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Spoken Language Scores of Children Using Cochlear Implants Compared to Hearing Age-Mates at School Entry

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This study investigated three questions: Is it realistic to expect age-appropriate spoken language skills in children with cochlear implants (CIs) who received auditory–oral intervention during the preschool years? What characteristics predict successful spoken language development in this population? Are children with CIs more proficient in some areas of language than others? We analyzed language skills of 153 children with CIs as measured by standardized tests. These children (mean age = 5 years and 10 months) attended programs in the United States ($N = 39$) that used an auditory–oral educational approach. Age-appropriate scores were observed in 50% of the children on measures of receptive vocabulary, 58% on expressive vocabulary, 46% on verbal intelligence, 47% on receptive language, and 39% on expressive language. Regression analysis indicated that, after controlling for the effects of nonverbal intelligence and parent education level, children who received their implants at young ages had higher scores on all language tests than children who were older at implantation. On average, children with CIs performed better on certain language measures than others, indicating that some areas of language may be more difficult for these children to master than others. Implications for educators of deaf children with CIs are discussed.

Before the advent of cochlear implants (CIs), children with profound hearing loss typically acquired language skills at about half the rate of hearing age-mates (Boothroyd, Geers, & Moog, 1991; Dahl et al., 2003), and many were enrolled in special education classes throughout elementary school (Geers, 1990). Now

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children who receive CIs at a young age (i.e., under 24 months of age) can be expected to achieve some language skills at a rate comparable to hearing age-mates (Hayes, Geers, Treiman, & Moog, 2009; Nicholas & Geers, 2007; Svirsky, Teoh, & Neuburger, 2004). These children are entering mainstream classrooms in the early primary grades (Francis, Koch, Wyatt, & Niparko, 1999; Geers & Brenner, 2003). However, age-appropriate spoken language skills are not being attained by all children with significant hearing loss when they reach school age, even those who receive a CI at a young age (Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006; Spencer, 2004). To the extent that specific language skills are delayed in relation to hearing classmates, these children may be at a disadvantage in a mainstream classroom. Identifying the difficult areas and the reasons for variability in spoken language outcomes in these children would be useful to educators as they plan the focus of instruction and prepare their students for education in the mainstream.

This investigation documents the spoken language skills measured in a large group of 5- and 6-year-old children with CIs who were enrolled in oral communication (OC) programs across the United States, including both auditory-verbal and auditory-oral educational settings. A broad range of OC environments was included in order to examine whether the relatively high language levels observed in selected OC programs (Hayes et al., 2009; Moog & Geers, 1999) can be generalized to similar educational settings. A battery of standardized language tests was employed to expand on previous findings from a nationwide sample of orally educated 3- to 4-year olds which indicated that rate of development may depend upon the language domain assessed (Nicholas & Geers, 2007). These data are used to estimate the likelihood that children who have the benefit of early educational intervention and cochlear implantation will develop age-appropriate spoken language, an important prerequisite for successful academic progress in a mainstream placement. Results are reported on tests that have been standardized on large normative samples of hearing children and that are commonly included in a clinical assessment battery. Student characteristics that could impact spoken language development are examined in order to determine their influence on measured outcomes across the test battery. The current study has three objectives: (a) to document language levels of children with CIs in OC programs, (b) to identify factors that predict variability in language scores, and (c) to identify differences in language scores related to the language domain tested.

Objective 1: Documenting Language Levels in OC Programs

First, we will document the proportion of children with CIs, enrolled in OC preschool programs, who acquire age-appropriate spoken language skills in time for kindergarten. To our knowledge, no other study has looked at several different spoken language skills in such a large, geographically diverse group of 5- to 6-year-old children with CIs. The 5- to 6-year-old age range was targeted because it marks the point of transition from preschool to elementary school in the United States and is frequently the age at which children with CIs are mainstreamed with hearing peers (Geers & Brenner, 2003). The current sample is restricted to students using exclusively spoken language to communicate so that variability in test scores that might be associated with communication mode can be eliminated.

The educational programs participating in this study represent a range of preschool options and OC intervention methods, including both parent-centered and child-centered and private and public. A common goal of these programs is to prepare children for successful integration with hearing age-mates at the earliest age feasible. The current study is designed to identify children who exhibit readiness for mainstreaming as evidenced by their scores on standardized measures of spoken language.

Objective 2: Identifying Factors that Predict Variability

Second, we aim to contribute information to the literature about which factors facilitate successful acquisition of spoken language in children who use CIs. A number of factors have been identified that may contribute to the rate of spoken language growth in children who are deaf or hard of hearing whether they use hearing aids or CIs (Geers, Nicholas, & Moog, 2007). For example, girls with CIs have been found to exhibit higher language scores than boys (Geers, Nicholas, & Sedey, 2003). Other factors include cognitive ability (Dawson, Busby, McKay, & Clark, 2002; Geers, Nicholas, & Sedey 2003; Moeller, 2000), family socioeconomic status (Powers, 2003), age at onset of deafness (Blamey et al., 2001; Stacey, Fortnum, Barton, & Summerfield, 2006), and pre-implant hearing levels (Kishon-Rabin, Taitelbaum-Swead, Ezrati-Vinacour, & Hildesheimer, 2005; Nicholas & Geers, 2006). Intervention factors have also been identified that influence spoken language outcome regardless of sensory aid used, including age at educational intervention (Moeller, 2000; Ramkalawan & Davis, 1992; Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998) and family involvement (Moeller, 2000).

When examining the effects of CIs on language scores, it is important to first identify variability that may be due to such intrinsic characteristics and environmental influences (Blamey, 2003). Only then can we accurately represent the contribution of implant-related factors such as age at cochlear implantation (Kirk, Miyamoto, Ying, Perdew, & Zuganelis, 2003; Nicholas & Geers, 2006; Svirsky et al., 2004), generation of implant technology and mapping characteristics (Connor, Hieber, Arts, & Zwolan, 2000; Geers, Brenner, & Davidson, 2003) or duration of implant use (Fryauf-Bertschy, Tyler, Kelsay, Gantz, & Woodworth, 1997).

Understanding the effects of these factors on language scores is complicated by the fact that they may covary and, thus, obscure the true source of variation. For example, some studies have documented that families who seek a CI for their child are more affluent and educated than parents who do not (Fortnum, Marshall, & Summerfield, 2002), which may independently influence the language levels observed in this group. Socioeconomic factors may also covary with age at cochlear implantation, placement in private educational settings, and choice of an oral communication option (Geers & Brenner, 2003; Stacey et al., 2006). Students with more recent CI technology may be implanted at younger ages due to changes in the criteria for CI candidacy over time (Connor et al., 2006). Cochlear implantation may be postponed for children who get more benefit from hearing aids so that children implanted at younger ages frequently have had less residual hearing preimplant, thereby attenuating the relative benefit of early cochlear implantation (Nicholas & Geers, 2006). In addition, children implanted at younger ages may have had longer durations of implant use when their language outcome is measured (Nicholas & Geers, 2007). There are many such examples of correlated predictor variables, and as a result, many of these studies have had conflicting results. Isolating one predictor from the other contributing factors would make it possible to more accurately ascertain the true source of variability. This study uses multiple regression analysis to examine the influence of a number of factors simultaneously. Such analyses require a large sample size as in this study, making it possible to identify variance associated with each predictor when the other contributing factors are statistically controlled (Strube, 2003).

Objective 3: Identifying Differences Related to Language Domains Tested

Our third objective is to investigate variability in language scores across a variety of language tests that assess different language domains and that have been standardized on children with normal hearing. These widely used language tests express a child's performance as a standard score in relation to normative samples of age-matched hearing children. It is possible that children with CIs have different levels of proficiency depending on the language domain being measured. If we find that children with CIs have higher scores on some tests than other tests relative to hearing norms, this is a potentially important piece of information for educators and parents who may rely on assessment results to determine educational placements. Documenting differences in standard scores among language tests may serve to highlight areas that are more difficult for deaf and hard-of-hearing children (e.g., syntax) and identify skills that reach age-appropriate levels more easily (e.g., vocabulary). This result has practical implications for professionals who must make decisions about mainstreaming these children, in part based on standardized test results.

Careful evaluation using a broad array of assessments is needed because children with CIs may not be equally proficient in all areas of language. Having the full range of language skills commensurate with hearing age-mates facilitates full participation and appropriate academic progress.

Rationale for the Current Study

To reiterate, the current study is intended to (a) estimate the proportion of children with CIs enrolled in OC programs across the United States who exhibit age-appropriate standard scores on language tests at 5–6 years of age, (b) identify factors that affect these spoken language scores, and (c) determine the extent to which standard scores and the factors affecting them depend upon the specific language skill measured. We hope these findings will inform professionals regarding performance level expected from early CI recipients in relation to hearing age-mates and further explain how language outcomes may depend on the language measures used and sample characteristics.

Methods

Participants

Thirty-nine OC education programs located in 20 different states across the US contributed test scores to this study. Language test results were recorded for all children enrolled between 2003 and 2006 who met the following selection criteria: (a) 5–6 years and 11 months of age at testing, (b) age at onset of profound deafness 20 months or younger, (c) age at CI activation before 5 years, (d) duration of CI use 12 months or greater, and (e) nonverbal IQ $\geq$ 70. A total of 153 children met these sample selection criteria. All participants were enrolled in early intervention programs that used auditory approaches to teach spoken language and which emphasized parent support and follow through. Most of the children were enrolled in private auditory–oral school programs, although four public school programs and three auditory–verbal practices were represented. Children received individualized spoken language instruction from certified teachers, speech-language pathologists, or auditory–verbal therapists. No sign language was used in any of the programs. Children received consistent audiological management, and CI use was carefully monitored by parents and teachers. Sample characteristics are summarized in Table 1. This OC group of children was of average intelligence and the mean highest educational level completed by either parent was close to completion of a 4-year college program. In all, 86% of the participants had onset of deafness at birth. Twelve of the children acquired deafness between 1 and 12 months and the remaining 10 between 13 and 19 months of age.

Table 1 Sample characteristics

	Mean	*SD*	Range	*N*
Age CI stimulation (years, months)	2, 4	0, 11	0, 11–5, 1	153
Age at onset (months)	2.09	5.75	0–20	153
PIQ	105.6	15.5	70–140	153
Highest parent education (years)	15.53	2.05	10–20	153
Age at test (years, months)	5,10	0, 6	4, 11–6, 11	153
Age first aided (months)	12.24	7.58	1–36	153
Duration CI use (years, months)	3, 6	0, 11	1, 0–5, 4	153
Year of implant	2001	1.5	1998–2004	153

Children received implants between 1998 and 2004 and had used an implant for at least a year at the time of testing. Only one child had received an implant below 1 year of age (i.e., at 11 months), 73 were implanted between 12 and 23 months, 45 between 24 and 35 months, 24 between 36 and 47 months, and 10 were implanted after their fourth birthday. The following devices were represented in this group: 5 Med-El, 66 Advanced Bionics (26 were C1.2, 38 were CII, and 2 were HiRes), and 78 Nucleus (22 were Nucleus-24, 17 were Nucleus 24-R, and 39 were Nucleus-24M). Device type was unknown for four of the children. Four children had bilateral implants. Children who had experienced device failures lasting more than 30 days were excluded from the sample.

Procedures

Participating programs either provided the requested test results from their records or obtained parent consent for our research staff to travel to their facility to test all children who met the sample selection criteria. All tests were administered by qualified speech-language pathologists, teachers of the deaf, or psychological examiners who had received training in standardized administration procedures. The spoken language skill areas evaluated were Vocabulary (receptive and expressive), Language (receptive and expressive), and Intelligence (Performance and Verbal). The test battery typically consisted of the same set of tests, but occasionally, results on a different test were accepted if administered as part of a completed assessment battery that contained all the other measures and the alternate test targeted the same language domain. On all tests, items increase in difficulty and testing proceeds until the child reaches a specified ceiling of incorrect responses. Standard scores are obtained in relation to the normative sample of age-matched hearing children, where the group mean is set at 100 and scores between 85 and 115 represent ± 1 *SD*.

Expressive Vocabulary

The majority of children ($N = 126$) received the Expressive One-Word Picture Vocabulary Test (EOWPVT; Gardner, 2000). The remaining 27 children received the Expressive Vocabulary Test (EVT; Williams, 1997). Both tests measure the quality and quantity of vocabulary by having the student name a series of pictures that are ordered developmentally. Items on both tests represent both general and concrete concepts as well as semantic categories.

Comparability of standard scores on the EOWPVT and EVT Tests was determined from a sample of 61 children with severe-profound hearing loss enrolled in the Moog Center for Deaf Education, who received these two tests within the same year (25 of these children had the two tests on the same day and 31 within the same week). The mean standard score on the EOWPVT test was 87.95 ($SD = 14.39$) and on the EVT was 85.79 ($SD = 15.15$). The difference between test means was not statistically significant ($t = 1.275$; $p > .20$).

Receptive Vocabulary

Most of the children (137) were tested on the Peabody Picture Vocabulary Test (PPVT) (L. Dunn & L. Dunn, 1997), a measure of comprehension of standard American English words. The remaining 16 children received the Receptive One-Word Picture Vocabulary Test (ROWPVT) (Brownell, 2000). In both tests, no verbal response is needed because the child simply selects the picture of the named item from a choice of four pictures. Items consist primarily of nouns, verbs, and adjectives. The mean standard score of children who took the PPVT (85.71; *SD* 18.5) did not differ significantly from that of children who took the ROWPVT (86.6; *SD* 19.5).

Spoken Language

Most of the children ($N = 147$) were administered the Clinical Evaluation of Language Fundamentals (CELF). Sixty-seven received the first edition of the preschool level (CELF-P; Wiig, Secord, & Semel, 1992) and 72 second edition (CELF-P2; Wiig, Secord, & Semel, 2004). Eight of the children were tested with the CELF-III (Semel, Wiig, & Secord, 1995) or IV (Semel-Mintz, Wiig, & Secord, 2003) and six subjects received the *Preschool Language Scale* (PLS; Zimmerman, Steiner, & Pond, 2002). These tests evaluate the oral language skills of children who have normal hearing and provide separate receptive and expressive standard scores. Subtest scores between 8 and 12 are considered within the average range for hearing age-mates. Receptive subtests tap skills such as understanding oral commands of increasing length and complexity (e.g., "Point to the turtle before you point to the fish."), understanding modifiers and spatial concepts (e.g., *last*, *empty*, *bottom*), understanding semantic relationships between words (e.g.,: *bread*, *a shoe*, and *an apple*), and understanding spoken sentences that increase in length and complexity (e.g., "The man is driving a big red truck."). Expressive subtests require skills such as repeating increasingly complex sentences modeled by the examiner (e.g., "I fell and hurt myself."), labeling pictures that illustrate nouns and present progressive verbs (e.g., *buttons, riding*), and using morphological rules and forms (e.g., "Here are three frogs. Here are three ____." *bugs*). Although there are some minor differences between the items employed on the CELF-P and the CELF-P2, there was no significant difference between the total language scores on these two versions (78 and 79, respectively).

Cognitive Ability

All but three children were administered The Wechsler Preschool and Primary Scale of Intelligence (WPPSI), Third Edition (Wechsler, 2002), an individually administered intelligence test standardized on children who had normal hearing and were 2 years, 6 months through 7 years, 3 months of age. The remaining three children received the Wechsler Intelligence Scale for Children (Wechsler, 1991), a similar test standardized on children 6–17 years of age. Both tests are composed of two subscales: the Performance Scale and the Verbal Scale. The Performance subtests do not require verbal responses. When given to children with language delay due to hearing loss, the Performance score most accurately reflects learning ability in relation to hearing age-mates (Ross, Brackett, & Maxon, 1991). The Verbal subtests reflect global language development and verbal reasoning compared to hearing age-mates.

On the WPPSI, the Verbal subtests include *Information*, requiring the child to answer a broad range of questions dealing with factual information, *Vocabulary*, requiring the child to define words, and *Word Reasoning*, requiring the child to identify the concept being described in a series of increasingly specific clues. The Performance subtests include *Block Design*, requiring the child to reproduce designs using red, white, and half-red/half-white blocks; *Matrix Reasoning*, requiring the child to recognize and complete visual analogies; and *Picture Concepts* requiring the child to look at two rows of items and choose two (one from each row) that have something in common. Scores on Verbal IQ (VIQ) and Performance IQ (PIQ) scales are standardized with a mean of 100 and an *SD* of 15. PIQ scores are included with subject characteristics listed in Table 1. VIQ scores are part of the language outcomes listed in Table 2.

Table 2 Language outcome standard scores with regard to hearing age-mates

	Mean	*SD*	Range	%[a]	*N*
Expressive vocabulary	90.67	18.98	55–134	58	153
Receptive vocabulary	86.11	18.67	41–124	50	153
VIQ	84.24	17.15	50–127	46	153
Receptive language	82.95	20.09	45–122	47	153
Concepts and directions[b]	6.10	3.54	1–15	33	125
Sentence structure[b]	6.53	3.17	1–14	40	125
Expressive language	79.11	20.96	45–128	39	153
Recalling sentences[b]	5.72	3.33	1–15	29	125
Expressive vocabulary[b]	7.85	3.89	1–17	57	125
Word structure[b]	5.76	3.87	1–17	33	125

[a]Percent of children scoring within 1 *SD* of hearing age-mates or higher.
[b]Combined subtest scaled scores from CELF-P and CELF-P2 (mean = 10; *SD* = 2).

Results

Spoken Language Outcomes

Table 2 summarizes the mean and standard deviation of scores on each of the language tests in the battery. The percent of children who scored within the average range when compared to age-mates with normal hearing is also provided. The highest scores were obtained on the receptive and EVTs, where at least half of the children scored within the average range for hearing age-mates. Lower scores were obtained on global language tasks (VIQ) and aspects of connected language and syntax represented on the CELF and PLS, where slightly fewer than half of the sample achieved age-appropriate scores. Subtest scores on the CELF-P or CELF-P2 were reported for 125 of the children. Subtest scores illustrate the relative difficulty of connected language (i.e., Recalling Sentences) and syntax (i.e., Word Structure) when compared to performance on a vocabulary task (i.e., Expressive Vocabulary).

Correlation coefficients were calculated among the total standard scores and results are summarized in Table 3. Language scores were highly, but not perfectly, correlated. The correlation between scores on receptive and expressive vocabulary measures (r = .82) is almost identical to that observed in another study of 112 deaf and hard-of-hearing 5-year-olds that compared PPVT with EOWPVT scores (Moeller, 2000). Although tests score means reflected differences among measures in their relative difficulty for this sample of children, these correlations indicate that children tended to retain their relative position across language domains (i.e., those who scored high in vocabulary also scored high on syntax-related tasks). Correlations among CELF-P subtest scores and the

Table 3 Correlations among language measures: $N = 153$

	Receptive vocabulary	VIQ	Receptive language	Expressive language
Expressive vocabulary	.82***	.88***	.83***	.88***
Receptive vocabulary		.79***	.78***	.83***
VIQ			.83***	.88***
Receptive language				.88***

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

other language measures are presented in Table 4 for the 125 children for whom these scores were reported.

Predictors of Language Outcomes

Table 5 presents correlations among participant characteristics. These correlations reveal considerable redundancy between some predictor variables. For example, duration of implant use was highly correlated with age at implant ($r = -.878$) and year implanted ($r = -.664$). Children who received early hearing aid fitting had early onset of deafness ($r = .399$), were implanted at younger ages ($r = .369$), and had used an implant longer at the time of test ($r = -.313$). Children implanted at older ages were implanted more recently ($r = .473$). Children with higher IQs had more highly educated parents ($r = .243$). Accordingly, these variables are not independent and so their intercorrelations can cause interpretational problems.

Table 6 presents correlations between the predictor variables and scores on each of the five language measures. The highest correlations with language outcome were obtained from four predictor variables: PIQ (higher IQ was associated with higher language scores), Parent Education (families with a more highly educated parent had children with better language), gender (girls scored higher than boys) and age at implant stimulation (younger was better). These variables also exhibited relatively small redundancy when examined using a tolerance statistic. Tolerance values provide an indication of the redundancy of predictors or the proportion of variance in a predictor that cannot be explained by the remaining variables. A tolerance value of 1.00 indicates a completely unique predictor. These four participant characteristics contributed significant unique variance to one or more language outcomes, with tolerance values greater than .90.

Multiple Regression Analysis to Predict Language Outcome

The relative contribution of these four predictor variables to variance in each language outcome was determined using multiple linear regression analysis. Because all the predictor variables were entered into the analysis at the same time, we can determine the percentage of unique variance accounted for by each variable, controlling for the other three predictors. The contribution of the individual predictors in that set is indexed by the *regression coefficients* in the first column of Table 7. These regression coefficients indicate the expected change in language test score for a one-unit change in the predictor variable. For example, each point increase in PIQ increases the expected expressive vocabulary score by .423. These regression coefficients represent the "partialled" relations,

Table 4 Correlations with CELF subtest scores: $N = 125$

			CELF				
	Receptive vocabulary	VIQ	Concepts directions	Sent structure	Recalling sentences	Expressive vocabulary	Word structure
Expressive vocabulary	.82***	.89***	.77***	.77***	.79***	.80***	.77***
Receptive vocabulary		.78***	.72***	.74***	.71***	.75***	.70***
VIQ			.80***	.78***	.81***	.79***	.79***
Concepts/directions				.76***	.78***	.73***	.80***
Sent structure					.76***	.75***	.75***
Recalling sentences						.72***	.79***
Expressive vocabulary							.73***

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

Table 5 Correlations among predictor measures

	Age onset	PIQ	Parent education	Age at test	Age aided	Duration CI use	Year CI
Age at implant	.086	−.027	−.066	.172	.369***	−.878***	.473**
Age at onset	—	.048	−.042	.102	.399***	−.351***	.057
PIQ		—	.243**	−.153	−.052	.087	−.065
Parent education			—	.062	−.055	.063	−.188
Age at test				—	.078	.306***	.000
Age aided					—	−.313***	.017
Duration CI use						—	−.644***

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

meaning that they are adjusted for the other three characteristics. They estimate the expected changes in language score under the assumption that children have the same scores on the other variables. In this sense, the analysis provides a statistical control for these factors. The appeal of this partialling is that it allows a glimpse into the unique contribution that individual variables have. In this instance, all four predictors: PIQ, Gender, Age at Implant, and Parent Education have unique and statistically significant relations with expressive vocabulary (indicated by a p value of $< .01$ for all predictors). The fourth column in Table 7 indicates the proportion of unique variance that each individual factor explains after controlling for the other factors. The difference between the sum of each of these independent sources of variance and the total variance predicted is the amount of shared variance that is associated with correlations among predictor variables. In the case of expressive vocabulary, 12% of the total variance is shared among the four predictors.

Overall, 36%–43% of variance in language outcomes was accounted for by the four measured characteristics of participants. The most powerful predictor across all language outcomes was PIQ, which accounted for between 15% and 24% of unique variance in language scores. Children with higher PIQ had higher scores on all five language outcomes. The next most powerful predictor was level of parent education, which uniquely explained between 4% and 10% of outcome variance. Gender contributed significantly only to the levels achieved in Expressive Vocabulary and VIQ. Although the percentage of independent variance accounted for by age at implant was relatively small (approximately 2.5%), this variable explained significant variance in all language outcome measures even when the effects of PIQ, parent education, and gender were controlled.

Expected Outcomes

The regression analyses were used to calculate the language standard score that could be expected as a function of age at implant when the other predictors (PIQ, parent education, and gender) were centered at their respective sample means. Expected scores allow us to focus on the performance of 5- and 6-year-old children in OC programs based on how young they were when they received a CI, without the influence of

Table 6 Correlation of test scores with predictors

	Expressive vocabulary	Receptive vocabulary	VIQ	Receptive language	Expressive language
Gender	−.237**	−.146*	−.188*	−.136*	−.155*
Age CI stimulation	−.244**	−.231**	.254**	−.227**	−.252**
PIQ	.535***	.503***	.575***	.592***	.518***
Parent education	.408***	.375***	.445***	.334***	.399***
Age at onset	−.083	−.105	−.056	.002	−.040.
Age first aided	−.062	−.033	−.080	−.075	−.111
Duration of CI use	.204**	.175*	.215**	.183*	.225**
Year at implant	−.146*	−.159*	−.167*	−.144*	−.186*

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

Table 7 Multiple linear regression analysis

	Coefficient	*t*	*p*	% Variance
Expressive vocabulary				
Gender	−.19	−3.06	.003	3.40
Age at implant	−.163	−2.6	.010	2.60
PIQ	.423	6.55	.000	16.00
Parent education	.304	4.8	.000	8.80
Shared variance				12.7
Total % variance				43.5
Receptive vocabulary				
Gender	−.101	−1.52	.130	1.00
Age at implant	−.153	−2.3	.023	2.70
PIQ	.406	5.91	.000	19.40
Parent education	.278	4.12	.000	10.60
Shared variance				2.2
Total % variance				35.9
Verbal intelligence				
Gender	−.137	−2.3	.023	1.80
Age at implant	−.165	−2.75	.007	2.70
PIQ	.46	7.44	.000	19.40
Parent education	.334	5.5	.000	10.60
Shared variance				13.6
Total % variance				48.1
Receptive language				
Gender	−.082	−1.3	.195	0.60
Age at implant	−.134	−2.1	.037	1.70
PIQ	.515	7.86	.000	24.30
Parent education	.214	3.33	.001	4.20
Shared variance				11.0
Total % variance				41.8
Expressive language				
Gender	−.109	−1.69	.094	1.20
Age at implant	−.172	−2.65	.009	2.90
PIQ	.412	6.17	.000	15.60
Parent education	.299	4.56	.000	8.50
Shared variance				11.1
Total % variance				39.3

intrinsic characteristics such as intelligence, parent education, or gender. Based on previous research, we expected that children with less CI experience (i.e., older implant age) would have more difficulty catching up than children with more experience, and those results are exhibited in the function plotted in Figures 1–5. In these graphs, a standard score of 85 or higher (shaded area) indicates expressive vocabulary knowledge within or above 1 *SD* of the mean for hearing age-mates. The arrow along the abscissa indicates the implant age below which the expected mean standard score reaches the average range for age-mates with normal hearing.

These regression functions reveal that the expected standard scores on all tests *decrease* as age at implant *increases*. However, individual data points are also provided in these figures, demonstrating that some children did, indeed, reach age-appropriate language levels in spite of very limited implant experience (i.e., less than 24 months of use). These children were more likely to exhibit other characteristics that were associated with high language levels, like higher nonverbal IQ and parent education level, which had been set at the sample mean for these estimates. They are performing above expectation for average sample characteristics.

Figure 1 depicts the expected expressive vocabulary standard score for each age at implant stimulation represented. Based on the predicted group mean, where the influence of PIQ, gender, and parent education have been controlled, we expect 5- and 6-year-olds to score within the average range for expressive vocabulary if they receive an implant by their fourth birthday. It is important, however, to note the variability in observed scores around this predicted mean. Children with PIQ scores below 105 and parent education levels below 15 years were less likely to score at the level predicted for their implant age.

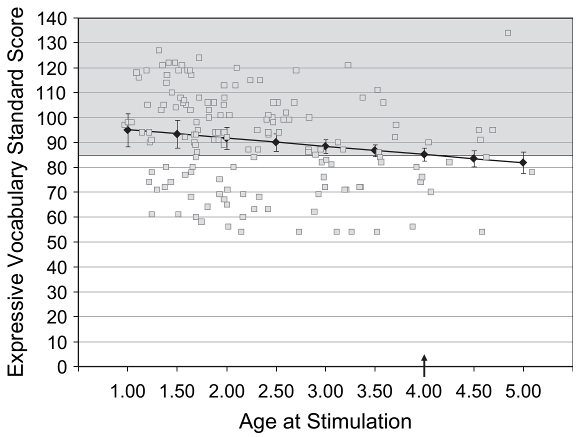

Figure 1 Expressive vocabulary standard scores are plotted by age at implant stimulation for 153 5- and 6-year-old children. The regression line depicts the expected score with gender, nonverbal IQ, and parent education level held constant at the sample means. The shaded area denotes standard scores within 1 *SD* of hearing age-mates or higher. The arrow on the abscissa indicates the point at which the expected standard score is within the age-appropriate range.

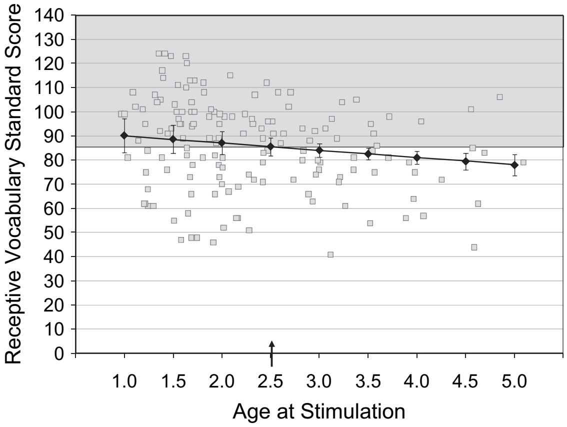

Figure 2 Receptive vocabulary standard scores are plotted by age at implant stimulation for 153 5- and 6-year-old children. The regression line depicts the expected score with gender, nonverbal IQ, and parent education level held constant at the sample means. The shaded area denotes standard scores within 1 *SD* of hearing age-mates or higher. The arrow on the abscissa indicates the point at which the expected standard score is within the age-appropriate range.

Figure 2 presents the regression line for receptive vocabulary standard scores as a function of age at implant. Again, the expected mean standard score decreases as implant age increases. The arrow on the abscissa indicates that the expected mean receptive vocabulary score is within 1 *SD* of hearing age-mates for 5- and 6-year-olds who are implanted by 2.5 years of age.

Figure 3 presents the regression function for VIQ scores. For this outcome, expected mean standard scores reach age-appropriate levels for 5- and 6-year-old children who are implanted by 2 years of age.

Figure 4 shows the function for receptive language scores. For this outcome, expected mean standard scores reach the average range for 5- and 6-year-old children who are implanted by one and a half years of age. Figure 5 presents the function for the expressive language scores. For this outcome, the expected mean standard score does not reach the average range for hearing age-mates unless children received a CI by 12 months of age.

Discussion

This study describes language abilities in a large sample of 5- and 6-year-olds with at least 1 year of CI experience from OC education settings across the United States. The objectives of this study were to determine whether children implanted for a year or more could achieve spoken language skills commensurate with their hearing peers, to investigate factors that contribute to successful spoken language learning, and

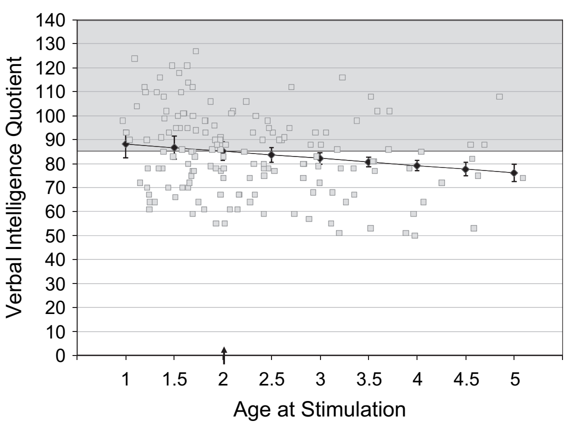

Figure 3 VIQs are plotted by age at implant stimulation for 153 5- and 6-year-old children. The regression line depicts the expected score with gender, nonverbal IQ, and parent education level held constant at the sample means. The shaded area denotes standard scores within 1 *SD* of hearing age-mates or higher. The arrow on the abscissa indicates the point at which the expected standard score is within the age-appropriate range.

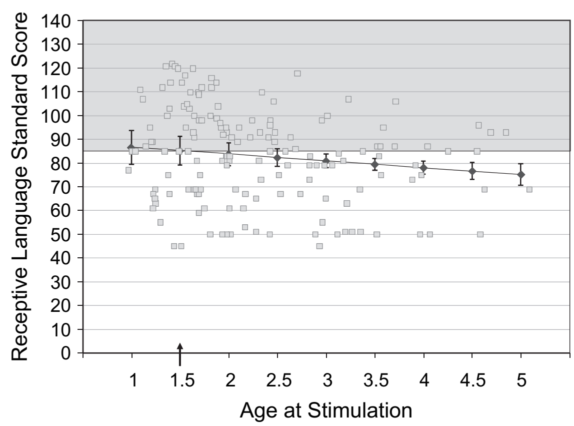

Figure 4 Receptive language standard scores are plotted by age at implant stimulation for 153 5- and 6-year-old children. The regression line depicts the expected score with gender, nonverbal IQ, and parent education level held constant at the sample means. The shaded area denotes standard scores within 1 *SD* of hearing age-mates or higher. The arrow on the abscissa indicates the point at which the expected standard score is within the age-appropriate range.

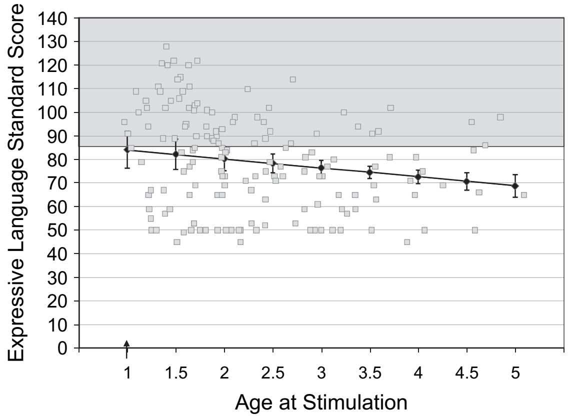

Figure 5 Expressive language standard scores are plotted by age at implant stimulation for 153 5- and 6-year-old children. The regression line depicts the expected score with gender, nonverbal IQ, and parent education level held constant at the sample means. The shaded area denotes standard scores within 1 *SD* of hearing age-mates or higher. The arrow on the abscissa indicates the point at which the expected standard score is within the age-appropriate range.

to identify whether children demonstrate differing levels of success in developing spoken language depending on the language domain measured.

Spoken Language Outcomes and Differences across Language Domains

Vocabulary was a particularly strong language skill in this sample. Scores on EVTs were generally higher and reached age-appropriate levels sooner following cochlear implantation than scores on receptive vocabulary tests. This apparent expressive advantage may be associated with teaching strategies that encourage labeling in beginning language instruction. Similar results have been reported for profoundly deaf hearing aid users before the advent of CIs (Geers & Moog, 1989), where a 2-year mean language age advantage was observed on the EOWPVT over the PPVT. In another study of 112 deaf and hard-of-hearing children using either oral or total communication, 92% scored lower on the PPVT than on the EOWPVT (Moeller, 2000). Because of this difference in the rate of acquisition of receptive and expressive vocabulary skills, it is important that a comprehensive assessment battery include estimates of both vocabulary domains.

When compared to performance on vocabulary measures, fewer children achieved age-appropriate scores on a measure of verbal intelligence (the WPPSI) and on a comprehensive language test evaluating connected language and syntactic knowledge (the CELF-P). Lower scores in syntax may reflect deficiencies in aspects of language that are difficult to hear and produce (e.g., bound morphemes, such as the *ed* in *cried)*. Furthermore, connected language tasks may place demands on auditory memory, which has been shown to be negatively affected by hearing impairment (Pisoni & Cleary, 2003). Similar differences between vocabulary and verbal reasoning/global language skills were reported in samples that included children using total communication; first in 5-year olds with a wide range of hearing losses (Moeller, 2000) and again in 4- to 8-year-old CI users (Spencer, 2004). In a nationwide study of 181 early elementary school-aged children (both oral and total communication) with CIs (Geers, Nicholas, & Sedey, 2003), age appropriate scores on a measure of lexical diversity (number of different words per minute in a language sample) were observed in 62% of the children. However, syntactic measures derived from the same language samples, including number of bound morphemes per word and the Index of Productive Syntax (Scarborough, 1990), revealed age-appropriate skills for only 22 and 44 percent of the sample, respectively. In addition, receptive syntax as measured on the Test for Auditory Comprehension of Language (Carrow, 1985) was within 1 *SD* of hearing age-mates for only 30 percent of this same sample of children. Therefore, the relative advantage of vocabulary skills over verbal reasoning and syntax skills as measured in relation to hearing age-mates appears to be characteristic of children with hearing loss, regardless of age, communication mode, hearing level, or type of sensory aid.

Predictors of Language Outcomes

This study also identified predictors of language levels achieved by 5–6 years of age in order to explain the observed variability among the children in their rate of growth in acquiring spoken language skills. Nonverbal intelligence predicted the largest amount of variance in all language outcomes. PIQ has often been identified as a significant predictor of language outcome in children with hearing loss (Moeller, 2000; Spencer, 2004). However, data gathered from one specific oral program found that IQ did not contribute significantly to language score variance (Hayes et al., 2009). Different results may be associated with the range of IQ scores represented in the sample, particularly at the lower end. Including children with IQs as low as 70 in this sample may have contributed to the significant findings. Scores that are more than a standard deviation below the normal range may reflect additional disabilities, which have been associated with poorer language outcomes following cochlear implantation (Holt & Kirk, 2005; Stacey et al., 2006).

Parent education level also accounted for substantial variance in all outcome measures, even though this sample represented a relatively high average education level (close to graduation from college). Parent education level was likely correlated with other parent variables that have been found to contribute to language development in children with hearing loss, including family income (Powers, 2003) and degree of involvement in the child's intervention program (Moeller, 2000). Socioeconomic level was found to predict communication level in children with normal hearing when low-income families were included in the analysis (Arriaga, Fenson, & Pethick, 1998). However, in a large study of children in the United Kingdom with CIs, speech and language outcomes did not vary with the occupation skill level of the parents (Stacey et al., 2006)
.

In this study, age at CI stimulation accounted for a relatively small, but significant, proportion of variance in language level achieved after gender, IQ, and parent education level were held constant. Language scores improved as age at CI stimulation was reduced. The small size of the implant age effect could have resulted from a restricted range of implant ages in this sample compared to other studies. Most of the children in this sample received an implant between 1 and 4 years of age (only one child received an implant at 11 months and one was implanted just after his fifth birthday). Some studies suggest the critical age for receiving a CI may occur as early as the first year of life (Dettman, Pinder, & Briggs, 2007). Others find that implanting children at a somewhat older age may provide similar advantages (Holt & Svirsky, 2008). Data presented in this study suggest that the critical age for initiating auditory input to maximize a child's chances for catching up with hearing age-mates may vary depending on the language skill being assessed.

It is also likely that some of the children in this sample who were implanted at later ages had received more benefit from hearing aids before receiving a CI. Pre-implant aided hearing level was not included in this analysis, but has been found to improve with increased age at cochlear implantation (Nicholas & Geers, 2006). Early auditory experience with hearing aids provides children with a spoken language advantage that is inconsistent with an older age at implant. Consequently, it is surprising that age at onset of hearing loss did not predict significant language outcome variance because some of the children had normal hearing for a number of months before the onset of profound deafness. However, the range of onset age was so restricted (under 20 months of age), and so few children had onset after birth (only 22 of the 153) that possible effects of normal hearing at a young age were not evident in this sample.

The apparent effects of implant age on language scores may also have been reduced by the homogeneous educational background of this sample. The children had the benefit of early identification of their hearing loss and prompt fitting of hearing aids followed by cochlear implantation during the preschool years. They experienced individualized and intensive spoken language stimulation in infancy from parents who received professional guidance from skilled clinicians. By age 2 or 3, most of the children were enrolled in preschool programs that provided specialized language instruction. Therefore, it is likely that children implanted at later ages had some spoken language pre-implant, which has been positively associated with language acquisition following implantation (Tait, Lutman, & Robinson, 2000).

Contrary to previous findings (Moeller, 2000; Ramkalawan & Davis, 1992; Yoshinaga-Itano et al., 1998), age at diagnosis, intervention, and hearing aid fitting (all occurring at approximately the same age) failed to correlate significantly with any of the language outcome measures. The previous studies, including both deaf and hard-of-hearing children from both oral and total communication settings, documented that age at first intervention is a critical factor determining rate of language acquisition. However, for the current sample of children with profound deafness, early intervention in an OC program did not result in optimum spoken language skill development unless the child received a CI at an early age. Similar results were reported for another nationwide sample of early-implanted children from oral programs (Nicholas & Geers, 2006). This study found that the amount of pre-implant intervention with a hearing aid was not related to spoken language outcome at age 3.5 years. Rather, it was cochlear implantation at a younger age that served to promote spoken language competence.

Although a number of factors might have reduced the impact of younger implantation age on language levels exhibited at age 5 and 6 years, these results indicated that children who received a CI at younger ages were more likely to achieve age-appropriate spoken language levels in time for entering kindergarten or first grade with hearing age-mates. Furthermore, the age by which CI use was associated with this goal varied depending upon the language skill measured. Age-appropriate development of complex language skills seemed to require *earlier* cochlear implantation and longer experience with the implant than the development of vocabulary skills.

Including more variables in future analyses could increase the total variance in language outcome scores accounted for. Additional variables might include aided thresholds, both before and after cochlear implantation, current speech perception scores, amount of family participation in the child's intervention program, and characteristics of the child's implant device. All these factors have been found in previous research to predict language levels achieved following cochlear implantation.

Conclusions

These results on a set of commonly used language instruments reported for a large sample of children from OC education settings confirms and extends previous studies with this population. In addition to supporting the decision to provide CIs to children with profound deafness at the youngest age feasible, these results have important implications for clinicians conducting assessment and intervention in OC education settings. When assessing a child's readiness for mainstreaming, it is important to include measures of all these language domains in order to conclude that the child has "caught up" with hearing age-mates or needs further intervention in a particular area.

The results reported here for a large sample of children, who received CIs at a young age and were enrolled in OC programs across the country, provide evidence that early cochlear implantation has a positive effect on how quickly children with severe profound hearing loss can catch up with their hearing age-mates in spoken language. About half of this sample exhibited spoken language standard scores within the average range for hearing age-mates. This result represents a remarkable achievement for children with this degree of hearing loss and is not unique to this particular sample. Other studies have reported similar results for largely independent samples of OC children who use a CI (Hayes et al., 2009; Nicholas & Geers, 2008). Although there may be some overlap in these samples, this study provided confirmation of language levels observed in a much larger sample of OC children than ever before and expanded these results across a range of standardized language tests. These data suggest that children with CIs who have the benefit of early OC language intervention can be expected to achieve spoken language levels that closely approach those of their hearing age-mates by the early elementary school years.

However, there were a number of children who did not reach age-appropriate levels of spoken language competence. Some factors were identified that were intrinsic to the child and family and are associated with verbal development in populations with normal hearing as well as those with hearing loss. These include the child's intelligence, parent education level, and gender, with girls progressing faster than boys. After holding these factors constant, and with all children receiving early intervention focused on the development of listening and spoken language skills, younger age at implantation was a facilitating factor in language development. However, the optimum age of implantation varied, depending on the language domain being tested. Complex language continues to represent an area of weakness for deaf children, so educators should be strongly encouraged to assess not only vocabulary development but also verbal intelligence, connected language, and complex syntax when considering the amount of support that a child requires and/or the need for continued special education.

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