benefit is the communication mode used in the child's classroom. This variable is most often dichotomized into oral communication (OC) approaches and total communication (TC) approaches. Proponents of the OC approach maintain that dependence on speech and audition for communication is critical for achieving maximum auditory benefit from any sensory aid. Constant use of auditory input to monitor speech production and to comprehend spoken language provides the concentrated practice needed for optimum benefit from a cochlear implant. Types of OC approaches differ in their emphasis on the auditory and visual channels for the reception of spoken language. Methods range from the cued speech approach, in which manual cues are used to complement lipreading, to the auditory-verbal approach, in which lipreading is discouraged and the child learns from an early age to make use of whatever auditory information is available through his or her sensory device to understand speech.

Proponents of the TC approach maintain that the child with severe-to-profound deafness benefits most when some

form of Manually Coded English accompanies speech. The use of a sign system allows for easier assimilation of language through the unimpaired visual modality. The child is then able to associate what he or she hears through the implant with signed representations of language in order to support spoken language development. In practice, TC programs range from those that rely heavily on signed input with less emphasis on speech and English syntax to those that emphasize speech, audition, and lipreading and maintain careful adherence to English syntax and morphology. Although there is evidence that children enrolled in OC programs demonstrate better speech perception and language improvement postimplant than those in TC programs (Miyamoto, Kirk, Svirsky, & Sehgal, 1999), other studies indicate greater vocabulary improvement for children enrolled in TC programs (Connor, Hieber, Arts, & Zwolan, 2000; Robbins, Bollard, & Green, 1999).

Documenting the effects of educational choices on speech and language outcomes is especially difficult when other factors that could also affect performance vary a great deal. Factors such as the child's age at onset of deafness, at implant, and at test; duration of implant use; family characteristics; and intelligence can have a substantial impact on test scores. Parents and children with particular characteristics may be drawn to certain kinds of programs, and programs emphasizing spoken or sign language may favor the admission of children with certain other characteristics. Furthermore, factors such as type of device and/or processing strategy and preimplant candidacy criteria are constantly changing, making control of these factors difficult to achieve over time. Failure to control for any of these intervening variables may obscure the underlying causes of exceptionally good or poor performance with an implant (see Kirk, 2000 for a discussion of these issues). It is important to undertake studies that control for as many of these factors as possible so that the relative benefits of specific educational approaches can be documented. Parents and educators can then interpret these results to make informed educational choices designed to maximize a child's postimplant hearing, speech, and language development.

In 1996, the Center for Applied Research in Childhood Deafness at the Central Institute for the Deaf initiated the study that is reported here. This study, titled "Cochlear Implants and Education of the Deaf Child," was funded by the U.S. National Institutes of Health and was designed to document the effects of various education and rehabilitation models on the ability of the child who is deaf to understand, produce, and read English while using a Nucleus 22-channel cochlear implant (Geers et al., 2000). This study was designed to reduce variability as much as possible through sample selection criteria and to include a sufficiently large number of children to control for intervening variables in the analysis. This report examines the effects of communication mode, class placement, and therapy on five outcome variables (speech perception, speech production, spoken language, total language, and reading) after controlling for the effects of intervening variables associated with the child, the family, and the implant device.

## METHOD

### Participants

Over a 4-year period, 180 8- and 9-year-old children from 33 different states and 5 Canadian provinces came to St. Louis to attend the Cochlear Implant Summer Research Camp. This preliminary report describes 136 children who were tested during the first 3 years of data collection. Participants were selected to be as homogeneous as possible on a number of key factors known to affect performance postimplant. Characteristics of these participants are summarized in Table 1. These children all received their implants when the candidacy requirements included no observable benefit from conventional amplification. Thus, none of these children exhibited any open-set speech perception ability with hearing aids before receiving an implant. The participants do not represent any single educational program or method, but rather come from the full range of educational settings available across the United States and Canada.

### Procedure

Approximately 15 children, accompanied by a parent, were included in each data collection camp session. All expenses were paid, including transportation, hotel accommodations for 4 nights, and daily entertainment activities. Testing took place 2 hours each day for 3 days. All children were tested under similar conditions with a consistent group of examiners on an identical battery of tests. Children were tested individually in their hotel rooms, which were converted to testing suites each morning. The parents attended educational seminars during this time and completed questionnaires and signed release forms for questionnaires sent to implant centers and clinicians. In the afternoon, families participated in planned recreational activities. Three categories of measures were obtained: (a) intervening variables that were controlled in the analysis, (b) independent educational variables that were the focus of the study, and (c) outcome measures that represented each child's auditory, speech, language, and reading abilities.

**Intervening variables.** These are factors that are either known or suspected to affect speech and language develop-

ment postimplant independent of educational factors. Controlling for child, family, and implant characteristics in the analysis minimizes the chances that a difference in outcome will be mistakenly interpreted as being associated with educational factors when they are caused by sample differences on these variables.

Child characteristics included age at test, age at onset of deafness, age at implant, and nonverbal intelligence. Chronological age at testing was restricted to children aged 8;0 (years;months) to 8;11 ( $n = 62$ ) and those aged 9;0 to 9;11 ( $n = 74$ ). Age at onset of deafness was restricted in the sample selection process to less than 3;0. Most ( $n = 102$ ) of the 136 children were known or presumed to be deaf from birth, 12 were deafened before 1 year of age, 15 between 1 and 2 years of age, and 7 became deaf when they were 2 years old. Age at implant was restricted at sample selection to less than 5 years of age: 41 were implanted before age 3, 59 between 3 and 4 years of age, and 32 between ages 4 and 5. Four children were implanted by age 4 but did not complete hookup until they had turned 5. Although sample selection criteria were designed to include only children with average or above-average intelligence, 9 of the children obtained a Performance IQ on the Wechsler Intelligence Scale for Children, Third Edition (WISC-III; Wechsler, 1991) below the average range for their age.

Measured family characteristics were education, income, and size. More than half of the families included at least one college graduate as a parent. Parents were asked to select, from a choice of categories, the income range best representing their family. The median family income was between \$50,000 and \$80,000, with 35 families reporting an income of more than \$80,000 per year. Most of the children were being raised in two-parent families with an average of two children per family. Eleven of the children were from single-parent families.

Variables associated with the implant itself included duration of implant use and duration of use of the Spectra speech processor with the updated Spectral Peak (SPeak) coding strategy. The implant map includes parameters that are set by the audiologist to maximize the child's perception of speech. The map was characterized by the number of currently active electrodes, the size of the dynamic range from threshold to comfortable listening level, and the average range over which the child perceived growth of loudness.

All 136 children had used the same electrode array, the Nucleus 22 from Cochlear Corporation, for between 4 and 7 years. Many of these children were first fitted with the Mini speech processor and later received the newer SPeak processor. All but 20 of the children had switched to the SPeak coding strategy by the time of the study. Fifty of them had used SPeak for 4 or more years. Almost half had a fully active array with 20 or more electrodes in their map. Only 12 of the 136 children had fewer than 16 active electrodes. More than half of the children exhibited a dynamic range of greater than 60 clinical units per electrode ( $M = 60.9$ ;  $SD = 23.4$ ). This indicates that a wide range of loudness levels in speech was available to these children from their processor. An estimate of growth of

**Table 1.** Sample characteristics for 136 subjects.

	M	SD	Minimum	Maximum
Age at test (years;months)	9;0	0;6	8;0	9;11
Age at onset	0;4	0;9	0	3;0
Age at implant	3;6	0;9	1;10	5;2
Performance IQ	102	15	65	136
Duration of CI use	5;6	0;9	3;9	7;6
Duration of SPeak use	3;0	1;8	0	5;2
# of active electrodes	18	2.86	6	22

**Note.** CI = cochlear implant.

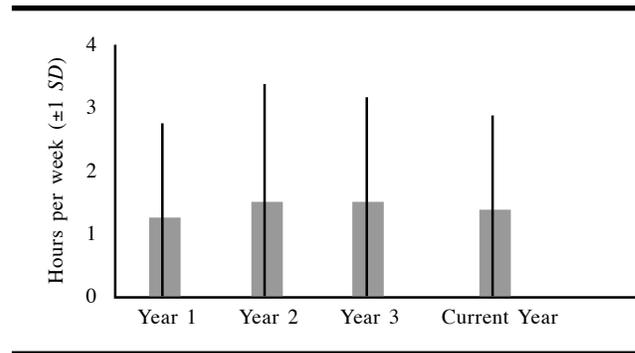
loudness for randomly presented stimuli representing three different noise bands at seven intensity levels between 55 and 80 dB SPL was obtained for each child on a 5-point scale from “nothing” to “too loud” (Davidson, Brenner, & Geers, 2000). The average increment in ratings between loudness levels was 0.43, slightly less than half a rating scale point. Variability was 0.53, or approximately half a rating scale point.

**Independent variables.** These variables describe each child’s therapy, class placement, and classroom communication mode. The effect of these variables is the focus of this investigation. Because educational practices and placement could change from year to year, values were recorded for each of 3 years following implantation plus the year just completed before the child attended camp.

Variables used to assess the impact of therapy were number of hours of therapy, clinician experience, and parent participation in therapy. Parents identified all clinicians who saw their child for individual or small group speech and/or auditory training (outside of classroom instruction) since receiving the implant. A questionnaire was mailed to each clinician. The return rate on questionnaires after follow-up phone calls to nonrespondents was 87%. Number of hours of therapy per week averaged over 12 months for the entire sample is depicted in Figure 1. These children averaged almost 1.5 hours per week of therapy during each year postimplant.

Clinicians varied in their level of experience teaching deaf children and children with cochlear implants. These differences are depicted in Figure 2, where clinicians are categorized by whether they had prior experience teaching an implanted child before they began working with the child in this study. Within each category, the distribution of clinicians is plotted according to the number of deaf children they had previously treated, regardless of sensory aid used. Responses ranged from no prior experience with either deaf children or children with cochlear implants (5%)

**Figure 1.** Amount of therapy over time averaged across 136 children.

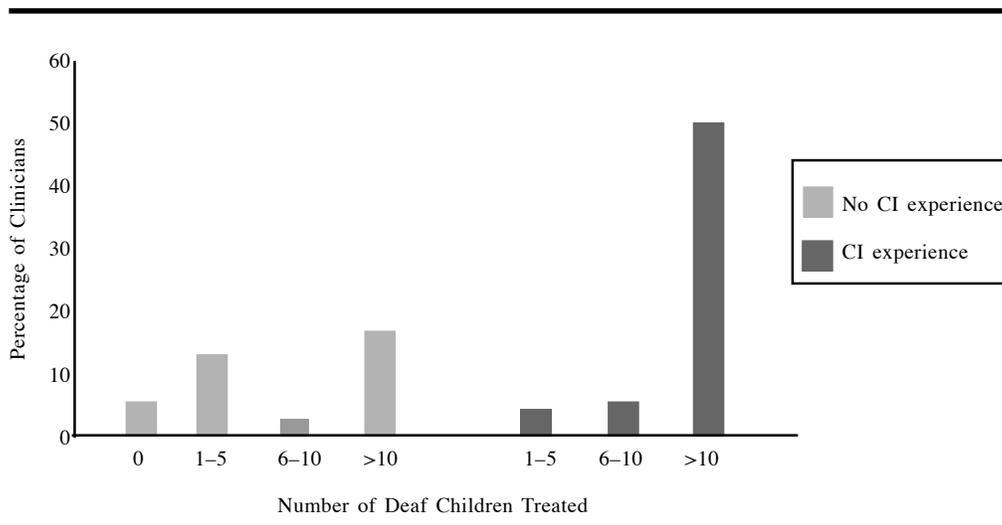


to those who had taught more than 10 deaf children, including those with implants (50%).

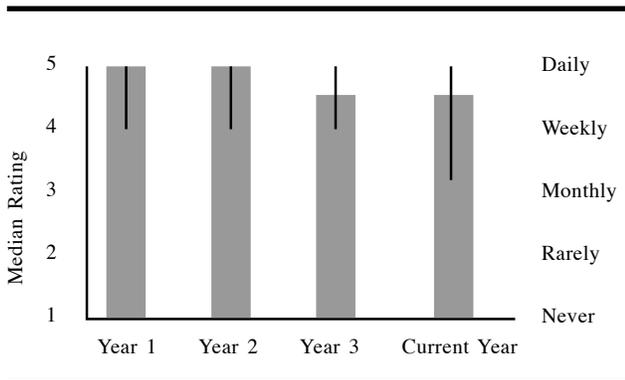
A questionnaire asked parents to estimate the frequency with which they participated in activities designed to stimulate auditory and speech development at home. Results are summarized in Figure 3, where the average parent responses over all questions over all respondents are plotted along with the standard error of these values for each postimplant year. On average, parents reported that they worked with their child daily for the first 2 years postimplant, and between daily and weekly for the third year postimplant and the year just completed.

Variables used to assess the impact of educational setting included public or private school placement and special education or mainstream classroom. Parents reported their child’s school setting each year as none, public, private, or both public and private. Figure 4 indicates an increase in public school placement over time. Type of class is depicted in Figure 5. The percentage of children enrolled in full-time special education classes decreased

**Figure 2.** Clinicians returning therapy questionnaires described in terms of their prior experience with children who are deaf and children who use cochlear implants (CIs).



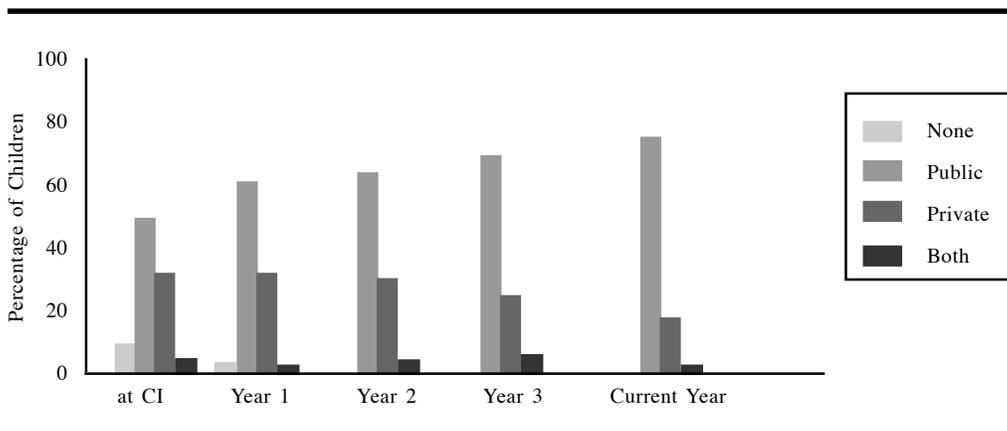
**Figure 3.** Median frequency of parent participation in therapy and interquartile range of ratings obtained over 4 years postimplant.



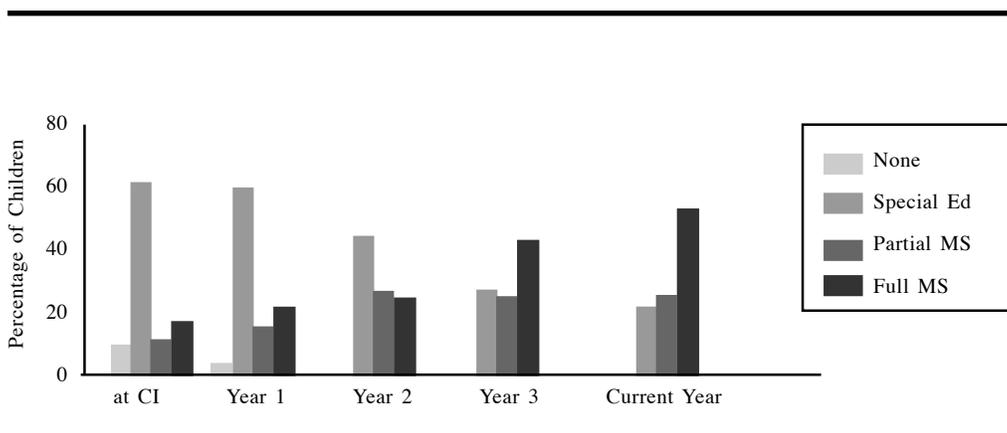
from approximately 60% before implant to approximately 20% at the time of the study. By the time of the study, more than half of the children were fully mainstreamed.

Classroom communication mode was assessed with a rating scale completed by the parents that was intended to reflect the amount of emphasis on speech and auditory skill development provided in the child's classroom (see Table 2). A rank between 1 and 6 was assigned to each instructional mode for each year. Ratings between 1 and 3 were assigned to TC programs. In *mostly sign* programs, sign-only was used for communication during some of each day. In *speech and sign* programs, speech almost always occurred simultaneously with each signed word, and sign-only or speech-only were rarely used. In *speech emphasis* programs, speech-only was used for communication during some of each day. Ratings between 4 and 6 were applied to OC programs. In *cued speech* programs, a formal system of

**Figure 4.** Percentage of children enrolled in no school program, public school program, private school program, or both public and private school programs at the time a cochlear implant was fitted (at CI) and each of 4 years thereafter.



**Figure 5.** Percentage of children enrolled in no program, special education class, part-day mainstream (MS) class, or full-day mainstream class at the time a cochlear implant was fitted (at CI) and each of 4 years thereafter.



**Table 2.** Classroom communication mode rating scale.

1	2	3	4	5	6
Mostly sign	Speech & sign	Speech emphasis	Cued speech	Auditory–oral	Auditory–verbal
Total Communication → Increasing speech emphasis			Oral Communication → Increasing auditory emphasis		

manual cues was used to facilitate lipreading. In *auditory–oral* programs, the child was encouraged throughout the day to both lipread and listen to the talker. In *auditory–verbal* programs, the child was taught to rely on listening alone to understand speech. Classroom communication mode scores were averaged across 5 years and are depicted for individual children in Figure 6. The 67 children with average scores of 4 or higher had spent most of their years in an oral setting. The 69 children with average mode scores of less than 4 had been mostly in TC settings.

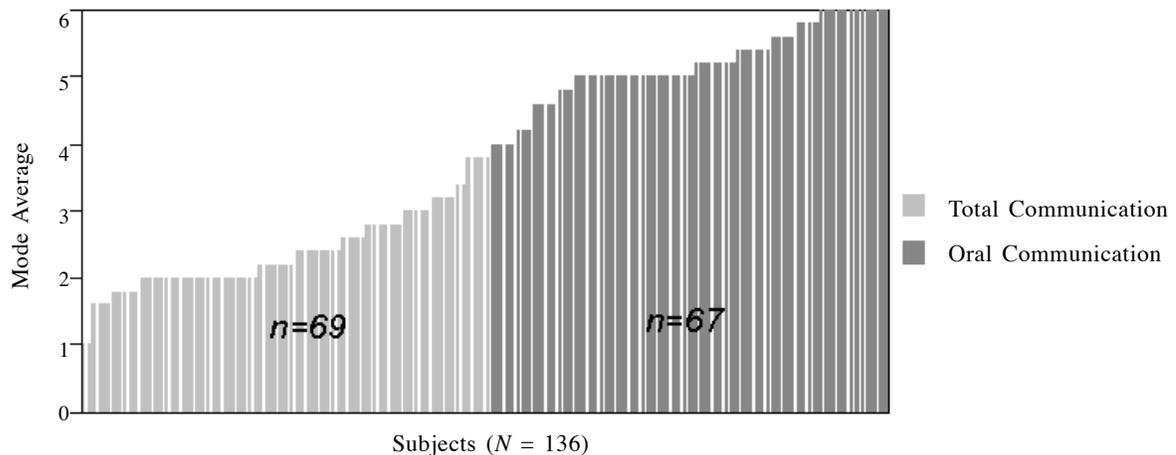
**Outcome measures.** Five dependent variables were selected to represent the areas most likely to be affected by cochlear implantation: speech perception, speech production, language (assessed in two ways: spoken only and total communication), and reading. It was anticipated that post-implant therapy and education factors might explain differences in the ultimate outcome level achieved for these variables once the impact of intervening variables associated with child, family, and implant characteristics had been accounted for. Because each of these outcomes is multifaceted and not readily quantified by a single test, batteries of tests were administered to each child. Ultimately, performance on these measures was reduced to a single factor score for each outcome by creating a weighted combination of scores from each test battery using principal components analysis.

Principal components analysis provides a means of summarizing a collection of measures by substituting a

single score for the collection of original variable scores. The approach is motivated by the belief that a collection of measures all tap the same ability or aptitude and that a single summary score would be more economical than multiple scores. Principal components analysis forms this summary score by creating a weighted linear combination of the original variables, which is no different in principle than the common practice of summing multiple items on a questionnaire. However, in the case of principal components, the variables are weighted optimally so that the composite score best captures the information in the set of original variables. When a single principal component accounts for the majority of variability in the set of original variables, we can be assured of its validity as a representative index. The proportion of original variable variance that overlaps with the principal component provides an objective measure of the validity of the derived score. To say that a principal component accounts for 60% of the original variable variance means that 60% of the information in the set of original variables is represented in the single principal component score. Generally, components that account for more than 50% of the original variable variance are considered to be excellent summary scores. The battery of tests used to measure each dependent variable is listed in Table 3, along with each test’s relative factor loading (FL) in the overall factor score.

All speech perception tests were administered using recorded stimuli presented at 70 dB SPL in the soundfield.

**Figure 6.** Classroom communication mode rating for each of 136 subjects averaged over 5 years plotted in order of increasing emphasis on speech and auditory skill development.



**Table 3.** Test battery and factor loadings (FL) for composite score on each outcome.

<i>Speech perception</i>	<i>FL</i>	<i>Speech production</i>	<i>FL</i>	<i>Spoken language</i>	<i>FL</i>	<i>Total language</i>	<i>FL</i>	<i>Reading</i>	<i>FL</i>
ESP	.88	McG-HC	.93	IPSyn NP <sup>a</sup>	.87	IPSyn NP <sup>b</sup>	.79	PIAT rec	.95
WIPI	.88	McG-LC	.91	IPSyn VP <sup>a</sup>	.95	IPSyn VP <sup>b</sup>	.89	PIAT comp	.90
LNT	.93	% consonants	.95	IPSyn QN <sup>a</sup>	.67	IPSyn QN <sup>b</sup>	.52	WRMT wa	.88
MLNT	.92	% vowels	.68	IPSyn SS <sup>a</sup>	.93	IPSyn SS <sup>b</sup>	.89	RHYME	.59
BKB	.92	Dyalog	.87	Types <sup>a</sup>	.96	Types <sup>b</sup>	.85	LD	.65
VidSPAC	.78	% plosives	.73	Morph <sup>a</sup>	.83	Morph <sup>b</sup>	.82		
CHIVE	.94	SPQ	.89	Wd/Utt <sup>a</sup>	.89	Wd/Utt <sup>b</sup>	.89		
ARQ	.69			Fluency <sup>a</sup>	.87	NAS	.83		
						WISC-sim	.79		
						TACL-wc	.56		
						TACL-gm	.62		
						TACL-es	.77		

**Note.** Speech Perception: ESP = Early Speech Perception Test for Profoundly Deaf Children (Moog & Geers, 1990); WIPI = Word Intelligibility by Picture Identification (Ross & Lerman, 1971); LNT = Lexical Neighborhood Test (Kirk, Pisoni, & Osberger, 1995); MLNT = Multisyllabic Lexical Neighborhood Test (Kirk, Pisoni, & Osberger, 1995); BKB = Bamford Kowal Bench Sentences (Bamford & Wilson, 1979); VidSPAC = Video Game Test of Speech Pattern Contrast Perception (Boothroyd, 1997); CHIVE = Children's Visual Enhancement Test (Tye-Murray & Geers, 1997); ARQ = Auditory Responsiveness Questionnaire. Speech Production: McG = McGarr sentences (McGarr, 1983); HC = high context; LC = low context; Dyalog = Dyalog Communication Analysis (Erber & Weiner, 1997); SPQ = Use of Speech Questionnaire. Spoken/Total Language: IPSyn = Index of Productive Syntax (Scarborough, 1990); NP = noun phrases; VP = verb phrases; QN = questions/negatives; SS = sentence structures; NAS = Narrative Ability Score (Crosson & Geers, 2001); WISC-III = Wechsler Intelligence Scale for Children, Third Edition (Wechsler, 1991); TACL = Test for Auditory Comprehension of Language-Revised (Carrow, 1985); wc = word classes; gm = grammatical morphemes; es = elaborated sentences. Reading: PIAT = Peabody Individual Achievement Test-Revised (Dunn & Markwardt, 1989); Rec = reading recognition; Comp = reading comprehension; WRMT = Woodcock Reading Mastery Tests-Revised (Woodcock, 1987); wa = word attack; LD = lexical decision task. <sup>a</sup>Based on spoken language sample; <sup>b</sup>Based on spoken and signed language sample.

Measures of closed-set word identification included the Central Institute for the Deaf Early Speech Perception Test (ESP; Moog & Geers, 1990) and the Word Intelligibility by Picture Identification test (WIPI; Ross & Lerman, 1971). Open-set word recognition was assessed with the Lexical Neighborhood Test and the Multisyllabic Lexical Neighborhood Test (LNT/MLNT, Kirk, Pisoni, & Osberger, 1995). Open-set sentence recognition was assessed with the Bamford Kowal Bench Sentences (BKB; Bamford & Wilson, 1979). Discrimination of phonetic contrasts representing the features of place, manner, voicing, and vowels was assessed with the Video Game Test of Speech Pattern Contrast Perception (VidSPAC; Boothroyd, 1997). Lipreading enhancement was assessed with the Children's Visual Enhancement Test (CHIVE; Tye-Murray & Geers, 1997). An "Auditory Responsiveness Questionnaire" (ARQ) specifically developed for this study recorded the parents' observations of the child's auditory behaviors while wearing the implant. The speech perception outcome variable score accounts for 76% of the total variance in the eight speech perception measures, making it a valid summary score.

The speech production battery included an estimate of overall speech intelligibility based on word recognition by naive listeners for audio recordings of the 36 McGarr sentences (McGarr, 1983; Tobey et al., 2000). The McGarr sentence list contains an equal representation of high-context sentences (McG-HC; e.g., the flag is red, white, and blue) and low-context sentences (McG-LC, e.g., the fat baby cried). Percentage correct phoneme production was

established for consonants (% consonants) and vowels (% vowels) by comparing a phonetic transcription of these sentences with the targeted production. Effective conversational use of speech was estimated by determining the percentage of time that was spent in a breakdown in a videotaped conversation using the Dyalog analysis procedure (Erber & Weiner, 1997). Correct manner of production was established for plosive sounds in imitated sentences (% plosives; Uchanski, Torretta, Geers & Tobey, 1999). Speech intelligibility ratings were obtained from the child's parent, who completed a "Use of Speech Questionnaire" (SPQ) developed for this study that reported how well the child's speech was understood by listeners with varying degrees of experience with deaf speech. The speech production outcome variable score accounts for 83% of the total variance in the seven speech production measures, making it a valid summary score.

Spoken language competence was measured in a videotaped 20-minute conversation with an examiner who did not use sign language. The child's spoken words were transcribed orthographically and verified by trained teachers of the deaf using the CHAT format of the CHILDES system (MacWhinney, 1995). Each utterance was scored for syntactic complexity (Index of Productive Syntax; Scarborough, 1990) in four categories: noun phrase (IPSyn NP), verb phrase (IPSyn VP), question/negative (IPSyn QN), and sentence structure (IPSyn SS). In addition, counts were made of the number of different words (TYPES), number of bound morphemes per word (MORPH/WD), and number of words per utterance (WD/UTT). An oral

conversational fluency rating (FLCY) was obtained by subtracting the percentage of the last 10 minutes of the conversation spent in breakdown (Erber & Weiner, 1997) from the percentage of child talk time. The speech production outcome variable score accounts for 78% of the total variance in the eight spoken language measures, making it a valid summary score.

Total English language competence in speech and sign was assessed using total communication with all children, whether or not they knew sign language. A 20-minute language sample was elicited on videotape. The examiner communicated with the children using simultaneous communication (speech and Signed English). All of the child's recognizable utterances, whether spoken or signed, were transcribed and scored for syntactic complexity using the four IPSyn categories, and counts were made of the number of different words, number of bound morphemes per word, and number of words per utterance. Use of cohesive language was assessed with a picture sequence story from which a Narrative Ability Score was obtained (NAS; Crosson & Geers, 2000). Verbal reasoning was assessed with the Similarities subtest of the WISC-III (WISC-sim; Wechsler, 1991). The Test for Auditory Comprehension of Language-Revised (TACL-R; Carrow, 1985) was used to assess comprehension of language structures. Scores were obtained for the three subtests: Word Classes (TACL-wc), Grammatical Morphemes (TACL-gm), and Elaborated Sentences (TACL-es). The total language outcome variable score accounts for 61% of total variance in the 12 total language measures, making it a valid summary score.

The two reading subtests from the Peabody Individual Achievement Test-Revised (Dunn & Markwardt, 1989) were administered: Reading Recognition (PIAT-rec) and Reading Comprehension (PIAT-comp). Responses could be either spoken or signed. The Word Attack subtest from the Woodcock Reading Mastery Test (WRMT-wa; Woodcock, 1987) was used to determine grade-equivalent scores for phonic and structural analysis skills. This task required the child to pronounce nonsense words using speech. Finally, two tasks were constructed to assess phonological coding skills. The rhyme recognition (RHYME) task consisted of

40 cards, each containing 2 printed words. The child sorted the cards into word pairs that "sound alike" and those that "don't sound alike." Results are expressed as a percentage of errors on word pairs where auditory and visual cues conflict and the child must use phonological skills to respond correctly. The lexical decision (LD) task consisted of 132 cards each containing a printed word that the child sorted as a real word or a nonword. Half of the nonwords were homophonic to their corresponding real word (e.g., *word*, *werd*) and the remaining half were nonhomophonic (e.g., *some*, *somo*). Results are expressed as the percentage of errors in which homophonic nonwords are classified as words. The reading outcome variable score accounts for 65% of the total variance in the five reading measures, making it a valid summary score.

## RESULTS

The purpose of the analysis was to assess the effects of the independent (i.e., educational) variables on each of the five dependent variables after variance as a result of intervening variables had been removed. Linear regression was used to partial out the variance in each outcome that was associated first with child and family characteristics, then with implant characteristics, and finally with the remaining variance predicted by the educational variables. Results for child and family characteristics are summarized in Table 4. Standardized coefficients represent the magnitude of contribution of each intervening variable to an outcome after variance as a result of all of the other listed variables has been accounted for. The total variance accounted for by child and family characteristics ranged from 11% for spoken language to 20% for reading. Performance IQ on the WISC-III (Wechsler, 1991) contributed significant variance to all outcomes and was the only significant independent predictor among the child and family characteristics in speech perception, speech production, and spoken language. Older children (i.e., 9-year-olds) achieved higher reading scores than younger children (i.e., 8-year-olds), and children who lost their hearing later

**Table 4.** Effect of child and family characteristics on each outcome variable.

	<i>Speech perception</i>	<i>Speech production</i>	<i>Spoken language</i>	<i>Total language</i>	<i>Reading</i>
Age	-.10	-.09	.00	-.06	.19*
Age at onset	-.03	.07	.11	.20*	.17*
Age at implant	-.07	-.10	-.07	-.05	-.08
Performance IQ	.32***	.29***	.20*	.21*	.34***
Family size	-.15	-.15	-.16	-.17*	-.11
Parent's education	.08	.07	.13	.20*	.13
Total variance (R <sup>2</sup> )	18%	15%	11%	17%	20%

(*df* 6,129)

\**p* < .05, \*\**p* < .01, \*\*\**p* < .001

achieved higher reading scores than those who were deaf from birth. In addition to IQ and age at onset, higher levels of total language performance were associated with smaller family size and more highly educated parents.

Added variance accounted for by implant characteristics (after variance as a result of child and family characteristics was removed) is summarized in Table 5. Measures derived from the implant and the map accounted for between 17% and 26% of variance in outcome factor scores. With the exception of loudness growth, all implant characteristics contributed significant independent variance to every outcome.

Table 6 identifies the educational variables that made a significant contribution to outcome performance after all intervening variables associated with the child, the family, and the implant were controlled. The amount of added variance ranged from 5% for total language outcome to 18% for speech production outcome. With implant and family characteristics held constant, the consistently significant variable associated with performance on speech perception, speech production, spoken language, and reading outcome measures was classroom communication mode. This variable represents the extent to which the child's program emphasized speech and auditory input over signed input. Classroom communication mode made no significant contribution to the total language factor score

(i.e., there was no advantage exhibited by children from either oral or total communication programs). Higher outcome scores in language and in reading were associated with placement in a mainstream classroom.

Some of the independent variables that did not reach significance when all of them were considered together were significant when they were considered individually. A greater number of hours of therapy and parent participation in therapy were each independently associated with speech perception and speech production skill. However, when these factors were considered in combination with communication mode, the effects were no longer significant. Children who achieved the most intelligible speech were more likely to be placed in private schools and in mainstream classes. However, as with speech perception, when these factors were combined with communication mode, they no longer contributed significant additional variance.

When all outcomes were combined together into a single factor score, the predictor variables included in this analysis accounted for 54% of the variance in overall post-implant outcome. The largest sources of variability were from child and family characteristics, which accounted for 18%, and implant characteristics, which accounted for 24%. Once the variance as a result of these intervening variables was removed, educational factors, primarily communication mode, accounted for 12% of additional variance.

**Table 5.** Effect of implant characteristics on each outcome variable.

	<i>Speech perception</i>	<i>Speech production</i>	<i>Spoken language</i>	<i>Total language</i>	<i>Reading</i>
Duration of SPEak	.23**	.22**	.19*	.25**	.20*
# of active electrodes	.24***	.16*	.22**	.18*	.16*
Dynamic range	.27***	.21**	.20**	.21**	.23**
Loudness growth	.17*	.24**	.24**	.18*	.15
Added variance ( $\Delta R^2$ )	26%	22%	23%	21%	17%

(*df* 4,131)

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

**Table 6.** Effect of educational factors on each outcome variable.

<i>Independent variables</i>	<i>Speech perception</i>	<i>Speech production</i>	<i>Spoken language</i>	<i>Total language</i>	<i>Reading</i>
Hours of therapy	.13	.13	.08	.12	.06
Therapist experience	.03	.05	.01	-.02	-.02
Parent participation	-.04	-.04	.06	.07	.05
School setting <sup>a</sup>	.02	.12	.01	-.07	-.06
Type of class <sup>b</sup>	.06	.13	.13*	.18*	.23**
Communication mode	.37***	.30***	.30***	.14	.18*
Added variance ( $\Delta R^2$ )	16%	18%	10%	5%	7%

(*df* 6,129)

<sup>a</sup>Public/private; <sup>b</sup>Mainstream/special education.

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

## CONCLUSION

Children who receive cochlear implants before 5 years of age are presented with auditory information at a crucial time for speech and language development. The extent to which a child will use this information to achieve speech, language, and reading competence is affected by a variety of factors: (a) those that the child brings to the learning environment, (b) those that are provided by the implant itself, and (c) those that are provided by parents and professionals conducting the child's rehabilitation program. The results of this study help us to understand the importance of each of these components.

### What the Child Brings to the Learning Environment

Our findings indicate that the most important characteristic that a child brings to the task of learning from a cochlear implant is good nonverbal intelligence. Once this variable is held constant, earlier age at implant (for children implanted between 22 and 62 months of age) and later age at onset of deafness (for children who lose hearing before age 3) do not contribute significantly to speech perception and production skill levels measured at ages 8–9. Although some period of normal hearing appears to affect overall language and reading skill development, age at implant has no such effect on the development of speech perception, speech production, or language or reading skills. This result suggests that the urgency to implant children in infancy deserves further evaluation.

Likewise, characteristics of the family do not seem to provide a particular advantage or disadvantage (given that an adequate motivation for implantation and follow-up rehabilitation is present). Children of highly educated parents did not achieve significantly better outcomes than those of less educated parents when intelligence was factored out. However, there was a tendency for smaller families to have children who had somewhat better total language development.

### What the Implant Contributes

The overall functioning of the cochlear implant, particularly duration of use of the updated SPEak coding strategy, had a substantial impact on all outcome areas examined. As engineering improvements in speech processing are made, it is important that children gain access to the technological improvements provided as soon as they are available. Because the field of electronic speech processing is evolving rapidly, upgrades in speech processors should be considered on a relatively frequent basis. No child should be left with an outdated processor. The benefits of improved technology are apparent in these data.

Better outcomes were associated with a larger number of active electrodes in the cochlear implant map. The importance of number of active electrodes should not be interpreted to suggest that "more is always better." The fact that

all of the reported data were derived from the only implant device available when these children were first implanted (the Nucleus 22-electrode model from Cochlear Corporation) means that anything with fewer than 20 electrodes represents a less than optimal device. Alternative cochlear implants that are currently available (e.g., the Clarion and Med-El devices) use different speech processing strategies on differing numbers of electrodes. A complete insertion of the electrode array and a map that activates all available electrodes will go a long way toward promoting optimal performance.

The audiologist who programs the cochlear implant makes a particularly important contribution to the child's potential successful outcome with the device. Once the processing strategy and the number of active electrodes have been maximized, it is the audiologist's role to achieve the most appropriate and balanced map possible for that child. A well-fitted map, as evidenced by a wide dynamic range and optimal growth of loudness characteristics, contributed substantial variance for all outcomes. This is a particularly important consideration in the mapping of newly implanted infants, who may not be able to respond to traditional mapping techniques.

### What the Rehabilitation Program Provides

The primary rehabilitative factor associated with desirable performance outcomes was educational emphasis on oral–aural communication. Communication mode was more important to auditory and spoken language development than any other rehabilitative factor examined, including classroom placement (public or private, special education, or mainstream), amount of therapy, experience of therapist, or parent participation in therapy. Children whose educational program emphasized dependence on speech and audition for communication were better able to use the information provided by the implant to hear, speak, and read. Use of sign communication with implanted children did not promote auditory and speech skill development and did not result in an advantage for overall English language competence, even when the outcome measure included sign language. Oral education appears to be an important educational choice for children who have received a cochlear implant before 5 years of age.

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 months and 10 years. The Connor et al. study compared consonant production and vocabulary development of children with cochlear implants who were enrolled in OC or TC settings throughout Michigan and parts of Ohio and Indiana. Results for 70 children implanted by age 5 showed no difference between OC and TC groups in consonant production accuracy. However, relatively greater vocabulary growth was observed for the TC group. Differences between the current study and the Connor et al. results may be related to the samples studied and the types of speech and language measures employed. Unlike in the present study, the number of children followed for 4 to 6 years after implantation in the Connor et al. study was small

(<30) and included even fewer children implanted under the age of 5. Furthermore, the group in the present study was much more homogeneous in chronological age and heterogeneous in the geographical distribution of educational programs sampled and the breadth of measures used to assess speech and language abilities. Conner et al. pointed out that most of the children in their sample were from Michigan, a state that may provide an emphasis on quality TC programming. In the present study, the speech outcome was heavily weighted for intelligibility and the language outcome for English syntax. In contrast, the findings of the Conner et al. study were based on phoneme production and single-word vocabulary. Clearly, each study examined critical, yet different, components of OC. Additional studies are needed to achieve a comprehensive picture of the influences of communication modalities on the development of all oral language components for children with cochlear implants.

Parents and clinicians can do little to change their child's intelligence or electrode array. However, they can ensure that the child acquires the most up-to-date processing strategy with a well-fitted map that permits maximum dynamic range and loudness growth. They can also strive for a consistent emphasis on speech and auditory skill development in their chosen educational program and in communication interactions throughout the day. Results of this study indicate that attention to these factors can make a significant difference in the overall benefit children obtain from cochlear implantation.

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