Expected Test Scores for Preschoolers with a Cochlear Implant Who Use Spoken Language

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Abstract

Purpose—The major purpose of this study was to provide information about expected spoken language skills of preschool-aged children who are deaf and who use a cochlear implant. A goal was to provide "benchmarks" against which those skills may be compared, for a given age at implantation. We also examined whether parent-completed checklists of children's language were correlated with results of standardized language tests and whether scores increased linearly with decreasing age-of-implantation and increasing duration of cochlear implant use.

Method—Participants were a nation-wide sample of 76 children who were deaf and orally-educated and who received an implant by 38 months of age. Formal language tests were administered at age 4.5 years. The MacArthur-Bates Communicative Development Inventory (MBCDI) was completed by parents when children were ages 3.5 and 4.5 years.

Results—Based on regression analyses, expected test scores for each age at implant are provided for two commonly administered language tests at 4.5 years of age and MBCDI subscale scores at 3.5 and 4.5 years. Concurrent test scores were significantly correlated on all measures. A linear relation was found which predicted increasing test scores with younger ages at implantation for all scales administered.

Conclusions—While the expected scores reported here should not be considered as normative data, they are benchmarks which may be useful for evaluating spoken language progress of children with cochlear implants in enrolled in spoken language-based programs.

Published literature shows that children who are profoundly deaf and who receive a cochlear implant often achieve spoken language skills much closer to the skills of their hearing peers than previously possible. Levels of spoken language skill previously achieved only occasionally in children who were profoundly deaf and used hearing aids have now become the norm, with higher levels seen in the areas of speech perception (Eisenberg et al., 2006), speech production (Chin, Tsai & Gao, 2003; Flipsen & Colvard, 2006; Horga & Liker, 2006; Tobey, Geers, Brenner, Altuna, & Gabbert, 2003), language (Moog, 2002; Nicholas & Geers, 2006a; 2006b), and reading (Geers, 2003; Spencer, Tomblin & Gantz, 1998). Many educators and clinicians working with children who have severe-profound hearing loss are revising educational strategies and expectations based upon the general success facilitated by cochlear implant (CI) devices.

Sources of Variability

Prior to surgery, parents often ask clinicians to describe the spoken language proficiency that may be expected following cochlear implantation. During post-implant habilitation, they may

ask whether their child is making expected progress in relation to other children with CIs. Despite the impressive skills achieved by many children with CIs, variability in progress remains a significant concern. The range of observed outcomes adds uncertainty to projecting future progress for individual children and to assessing relative progress as the child gains experience with the implant. When attempting to estimate the spoken language level expected for an individual child, the clinician must consider a range of possible factors that might contribute to or detract from post-implant outcomes.

Early cochlear implantation, in itself, does not insure that a child will develop facility with spoken language. Even in the best case, several years of intensive intervention in a school, therapy, or home setting is usually required for children to be able to achieve age-appropriate spoken language skills. The need for this period of orientation, training, and practice cannot be over-estimated. However, even with this programming in place, there are some children who do not progress in spoken communication skills as quickly as others. It is unclear, in many cases, why some children seem to benefit more from the hearing provided by the implant than others.

There are a number of factors that are being investigated as possible causes of this variability. Potential sources include rehabilitative factors such as the age of the child at diagnosis, amplification, habilitation, CI fitting (Yoshinaga-Itano, 2003; Kirk, Miyamoto, Lento et al., 2002; Nicholas & Geers, 2006a) and whether post-implant educational intervention is speech-based or sign-speech based (Connor, Hieber, Arts & Zwolan, 2000; Moog & Geers, 2003), and whether the child is in a special education or mainstream classroom (Geers, Nicholas & Sedey, 2003). Another set of factors being examined are medical/audiological in nature, including cause of deafness (Mitchell, Psarros, Pegg, Rennie & Gibson, 2000; Bauer, Geers, Brenner, Moog & Smith, 2003; Nikolopoulos, Archbold, & O'Donoghue, 2006), age at onset of deafness (Geers, 2004a), whether better or poorer hearing ear receives the implant (Friedland, Venick & Niparko, 2003; Francis, Yeagle, Bowditch & Niparko, 2005), whether a contralateral hearing aid is used (Holt, Kirk, Eisenberg, Martinez & Campbell, 2005; Ching, Psarros, Hill, Dillon & Incerti, 2001), the CI technology (Geers, Brenner, & Davidson, 2003) and the degree of pre-implant hearing available to the child (Nicholas & Geers, 2006b). The impact of all of these factors must be considered in light of child and family characteristics that may affect language development, including level of nonverbal intelligence (Holt & Kirk, 2005), motor skills (Horn, Pisoni & Miyamoto, 2006), memory/processing abilities (Pisoni & Cleary, 2003; Dawson, Busby, McKay & Clark, 2002), and demographic characteristics such as the child's gender, family size and parents' education (Stacey, Fortnum, Barton & Summerfield, 2006; Geers, Nicholas & Sedey, 2003). In addition, expected language skills change over time as the child matures and accumulates more experience with the CI device. It is important to take into account the effects of these factors on an individual child's expected spoken language achievement at any given point in time.

Pre-Implant Residual Hearing

There is evidence that children with some pre-implant speech recognition ability achieve better open-set speech perception at one year post-implant than children with no pre-implant speech recognition (Zwolan et al., 1997). Furthermore, children with pre-implant speech perception scores as high as 30% with hearing aids have shown improved speech perception following cochlear implantation. This finding has resulted in expanded FDA candidacy criteria (ASHA, 2003) for children implanted at age 24 months or later. However, children implanted at the youngest ages (12-23 months) tend to have more profound hearing losses than those implanted somewhat later (Nicholas & Geers, 2006b). Further, children with greater residual hearing pre-implant have been found to exhibit better spoken language skills following cochlear implantation (Nicholas & Geers, 2006b; Szagun, 2001). This may be due to their early pre-

implant access to language or to better auditory nerve survival. Kuo and Gibson (2000) found better post-implant gains for those with better aided hearing ability above 2000 Hz, though only for children implanted above the age of 10 years. Regardless of the reason for a possible advantage, it is important to control for the effects of pre-implant hearing before examining the effects of implant age on spoken language outcome. We have previously reported (Nicholas & Geers, 2006b) that when the effects of pre-implant hearing were controlled, children who received a CI by their 2nd birthday exhibited an advantage over children who received one between 25-38 months of age.

Validity of Early Language Measures

Obtaining valid estimates of language levels at young ages may present difficulties. Preschool-aged children's day-to-day or hour-to-hour behavior can be highly variable. This variability is one of the major advantages of parent report measures over direct testing, and of using multiple over single measures (Lidz, 1983). While direct sampling of conversational language rates high marks for face validity, it is not a procedure that is easily translated into classroom or therapy assessment situations and it may be affected by a child's attitude or willingness to communicate. On the other hand, use of parent-completed checklists take into consideration a child's maximum performance across a wide variety of situations and are not dependent upon child cooperation at a given moment in time (Fenson et al., 1994; Fenson et al., 1993). However, because parents may not be truly objective, it is important to establish validity of these reports by comparing them to measures based on direct observation, such as from a language sample or formal testing. Studies have been published showing good agreement between such measures when used with normally hearing, typically-developing children (Dale, 1991; Feldman, Dale, Campbell, et al., 2005).

Several recent studies have confirmed the validity of using a parent report checklist in estimating the language of young children with CIs. Thal, DesJardin, & Eisenberg (2007) asked parents to complete the MacArthur-Bates Communicative Development Inventory (MBCDI; Fenson et al., 1993) with reference to 24 children with CIs who were between 32-86 months of age at time of testing. These children were considerably older than the MBCDI's chronologic age norming range. They reported moderate-large correlations between scores on the MBCDI with both formal language test scores and with language variables derived from spontaneous language samples. Similarly, Stallings, Gao & Svirsky (2002) utilized the MBCDI to document the language skills of children with CIs who were older than children in the normative sample and found significant correlations between those scores and concurrent scores on the Reynell Developmental Language Scales (Reynell & Gruber, 1990). Other validity studies have been published utilizing the MBCDI with children who experienced language delay and who also were older the normative sample (Thal, O'Hanlon, Clemmons & Fralin, 1999).

In our previous work, comparison of scores on variables derived from videotaped language samples with those based on parent- or teacher- checklist reports revealed a high degree of association, with correlation coefficients ranging from .64 to .89 (all $p \leq .001$). In fact, the scores on these measures could be combined into a single score that accounted for 77% of the variance in the original set of variables. Those results suggested that parent and teacher reporting instruments may provide valid estimates of language level in a more convenient manner than language sampling, especially at very young ages (Nicholas & Geers, 2006b).

By the time a child is four to five years old, teachers and clinicians typically must limit their assessment efforts to the use of standardized tests that provide age-appropriate normative data for reasons of efficiency and accountability. At the present time no tests are available that provide normative spoken language data gathered on preschool aged children with CIs. Clinicians are left to "make do" with tests designed for administration to children with normal hearing or those normed on children with hearing loss before the advent of CIs. Neither

comparison provides information entirely appropriate for use with this population of children. Comparisons based on children who have heard normally since birth set an unrealistically high standard for those who have not had access to sound during the early language-learning years. On the other hand, comparisons with children who are profoundly deaf and have had very limited auditory speech perception with hearing aids may be unrealistically low when assessing those who have had the benefit of early cochlear implantation.

Language Test Scores following Early Cochlear Implantation

Rate of spoken language progress is often reflected in standardized language tests by a language quotient score. This score is sometimes expressed as a ratio between a norm-based language age-equivalency score and chronological age. More recently, the language quotient is expressed as a standard score relative to the mean and standard deviation of an age-appropriate normative group. Hearing children who comprise normative samples for language tests tend to maintain a fairly constant quotient score over time. Children who are profoundly deaf and use hearing aids display slower spoken language development than hearing age-mates, averaging about half the rate of hearing peers (Boothroyd, Geers, & Moog, 1991). On the other hand, other studies have shown that following cochlear implantation these children start developing language at a near-normal rate (Svirsky, Teoh & Neuberger, 2004). Children who receive a CI by age 3 years have been observed to narrow the gap between their language abilities and those expected for hearing children at their chronologic age. As a result language quotient scores actually improve with longer duration of CI experience (Kirk, Miyamoto, Lento et al., 2002; Kirk, Miyamoto, Ying, Perdew & Zuganelis, 2002) and speech production skills develop at an accelerated rate (Connor, Craig, Raudenbush, Heavner & Zwolan, 2006). Consequently, many children who receive a CI under the age of two years and who receive speech and language services during the preschool years can achieve nearly age-appropriate spoken language by 4.5-6.0 years of age (Nicholas & Geers, 2007; Moog, 2002; Manrique, Cervera-Paz, Huarte, & Molina, 2004). Age-appropriate language scores on standardized tests may be considered an important prerequisite to successful placement in classes with hearing age-mates. Knowing in advance when an individual child might be expected to score at age-appropriate levels on standardized language tests could greatly aid educational planning. Knowing that a child is on-track for achieving normal levels as he/she progresses through a special education program can be reassuring for parents and teachers alike and may help to determine when a move to mainstream placement can be beneficial for the child's development.

Purposes of the Present Study

There were three purposes of the present study. The first was to determine whether parent reports of children's language were consistent with results of standardized language tests and whether they predicted later language scores. Second, it was important to further explore the relationship between language outcomes and age at implantation that was observed in previous studies and to determine whether those results hold for multiple language evaluation instruments. Third, we wanted to provide "benchmarks" against which some children's spoken language skills may be evaluated in comparison to children with similar characteristics and experiences.

Method

Participants

A nation-wide sample of 76 children was selected for participation in this study, 38 girls and 38 boys. This sample of children has been previously described in related publications (Nicholas & Geers, 2006b; Nicholas & Geers, 2007). Audiological characteristics of the sample are summarized in Table 1. Sample selection was used to control for a number of relevant variables as follows. (1) Age at Onset: All hearing losses were presumed to be congenital as

candidate children were not included in the study if there was any evidence of previously normal hearing or a progressive hearing loss. (2) Learning Ability: All children scored within or above the average range on either a nonverbal intelligence test administered by their school (specific test varied by school preference) or the Daily Living Skills and Motor domains of the Vineland Adaptive Behavior Scales (Sparrow, Balla & Cicchetti, 1984). No other developmental or medical conditions that would likely interfere with communication had been identified. (3) Communication Mode: All children had been enrolled in some form of oral educational programming since receiving a CI and spoken English was the primary language of the home. (4) Technology: The children had received a CI between 1998 and 2003 and therefore used a similar generation of implant technology. Forty-seven of the children had received a Nucleus-24 implant from the Cochlear Corporation, 28 had a Clarion 1.2 or "CII" implant from the Advanced Bionics Corporation, and one child had a Med-El device. Seventy percent of the children in this sample were using processing strategies that were considered "up-to-date" at the time of this publication. Table 2 provides a complete listing of the processing strategies used with each of these implant types. All children entering the study had a full insertion of the electrode array and no prior problems with the implant leading to loss of use for more than 30 days. After the children entered the study at age 3.5 years, actual interruption of CI use was minimal. Three of the 76 children had processors replaced after 2-3 weeks of intermittent functioning. One child received a second (bilateral) implant and had the original implant turned off for a 10-week adjustment period. 5) Age at Implant: CI surgery took place between the ages of 12-38 months of age with the following distribution: N = 26 at 12-18 months, N = 20 at 19-24 months, N = 10 at 24-30 months, and N = 20 at 31-38 months. Seven children currently wore hearing aids in the ear contra-lateral to the CI.

Pre-implant hearing and hearing aid use

Audiograms were provided directly from each child's audiological services provider or school audiological records. Additionally, several questions regarding pre- and post- implant hearing aid and CI use were included in both audiologist- and parent- questionnaires. All pre-implant unaided pure-tone averages were calculated using better ear responses at 500, 1000, and 2000 Hertz under earphones. Aided PTA thresholds at 500, 1000 and 2000 Hz were obtained in the sound field. Average threshold values are presented in Table 1, along with responses at each of the component frequencies. Aided thresholds were obtained at an average of 3 months (SD = 3, Range = 0 to 16 months) prior to CI surgery. Parents' report on hearing aid use prior to CI surgery indicated that 67% of the children in the study wore their hearing aids "Almost All Waking Hours". The average aided PTA threshold was 62 dB HL (SD = 15.7, range = 32-80) for this group. Children who were reported to have worn their HAs less often had an average aided PTA of 70 (SD = 9.93, range = 48 - 80). Specific information about the type of hearing aid used was provided for 56/76 children. Only 6 of these children used digital aids with Wide Dynamic Range Compression. Aided thresholds may not accurately reflect audibility for children using compression hearing aids. However, because most of the children used linear amplification, audibility was accurately reflected in the mean aided PTA threshold. Measurements using real-ear systems were not reported for most of the children.

Demographics

Participants were recruited from 23 different U.S. states (18% Northeast, 16% Southeast, 20% Midwest, 5% Southwest, 11% West) as well as one Canadian province (6%). Host sites (and associated percentage of the sample) were: 14 private oral schools for the deaf (62%), four hospital-based implant programs (8%), three county child development centers (4%), four public schools (8%), and seven auditory-verbal therapy practices (18%). Administrators at each of these locations were asked to review their rosters for all children who met the criteria listed above. The parents of all children who met the criteria were given a letter describing the study and a release of information form to sign if they were interested in participating. A research

team member then traveled to the child's school or therapy location and completed the data collection in that setting. Family socio-economic characteristics as well as the educational setting of the children are summarized in Table 3. The demographics of this sample are consistent with previously reported income and education levels for the families of CI recipients nationwide (Stern, Yueh, Lewis, Norton, & Sie, 2005;Eisenberg et al., 2006).

Procedure

The following analysis was based on results of a parent-report instrument completed when the children were 3.5 years and again when they were 4.5 years of age (± 2 months) and two standardized language tests administered when they were 4.5 years old. All examiners had prior experience with testing young children

The MacArthur-Bates Communicative Development Inventories (MBCDI) – Words and Sentences (Fenson et al., 1993)—The *Words and Sentences* form was developed to facilitate estimation of the spoken vocabulary and early syntactic skills of 16-30 month-old toddlers with normal hearing but has been shown to be appropriate for older children with hearing loss, a CI, and delayed spoken language, as discussed above. Parent MBCDI reports were obtained when the children were 3.5 and again at 4.5 years of age (± 2 months of age), thereby allowing us to document change in expected outcomes with longer duration of CI use. The inventory is organized into four subscales: Vocabulary (productive), Irregular Words, Sentence Complexity, and 3 Longest Sentences. Standard instructions were provided to parents for completion of the MBCDI. Parents were asked to indicate their child's productive vocabulary from a list of 680 words organized into 22 semantic categories. The parent indicated the words they had heard their child produce spontaneously (i.e., not in imitation) to provide the score on the Vocabulary subscale. Use of syntax was indicated on a list of 37 examples of bound morphemes, function words and early-emerging complex sentence forms that were similarly based on the observed production, yielding scores for the Irregular Words as well as Sentence Complexity sub-scales. The 3 Longest Sentences score was estimated by having the parent provide examples of the three longest utterances that the child had recently produced.

Preschool Language Scale: Third Edition (PLS; Zimmerman, Steiner, & Pond, 1992)—This formal language test was administered by a trained research assistant at the child's school or speech-language therapy office at age 4.5 years (± 2 months). It consists of two subscales: Auditory Comprehension (AC) and Expressive Communication (EC). The test was standardized with a large (N = 1,200) normative sample of hearing children from birth through 6 years of age. The diversity of items provides a sampling of performance in several developmental areas in a relatively short time (20-30 minutes). The test was administered using spoken language with no deviations from standard administration procedures. In the current study, results were expressed as standard scores (mean = 100; SD = 15) for Auditory Comprehension and Expressive Communication in relation to hearing children between 4;0 - 4;5 (years; months) or 4:6 – 4;11 years of age, depending upon exact age at test, which ranged from 4;4 to 4;8. Because only standard scores were used and reported and do not differ substantially as new versions of the test are developed (Zimmerman, Steiner & Pond, 1992) interpretation of standard scores from the PLS – 4 are also applicable. A second research assistant re-scored 20% of the videotapes of the Expressive Communication portion as a check on inter-scorer reliability. This procedure resulted in point-by-point scoring agreement average of 94% for each individual test item.

Peabody Picture Vocabulary Test-III (PPVT; Dunn & Dunn, 1997)—This measure of receptive vocabulary was administered by a trained research assistant when the children were 4.5 years old (± 2 months). The test involves presentation of a picture to elicit a pointing response; no verbal response is required. Standard scores were developed with a large (N =

2,725) carefully-selected normative sample of typically-developing children. Each child was tested only on the vocabulary appropriate for his or her age and language development. Test administration used spoken language only. Scores are expressed as standard scores (mean = 100; SD = 15) in relation to hearing children between 4;4 and 4;9 years of age.

Results

Validation of Language Measures

To first aim was to establish the degree of predictive and concurrent validity among the language measures. Correlations were calculated between scores derived from MBCDI checklists and scores on the PLS and the PPVT at 4.5 years of age. Correlations summarized in Table 4 indicated a moderate to high degree of consistency among the three language assessment techniques. On the MBCDI, vocabulary size, use of irregular words, sentence complexity, and longest sentence length were all highly associated with one another. Further, MBCDI scores at age 3.5 years were compared with results obtained on the PLS and the PPVT at 4.5 years of age. These MBCDI scores, derived from parent checklists, were highly predictive of formal language test results at 4.5 years of age. Note that the alpha level was set, a priori, at $p < .01$ to account for multiple comparisons. Results indicated that similar estimates of language level could be obtained from either parent-completed checklists or from formal language tests. In a number of cases, predictive validity coefficients actually exceeded concurrent validity because of a tendency for scores on some MBCDI sub-scales to reach ceiling at age 4.5 years. The next issue concerned the performance level to be anticipated for an individual child in relation to the duration of accumulated experience with a CI.

Age at Implantation Effects

The second aim was to determine whether the current data were consistent with our earlier finding (Nicholas & Geers, 2006b; Nicholas & Geers, 2007) that language scores increase with decreasing pre-implant aided thresholds and longer duration of CI use (i.e., younger age at implant). Tables 5, 6, and 7 summarize results of a set of regression analyses that examined the linear relation between language test scores and age at cochlear implantation along with the effects of pre-implant aided residual hearing for test ages 3.5 and 4.5 years. In addition, the increment in those relations explained by looking at the quadratic component (i.e. change in the linear relation with increasing age at implant) was also documented. For all language measures there was a significant linear decrease in language scores with increasing age at cochlear implantation and increasing pre-implant aided threshold. The quadratic component was only significant for the following measures: MBCDI Irregular Words at 3.5, MBCDI Sentence Complexity at 3.5 years (Table 3), and PLS Expressive Language at 4.5 years (in Table 5). In all of these instances, the linear relation leveled off for children who received a CI at relatively older ages. Tables 5-7 report both linear and quadratic analyses, adopting an approach that uses the same model for examining all outcome variables. Consequently, for some analyses, quadratic effects are included that are not significant for that outcome. We believe that it is easier to make comparisons across outcomes when all have been analyzed using the same statistical model. Note that the analyses are reported in two steps. The first step is the linear model, which is more appropriate in those cases where the quadratic effect is not significant.

In each regression model listed in Tables 5-7, the squared semi-partial correlations for Age at CI and Pre-CI Aided Threshold represent the proportion of variance in the outcome variable that is accounted for by a given predictor after partialling or removing the variance accounted for by the other predictor from the outcome variable. Close inspection reveals that these sum to a value greater than the squared multiple correlation. In each case, the standardized regression coefficients are also larger than the simple correlations between predictors and

outcome. These analysis features indicate the presence of suppression (see Cohen & Cohen, 1983), which occurs when the simple relations between predictors and outcome are hidden or suppressed because of the relations between predictors. For example, the underlying analyses performed to allow for the creation of Table 6 revealed that both Age at CI ($r = -.48$) and Pre-CI Aided Threshold ($r = -.25$) are negatively related to the outcome, MBCDI Vocabulary raw score (RS), but are also negatively related to each other ($r = -.38$). That latter negative relation in part hides the relationship that each can have with the outcome variable. When each predictor is partialled from the other, the full and unsuppressed relation emerges, evident in this case by standardized regression coefficients that are larger in magnitude than the simple relations: Age at CI and MBCDI Vocabulary RS ($\beta = -.67$); Pre-CI Aided Threshold and MBCDI Vocabulary RS ($\beta = -.50$).

Expected Scores at Given Cochlear Implantation Ages

Further, we sought to obtain expected values on each language measure as a function of predictor variables. The quadratic analysis was used to establish an expected language score at each age of implantation when pre-implant aided PTA threshold at 500, 1000, and 2000 Hertz was set at the sample mean (which was 65 dB). To the extent that the relation between implant age and language score deviates from a strictly linear one, the quadratic analysis resulted in the most accurate estimate. The reader should refer back to the regression results in Tables (5-7) for significance of linear and quadratic effects for each outcome. Figures 1-3 are plots of the expected mean scores on the PLS and PPVT tests for any given age at implantation (or duration of use, given a test age of 4.5 years). Each expected score has an associated prediction interval. The size of the prediction interval is related to the amount of variance in the linear model accounted for by age at implantation and pre-implant aided threshold. The prediction interval describes the range over which an individual's score (with a specified age at implant and average aided threshold) would be located with approximately 68% confidence. Note that these prediction intervals are wider than commonly reported "confidence intervals" because they represent confidence around an *individual* score as opposed to a mean score. These prediction intervals should not be confused with standard deviation units.

Interpretation of Expected Scores

The same mean scores and associated prediction intervals are presented in tabular form in Appendices A1-4. They represent predicted values from regression models in which pre-CI aided thresholds were set equal to the sample mean and age at implantation was specified for values between 12 and 38 months. All predictions were based on models that included linear and quadratic effects for age at implantation. The quadratic effect was not statistically significant in every model but its inclusion in the generation of the expected scores provides consistency in the prediction models. Moreover, models including the quadratic terms provided more accurate predictions to the extent that the quadratic component accounts for variability in the outcome measure, even when that component does not reach a traditional level of statistical significance.

Preschool Language Scale—Figure 1 shows an expected mean Auditory Comprehension (AC) standard score for 4.5 year old children ranging from 67 for an implant age of 36-38 months to 102 for age at implant of 12 months. The expected score reached the average range for hearing age-mates (85 or higher) at 34 months of implant use (age at implant = 20 months). Similar results are depicted in Figure 2 for the Expressive Communication (EC) subscale. Expected mean EC scores ranged from a low of 60 for children implanted at 32-35 months of age to 104 for those implanted at 12 months of age. Expected scores within the prediction interval reached the average range (85 or higher) when children were implanted by 13 months of age. Similarly, an individual tested on the PLS at 4.5 years of age would be expected to

achieve age-appropriate AC and EC scores if they received a CI by about 13 months of age. Expected scores for each implant age are provided in tabular form in Appendix A1, along with the associated prediction intervals.

Peabody Picture Vocabulary Test—Figure 3 summarizes expected vocabulary standard scores by age at CI surgery Expected mean scores ranged from 64 for children implanted at 38 months of age to 103 for children implanted at 12 months. These results are summarized in Tabular form in Appendix A2. Children implanted by 12-13 months of age with a pre-CI aided threshold of about 65 dB can be expected to achieve age-appropriate vocabulary quotient scores on the PPVT by the time they are 4.5 years old.

MacArthur Communicative Development Inventory—Expected scores on the MBCDI are presented in Appendix A3 for test age 3.5 years and Appendix A4 for test age 4.5 years. Separate results are presented for each subscale: Vocabulary, Irregular Words, Sentence Complexity, and Three Longest Sentences.

Discussion

Consistency of Language Outcome Measures

These results indicate convergence of language level estimates obtained using a variety of instruments and techniques. At 4.5 years of age, children with CIs exhibited similar language levels on a parent report checklist (MBCDI), a comprehensive language measure (the PLS), and a specific receptive vocabulary test (PPVT). This result is consistent with the findings of Thal, DesJardin, & Eisenberger (2007) and Stallings, Gao, & Svirsky (2002) who also found good validity for the MBCDI. Furthermore, scores obtained via the parent checklist completed at child's age 3.5 years predicted performance on a language assessment one year later. It is tempting to conclude from these results that completion of a parent inventory is sufficient for tracking language development. However the complementary information obtained by including both observational ratings and formal language testing is extremely valuable. A child's response to specific language tasks that comprise a formal assessment is useful for planning intervention. Furthermore, standard scores derived from testing permit monitoring a child's progress in relation to a large normative sample of hearing children. It should also be noted that the parents providing MBCDI reports in this study were relatively well-educated and had participated in education programs following their child's diagnosis of deafness. As a result, these parents might have completed the forms in a manner that was more reliable and thus better correlated with clinician-administered language tests than would be expected from the general population.

Accounting for Variance in Language Outcome Scores

It should be noted here that we did consider the potential effect of gender, mother's education level, type of therapy setting, whether or not the CI technology is considered up-to-date in 2007, and whether the education/therapy services were provided in a private vs. public setting in the models presented in Tables 5-7. We explored these potentially important explanatory variables in the present study by also analyzing the data in two additional ways: (a) with these variables entered as separate co-variates and (b) using "propensity scores" (see Connor et al., 2006). The result was that neither procedure added additional explained variance and with neither method did the influence of the predictor variables that we had originally identified (pre-CI aided thresholds and duration of use) change or diminish. Approximately one-third of our sample declined to provide income information, therefore that variable was not available for analysis. That these factors were not found to be significant predictors in the present study may be due to the homogeneous nature of this sample (80% in private oral schools or Auditory-

Verbal Therapy, all 4 years old, all implanted by 3 years of age, all used relatively recent CI technology).

In contrast, significant amounts of variance were explained by degree of aided residual hearing before receiving a CI and age at implantation (i.e., duration of CI experience). Together the latter two factors accounted for 18 - 48% of the variance in language outcome, depending upon the particular outcome measure. The significant contribution of these factors to language outcomes reflects the importance of two recent trends in pediatric cochlear implantation: a reduction in CI candidacy age to 12 months and an expansion of the hearing loss criterion into the severe range. These results confirm our previous findings (Nicholas & Geers, 2006b) suggesting that enriched auditory experience in infancy, whether provided with hearing aids or CIs, is an essential ingredient for promoting age-appropriate spoken language acquisition during the preschool years.

The use of aided PTA thresholds provides only partial information about pre-implant residual hearing. The clinics that submitted pre-CI hearing aid data did not report real-ear measures and resulting speech intelligibility indices. Given the period in which most of these hearing aids were fitted (1997-2002) and the severity of the hearing losses represented, most children used linear rather than compression hearing aids. Although aided thresholds may overestimate the audibility of typical conversational speech inputs (especially for compression aids) they provide an estimate of audibility across the frequency range that is important for speech. Therefore, the lower the aided threshold obtained, the better the opportunity to hear the acoustic cues of soft speech (e.g., soft-level consonants that are important for speech understanding).

Using "Benchmark" Tables for Assessing Spoken Language Progress

Tables in the Appendix provide an expected mean score for each implantation age along with a range of values within which the expected score is likely to fall. Clinicians may use these tables to estimate the degree to which an individual child is making expected progress with a CI in relation to the sample described in this article. Children scoring within the expected range for implantation age may be considered "on track" in relation to a group of children who have experienced early oral intervention with an emphasis on auditory and speech development.

The values in Appendices A1-4 should not be considered normative for all children with CIs for several reasons. First, stratified randomization was not used in sample selection so that geographic location, family, child, and educational program characteristics may not be representative of the larger population of children with CIs. Second, children enrolled in programs based on Total Communication or American Sign Language were not included in this study. Finally, the number of children at each individual month of implantation age is relatively small. Nevertheless, these tables may allow clinicians in oral education settings to estimate whether a 3- or 4-year-old child is making expected progress in spoken language for his/her age at implant and duration of use. Because results are depicted for an average pre-CI aided threshold, the expectation would be somewhat higher for children with better pre-CI hearing and somewhat lower for children with poorer pre-CI hearing. This point is illustrated by examining the raw data plotted in Figures 1-3. For example, some children with relatively older ages at implantation (30+ months) scored unexpectedly well, probably due to better than average pre-implant aided hearing ability.

Additionally, these estimates are only accurate to the extent that the individual child meets the criteria of the sample used in this analysis. The following is a list of those factors along with the hypothesized impact (positive or negative) on projected language outcome scores based on the current literature. These tables are most accurate for children who:

1. *are within 2 months of the specified test age* (either 3.5 or 4.5 years): Increasing age at test should have a positive impact on scores to the extent that chronologic age is associated with increased CI experience.

2. *have been deaf since birth*: A period of normal hearing or relatively better hearing before the onset of profound hearing loss has been shown to positively affect language scores, especially if the period of profound deafness was less than one year prior to cochlear implantation (Geers, 2004a; Sarant, Blamey, Dowell, Clark & Gibson, 2001).

3. *have been enrolled in an oral education setting since the time of implantation.* The literature on this point shows mixed findings. Educational settings that include a sign language emphasis may negatively affect spoken language scores (Svirsky, Robbins, Kirk, Pisoni & Miyamoto, 2000; Geers, Nicholas & Sedey, 2003; Geers, 2004b). On the other hand, including sign along with speech has been associated with higher vocabulary scores in some samples (Connor et al., 2000) and with no difference in post-CI vocabulary scores in other samples (Connor & Zwolan, 2004). Although this study does not include children with sign language backgrounds and therefore does not demonstrate validity of the MBCDI for use with those children, a clinician may nonetheless choose to utilize the MBCDI to monitor a child's progress in spoken language development, noting strengths and weaknesses in the child's acquisition of spoken vocabulary, grammar and sentence length with or without reference to the Appendices.

4. *have pre-CI aided thresholds of 65 dB HL.* With better pre-CI aided thresholds, language scores have been shown to increase (Eisenberg, Kirk, Martinez, Ying & Miyamoto, 2004; Nicholas & Geers, 2006b). Therefore, language score expectations might be somewhat higher for children with pre-CI aided thresholds that are better (i.e., lower) than 65 dB, HL and somewhat lower for those with poor (i.e., greater) thresholds.

5. *use a generation of CI technology similar to that of the children in this sample* (see Table 2). The CI technology utilized by most of the children in the present study is considered "current" or "up-to-date" at the time of this publication. Our analyses revealed that whether or not the technology was the most current (in 2007) did not have a significant influence on the outcome scores. There are features on newer processors which may directly affect speech perception abilities but further research would be needed to determine whether these and future changes in hardware or software would result in different expected scores.

6. *were without an interruption of implant use lasting more than 30 days.* Technical problems with CI hardware or speech processor mapping may be expected to negatively affect spoken language scores (Nicholas, Geers & Sedey, 2003) but so few children in this study experienced CI problems that this was impossible to assess.

7. *have nonverbal intelligence (or motor development) at least in the average* range and no other medical or developmental conditions that might be expected to interfere with communication. Measured nonverbal intelligence scores are positively associated with language outcome (Holt & Kirk, 2005; Geers, Nicholas & Sedey, 2003).

8. *live in middle to upper-middle class households* (see Table 3). The majority of children in our sample (71%) were part of families in which the mother had a college degree. While this may not be representative of the maternal education of children who are deaf in general, it may indeed be representative of the educational levels found in families of children who have received a CI. Fortnum, Stacey & Summerfield (2006) reported that children with CIs tend to come from families who were more

affluent, more likely to use spoken language at home, and were more likely to provide an educational environment for their child which utilized spoken language only, in comparison with deaf peers who did not use a CI. Post-CI language levels in children are reported to be positively affected by parent education and income (Geers, Nicholas & Sedey, 2003). The fact that mother's education level was not related to language outcome in this sample may have resulted from the restricted range of education levels represented. Children from lower SES families might not be expected to acquire language at the levels reported here.

9. *live in a household in which English is the only language spoken to the child.* The effects of using a second language on the acquisition of spoken English following cochlear implantation have not been thoroughly documented. Results from a small sample of children in bilingual families who received their CI by age 3 years indicated that the primary language continued to develop at normal rates (Robbins, Green & Waltzman, 2004). However, to the extent that the child's exposure to spoken English input is reduced, one might expect slower progress.

A final caveat is that decisions about whether or not a child is progressing appropriately should always be made with as many sources of objective information as possible. In addition to modifications based on the degree to which the child shares characteristics of this sample, decisions utilizing the information provided here should also include a host of other observation/testing information. The goal is to gain a comprehensive view of language (form, content, use) and to gain information to guide education/intervention. Use of *only* the MBCDI or a single language test would give an overly narrow view of language, particularly at ages 4 and 5 years, when narrative skills and verbal reasoning may be important predictors of mainstream success. Clinicians/educators should use these benchmarks as augmenting material, and not be tempted to substitute this procedure for a complete assessment. Similarly, use of these benchmarks would not be appropriate for inclusion in a formal report on a child's language progress. As Thal et al. (2007) have noted, however, the MBCDI may also be useful in highlighting the strengths and weaknesses in the developing spoken language abilities of this population of children.

Directions for Future Research

It remains an empirical question if standard scores within normal limits on these measures at age 4.5 years are predictive of maintenance of language within normal limits and/or success in the mainstream. This is an important avenue for future research. The challenges of spoken language development at age 4.5 years may be qualitatively different than the challenges in the upcoming elementary school years. These include the acquisition of subject-matter vocabulary, verbal reasoning, literacy and narrative skills, as well as complex syntactic, grammatical, and non-literal language competencies.

Further research is needed to determine whether different scores would be expected from children who use a contra-lateral hearing aid or who have bilateral implantation, features that were not sufficiently represented in this sample for analysis. The significant positive effect of degree of aided residual hearing on language outcome in this study is consistent with positive speech perception findings from severely hearing impaired children who continued using hearing aids in their non-implanted ears (Holt, Kirk, Eisenberg, Martinez & Campbell, 2005).

Conclusions

Scores listed in the Appendices of this paper can allow the clinician to determine how closely children with early cochlear implantation approximate estimated benchmarks of spoken language development. They have the potential to be useful in tracking within-child progress

and making mainstreaming decisions in conjunction with other information. While variability in spoken language outcomes remains high, for families seeking mainstream placement, these data can be considered as benchmarks associated with early oral education and cochlear implantation by a child's third birthday.

Appendix A1: Expected Standard Scores on *Preschool Language Scales* (PLS) by Age at Implantation

Chronologic Age at Test = 4 years, 6 months (± 2 months)

Age at implant (in months)	Duration of Use	Expressive Communication (EC) Scale – Standard Score		Auditory Comprehension (AC) Scale – Standard Score	
		Expected Standard Score	68% Prediction Interval	Expected Standard Score	68% Prediction Interval
12	42	104	86-122	102	86-119
13	41	100	82-118	100	83-116
14	40	96	79-114	97	81-114
15	39	93	75-110	95	79-111
16	38	89	72-107	93	77-109
17	37	86	69-103	91	74-107
18	36	83	66-100	88	72-105
19	35	80	63-97	86	70-103
20	34	77	60-95	85	68-101
21	33	75	58-92	83	67-99
22	32	73	55-90	81	65-97
23	31	71	53-88	80	63-96
24	30	69	51-86	78	62-94
25	29	67	50-84	77	60-93
26	28	66	48-83	75	59-91
27	27	64	47-82	74	58-90
28	26	63	46-80	73	57-89
29	25	62	45-79	72	56-88
30	24	61	44-79	71	55-87
31	23	61	43-78	70	54-86
32	22	60	43-78	69	53-86
33	21	60	48-78	69	52-85
34	20	60	43-78	68	52-84
35	19	60	43-78	68	51-84
36	18	61	43-79	67	51-84
37	17	61	43-79	67	50-84
38	16	62	43-80	67	50-84

Appendix A2: Expected Standard Scores on *Peabody Picture Vocabulary Test* (PPVT-III) by Age at Implantation

Chronologic Age at Test = 4 years, 6 months (± 2 months)

Age at Implant (in months)	Duration of Use	Expected Standard Score at Age 4.5	68% Prediction Interval
12	42	103	86-119
13	41	101	84-117
14	40	99	83-115
15	39	97	81-113
16	38	95	79-111
17	37	94	77-110
18	36	92	76-108
19	35	90	74-106
20	34	88	72-105

Age at Implant (in months)	Duration of Use	Expected Standard Score at Age 4.5	68% Prediction Interval
21	33	87	71-103
22	32	85	69-101
23	31	84	67-100
24	30	82	66-98
25	29	81	64-97
26	28	79	63-95
27	27	78	61-94
28	26	76	60-92
29	25	75	59-91
30	24	74	57-90
31	23	72	56-89
32	22	71	55-87
33	21	70	54-86
34	20	69	52-85
34	19	68	51-84
36	18	67	50-83
37	17	65	49-82
38	16	64	47-82

Appendix A3: Expected Raw Scores on *MacArthur-Bates Communicative Development Inventory* (MBCDI) by Age at Implantation

Chronologic Age at Test = 3 years, 6 months (± 2 months)

Age at Implant (in months)	Duration of Use	*Vocabulary* Scale Raw Score		*Irregular Words* Scale Raw Score	
		Expected Raw Score [*]	68% Prediction Interval	Expected Raw Score	68% Prediction Interval
12	30	*589*	448 +	16	10-22
13	29	*562*	422 +	14	9-20
14	28	*535*	396 +	13	8-19
15	27	*510*	372 +	12	6-17
16	26	485	347-623	11	5-16
17	25	461	324-599	10	4-15
18	24	438	301-576	9	3-14
19	23	416	279-554	8	2-13
20	22	395	258-533	7	1-12
21	21	375	237-513	6	0-11
22	20	356	218-493	5	0-11
23	19	337	199-475	5	0-10
24	18	320	182-457	4	0-9
25	17	303	165-441	3	0-9
26	16	287	149-425	3	0-9
27	15	272	134-410	3	0-8
28	14	258	120-396	2	0-8
29	13	245	107-383	2	0-8
30	12	232	95-370	2	0-7
31	11	221	83-359	2	0-7
32	10	210	72-349	2	0-7
33	9	201	62-340	2	0-8
34	8	192	53-332	2	0-8
35	7	184	44-325	2	0-8
36	6	177	35-319	3	0-8
37	5	171	27-315	3	0-9
38	4	166	19-313	3	0-9

Age at Implant (in months)	Duration of Use	*Sentence Complexity* Scale Raw Score		*3 Longest Sentences* Scale Raw Score	
		Expected Raw Score [*]	68% Prediction Interval	Expected Raw Score	68% Prediction Interval
12	30	*28*	19 +	9	6-12
13	29	*26*	17 +	8	5-11
14	28	24	15-34	8	5-11
15	27	22	13-32	7	4-10

Age at Implant (in months)	Duration of Use	Vocabulary Scale Raw Score		Irregular Words Scale Raw Score	
		Expected Raw Score*	68% Prediction Interval	Expected Raw Score	68% Prediction Interval
16	26	21	11-30	7	4-10
17	25	19	10-28	6	4-9
18	24	17	8-27	6	3-9
19	23	16	6-25	6	3-9
20	22	14	5-24	5	2-8
21	21	13	4-22	5	2-8
22	20	12	2-21	5	2-7
23	19	11	1-20	4	1-7
24	18	10	0-19	4	1-7
25	17	9	0-18	4	1-7
26	16	8	0-17	3	1-6
27	15	7	0-16	3	0-6
28	14	6	0-15	3	0-6
29	13	5	0-15	3	0-6
30	12	5	0-14	3	0-6
31	11	4	0-14	3	0-6
32	10	4	0-13	3	0-6
33	9	4	0-13	3	0-6
34	8	4	0-13	3	0-6
35	7	3	0-13	3	0-6
36	6	3	0-13	3	0-6
37	5	3	0-13	3	0-6
38	4	4	0-14	3	0-6

* The upper limit of the prediction interval for this age of implantation is within 5% of the subtest score ceiling. Therefore, expected raw scores denoted in italics should be interpreted with caution.

Appendix A4: Expected Scores on *MacArthur-Bates Communicative Development Inventory* (MBCDI) by Age at Implantation

Chronologic Age at Test = 4 years, 6 months (± 2 months)

Age at Surgery (in months)	Duration of Use	Vocabulary Scale Raw Score		Irregular Words Scale Raw Score	
		Expected Raw Score*	68% Prediction Interval	Expected Raw Score*	68% Prediction Interval
12	42	665	539 +	21	14 +
13	41	653	529 +	20	14 +
14	40	642	518 +	19	13 +
15	39	630	507 +	19	12 +
16	38	618	495 +	18	11 +
17	37	605	483 +	17	10 +
18	36	593	471 +	16	10-23
19	35	580	458 +	16	9-22
20	34	568	446 +	15	8-21
21	33	555	432 +	14	7-21
22	32	541	419 +	13	7-20
23	31	528	406 +	13	6-19
24	30	515	392-637	12	5-19
25	29	501	379-623	11	5-18
26	28	487	365-610	11	4-17
27	27	473	351-595	10	4-17
28	26	459	337-581	10	3-16
29	25	445	322-567	9	2-16
30	24	430	308-552	9	2-15
31	23	415	293-538	8	1-15
32	22	400	278-523	8	0-14
33	21	385	262-508	7	0-14
34	20	370	246-494	7	0-13
35	19	355	230-479	6	0-13
36	18	339	213-465	6	0-13
37	17	323	195-451	5	0-12

Age at Surgery (in months)	Duration of Use	Vocabulary Scale Raw Score		Irregular Words Scale Raw Score	
		Expected Raw Score*	68% Prediction Interval	Expected Raw Score*	68% Prediction Interval
38	16	307	177-437	5	0-12

Age at Implant (in months)	Duration of Use	Sentence Complexity Scale Raw Score		3 Longest Sentences Scale Raw Score	
		Expected Raw Score*	68% Prediction Interval	Expected Raw Score	68% Prediction Interval
12	42	*38*	28 +	10	6-15
13	41	*36*	27 +	10	6-15
14	40	*35*	25 +	10	5-14
15	39	*34*	24 +	10	5-14
16	38	*32*	23 +	9	5-14
17	37	*31*	22 +	9	5-13
18	36	*30*	20 +	9	4-13
19	35	*29*	19 +	8	4-13
20	34	*27*	18 +	8	4-13
21	33	26	17-36	8	4-12
22	32	25	15-35	8	3-12
23	31	24	14-33	7	3-12
24	30	23	13-32	7	3-12
25	29	21	12-31	7	2-11
26	28	20	11-30	7	2-11
27	27	19	10-29	6	2-11
28	26	18	9-28	6	2-10
29	25	17	7-26	6	1-10
30	24	16	6-25	6	1-10
31	23	15	5-24	5	1-10
32	22	14	4-23	5	1-9
33	21	13	3-22	5	0-9
34	20	12	2-21	4	0-9
35	19	11	1-20	4	0-9
36	18	10	0-19	4	0-8
37	17	9	0-19	4	0-8
38	16	8	0-18	3	0-8

*The upper limit of the prediction interval for this age of implantation is within 5% of the subtest score ceiling. Therefore, expected raw scores denoted in italics should be interpreted with caution.

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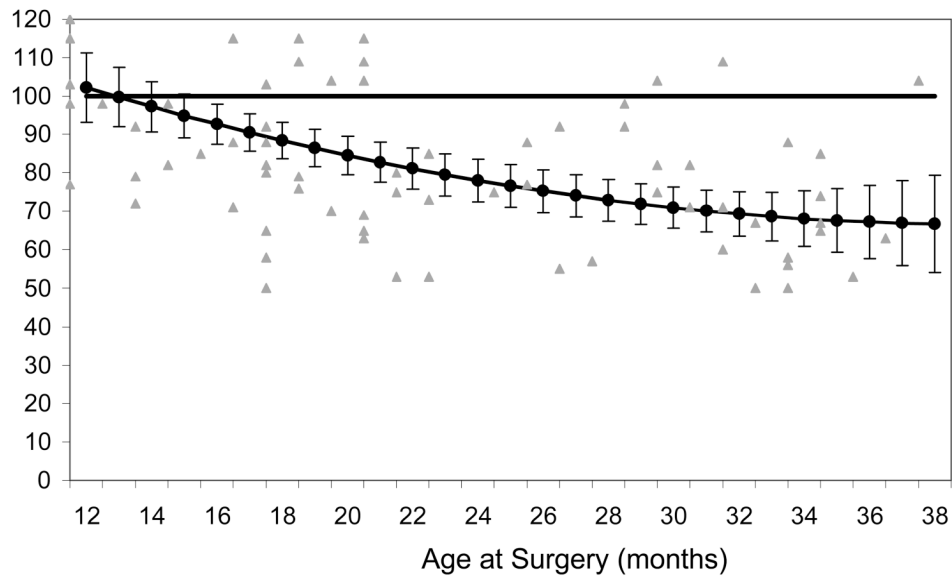
Figure 1.
Regression lines for PLS Auditory Comprehension subtest standard score by age at cochlear implantation (chronologic age at testing = 4.5 years). Note that expected scores are corrected for pre-implant aided hearing thresholds. Horizontal black line at 100 represents the average score of typically-developing, hearing children at the same chronologic age at test.
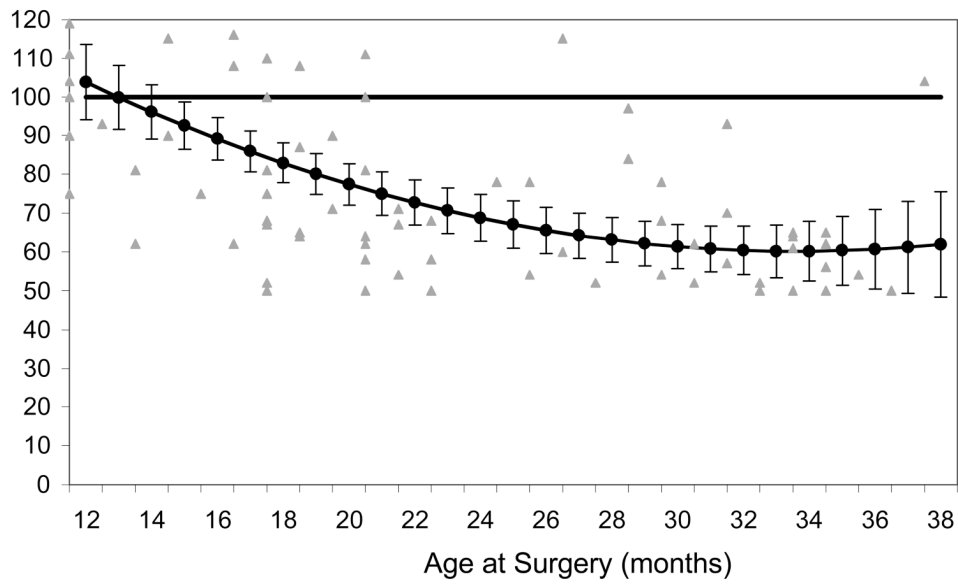
Figure 2.
Regression line for PLS Expressive Communication subscale standard score by age at cochlear implantation (chronologic age at testing = 4.5 years). Note that expected scores are corrected for pre-implant aided hearing thresholds. Horizontal black line at 100 represents the average score of typically-developing, hearing children at the same chronologic age at test.
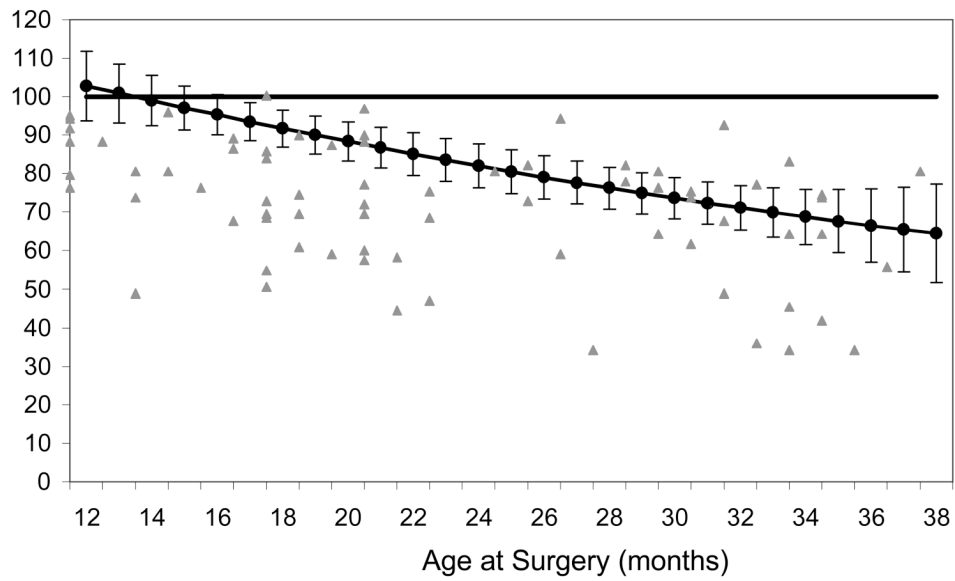
Figure 3.
Regression line for Peabody Picture Vocabulary Test standard scores by age at cochlear implantation (chronologic age at testing = 4.5 years). Note that expected scores are corrected for pre-implant aided hearing thresholds. Horizontal black line at 100 represents the average score of typically-developing, hearing children at the same chronologic age at test.

Table 1

Participant Audiological Characteristics

	Mean	Standard Deviation	Range	N
Unaided PTA (dB HL)	107.19	10.81	77-120	76
at 500 Hz	100.46	11.76	75-120	70
at 1,000 Hz	107.14	12.38	70-120	70
at 2,000 Hz	109.57	12.54	75-120	69
Pre-CI Aided PTA (dB HL)	64.62	14.57	32-80	76
at 500 Hz	60.99	14.60	30-80	71
at 1,000 Hz	62.69	15.12	35-80	66
at 2,000 Hz	66.23	15.00	30-80	64
Age first aided (months)	12.13	8.04	1-30	76
Duration of HA use (months) *	11.0	6.27	0-30	76
Age at Implant (months)	23.16	7.73	12-38	76
CI PTA (dB HL)	30.21	5.19	20-43	76
Age at 3.5 Test (months)	42.75	1.16	40-45	76
Duration of CI use (in months) at age 3.5 years Test Session	19.76	7.64	7-32	76
Age at 4.5 Test (months)	55.09	1.15	52-57	76
Duration of CI use (in months) at age 4.5 years Test Session	31.95	7.85	18-45	76

Notes: HL = Hearing Level, HA = hearing aid, CI = cochlear implant, Hz = Hertz, PTA = Pure tone average threshold in the sound field at 500, 1000 and 2000 Hz. Maximum possible response level was 120 dB, HL for unaided and 80 dB, HL for aided threshold. When calculating averages, if "No Response" was indicated for a specific frequency on an audiogram, the value of "120" was entered if Unaided and "80" if Aided. Aided PTAs for 4 children were reported as a single figure by the audiologist, with no aided audiogram provided.

*
7 children wore a hearing aid on the contra-lateral ear at the age of 4.5 years

Table 2

Configurations of implants, associated processors, and software.

Device	Processor	Programming Strategy	Number of Children
Cochlear	Sprint	ACE	38
Cochlear	3G	ACE	5
Cochlear	ESPrit	ACE	3
Cochlear	ESPrit	SPEAK	1
Advanced Bionics	PSP	SAS	10
Advanced Bionics	PSP	MPS	5
Advanced Bionics	PSP	HiRes-P	5
Advanced Bionics	PSP	CIS	1
Advanced Bionics	S-Series	CIS	1
Advanced Bionics	S-Series	SAS	1
Advanced Bionics	Auria	HiRes-P	1
Advanced Bionics	Platinum BTE	CIS	1
Advanced Bionics	Platinum BTE	MPS	1
Advanced Bionics	S-Series & BTE[**]	CIS	2
Med-El	Tempo+	CIS	1

[**] At the time of testing, two participants were using both a body-worn (S-Series) and a BTE

Programming Strategies:

ACE = Advanced Combination Encoder

SPEAK = Spectral Peak

SAS = Simultaneous Analog Stimulation

MPS = Multi-Paired Stimulation

HiRes-P = High Resolution Paired

CIS = Continuous Interleaved Sampling

Processor Types:

BTE = Behind the Ear

PSP = Platinum Speech Processor

Table 3

Percent of sample with various family demographic characteristics and child educational setting

MOTHER'S LEVEL OF EDUCATION		TOTAL FAMILY INCOME	
< High school graduation	4 %	< $15,000	1 %
HS graduation	14 %	$ 15,000 – 45,000	11 %
Some college or 2-Year Degree	9 %	$ 45,000 – 75,000	24 %
4-year college graduate	62 %	$ > 75,000	33 %
Graduate school	9 %	Did not provide information	31 %
Did not provide information	1 %		
RACE / ETHNICITY		EDUCATIONAL SETTING FROM 3.5 TO 4.5 YEARS OF AGE	
Asian	3 %	Special Education Preschool	82 %
Black / African American	4 %	Regular (Mainstream) Preschool	12 %
Hispanic	1 %	At home with speech/language therapy	6 %
White, not Hispanic	75 %		
Other or Multi-Ethnicity	17 %		

Table 4

Inter-correlations related to concurrent and predictive reliability of the MacArthur-Bates Communicative Development Inventory (MBCDI: Words and Sentences form.

Score	M/V 4.5	M/I 4.5	M/SC 4.5	M/3L 4.5	PLS/AC	PLS/EC	PPVT-III
					CONCURRENT VALIDITY		
M/V 4.5	-	.820 (74)	.865 (74)	.496 (74)	.728 (74)	.718 (74)	.813 (73)
M/I 4.5		-	.853 (74)	.508 (74)	.672 (74)	.728 (74)	.708 (73)
M/SC 4.5			-	.534 (74)	.670 (74)	.706 (74)	.753 (73)
M/3L 4.5				-	.433 (74)	.471 (74)	.506 (73)
					PREDICTIVE VALIDITY		
M/V 3.5 N= 75					.731 (75)	.800 (75)	.757 (74)
M/I 3.5 N= 75					.590 (75)	.685 (75)	.580 (74)
M/SC 3.5 N= 75					.629 (75)	.801 (75)	.632 (74)
M/3L_3.5 N= 75					.617 (75)	.689 (75)	.589 (74)

Notes: All correlations are significant at $p < .01$

Parentheses indicate number of children for whom both data points were available for correlation

M/V = MBCDI Vocabulary subscale

M/I = MBCDI Irregular Words subscale

M/SC = MBCDI Sentence Complexity subscale

M/3L = MBCDI - Three Longest Sentences subscale

PLS/AC = Preschool Language Scale-III – Auditory Comprehension scale

PLS/EC = Preschool Language Scale-III – Expressive Communication scale

PPVT-III = Peabody Picture Vocabulary Test – 3rd edition

3.5 = Test age 3;4 to 3;8 (Years;months)

4.5 = Test age 4;4 to 4;8

Table 5

Results of linear and quadratic regression analyses for parent MBCDI subscales from chronologic Test Age 3.5

Test/Subscale	Parameter	Step 1 – Linear Regression				Step 2 – Quadratic Regression			
		Regression Coefficient (β)	Standard Error	Semi-Partial r²	Step Increment in R²	Regression Coefficient (β)	Standard Error	Semi-Partial r²	Step Increment in R²
MBCDI Vocabulary RS	Intercept	1065.209	106.998		.460	1284.605	184.911		.016
	Pre-CI Aided	-4.749***	1.164	.125		-4.633***	1.158	.118	
	Age at CI	-17.201***	2.225	.448		-38.320**	14.738	.050	
	(Age at CI)²	—	–			.441	.304	.016	
MBCDI Irregular Words RS	Intercept	26.008	4.516		.328	44.281	7.462		.075
	Pre-CI Aided	-.102*	.049	.040		-.092	.047	.032	
	Age at CI	-.557***	.094	.328		-2.316***	.595	.127	
	(Age at CI)²	—	–			.037**	.012	.075	
MBCDI Sentence Complexity RS	Intercept	48.341	7.453		.389	70.348	12.673		.036
	Pre-CI Aided	-.172*	.081	.038		-.160*	.079	.033	
	Age at CI	-1.047***	.155	.387		-3.166**	1.010	.080	
	(Age at CI)²	—	–			.044*	.021	.036	
MBCDI 3 Longest Sentences RS	Intercept	16.189	2.290		.313	22.466	3.912		.035
	Pre-CI Aided	-.078**	.025	.093		-.075**	.024	.085	
	Age at CI	-.268***	.048	.302		-.872**	.312	.072	
	(Age at CI)²	—	–			.013	.006	.035	

***
p ≤ .001

**
p ≤ .01

*
p ≤ .05

Note: Squared semi-partial correlations can sum to greater than the squared multiple correlation under conditions of suppression. This occurs when the effect of a predictor is suppressed by another predictor and is only revealed when the other predictor is partialled. CI = Cochlear Implant, RS = Raw Score

Table 6

Results of linear and quadratic regression analyses for MBCDI subscales from chronologic Test Age 4.5

Test/Subscale	Parameter	Step 1 – Linear Regression				Step 2 – Quadratic Regression			
		Regression Coefficient (β)	Standard Error	Semi-Partial r²	Step Increment in R²	Regression Coefficient (β)	Standard Error	Semi-Partial r²	Step Increment in R²
MBCDI Vocabulary RS	Intercept	1183.699	94.994		.441	1138.906	168.593		.001
	Pre-CI Aided	-5.378 ***	1.029	.215		-.401 ***	1.038	.215	
	Age at CI	-13.614 ***	1.960	.379		-9.351	13.363	.004	
	(Age at CI)²	-	-	-	-	-.088	.273	.001	
MBCDI Irregular Words RS	Intercept	44.290	5.160		.372	49.383 ***	9.135		.004
	Pre-CI Aided	-.252 ***	.056	.180		.249 ***	.056	.175	
	Age at CI	-.642 ***	.106	.321		-1.126	.724	.022	
	(Age at CI)²	-	-	-	-	.010	.015	.004	
MBCDI Sentence Complexity RS	Intercept	78.834	7.417		.479	82.598	13.162		.001
	Pre-CI Aided	-.429 ***	.080	.209		-.426 ***	.081	.205	
	Age at CI	-1.170 ***	.153	.429		-1.529	1.043	.016	
	(Age at CI)²	-	-	-	-	.007	.021	.001	
MBCDI 3 Longest Sentences RS	Intercept	19.051	3.423		.178	19.215	6.08		<.001
	Pre-CI Aided	-.084 *	.037	.060		-.084 *	.037	.059	
	Age at CI	-.269 ***	.071	.169		-.285	.482	.004	
	(Age at CI)²	-	-	-	-	.000	.010	<.001	

***
$p \leq .001$

**
$p \leq .01$

*
$p \leq .05$

Note: Squared semi-partial correlations can sum to greater than the squared multiple correlation under conditions of suppression. This occurs when the effect of a predictor is suppressed by another predictor and is only revealed when the other predictor is partialled. CI = Cochlear Implant, RS = Raw Score

Table 7

Results of linear and quadratic regression analyses for PLS and PPVT at chronologic Test Age 4.5 years

Test/Subscale	Parameter	Step 1 – Linear Regression				Step 2 – Quadratic Regression			
		Regression Coefficient (β)	Standard Error	Semi-Partial r²	Step Increment in R²	Regression Coefficient (β)	Standard Error	Semi-Partial r²	Step Increment in R²
PLS Auditory Comprehension	Intercept	152.868	12.495		.337	176.297	21.703		.016
	Pre-CI Aided	-.574 ***	.136	.161		-.563 ***	.136	.154	
	Age at CI	-1.456 ***	.257	.292		-3.700 *	1.723	.042	
	(Age at CI)²	-	-			.047	.035	.016	
PLS Expressive Communication	Intercept	151.082	13.812		.361	198.187	23.314		.050
	Pre-CI Aided	-.521 ***	.151	.104		-.498 ***	.146	.095	
	Age at CI	-1.794 ***	.284	.349		-6.305 ***	1.851	.095	
	(Age at CI)²	-	-			.094 *	.038	.050	
PPVT	Intercept	158.664	12.406		.363	167.900	21.740		.002
	Pre-CI Aided	-.607 ***	.135	.178		-.602 ***	.136	.174	
	Age at CI	-1.511 ***	.254	.312		-2.402	1.735	.017	
	(Age at CI)²	-	-			.019	.036	.002	

***
 p ≤ .001

**
 p ≤ .01

*
 p ≤ .05

Note: Squared semi-partial correlations can sum to greater than the squared multiple correlation under conditions of suppression. This occurs when the effect of a predictor is suppressed by another predictor and is only revealed when the other predictor is partialled. CI = Cochlear Implant, RS = Raw Score