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Estimating the Influence of Cochlear Implantation on Language Development in Children

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Abstract

Research studies reviewed here have identified a wide variety of factors that may influence a child's auditory, speech and language development following cochlear implantation. Intrinsic characteristics of the implanted child, including gender, family socio-economic status, age at onset of hearing loss and pre-implant residual hearing may predispose a child to greater or lesser post-implant benefit. Intervention characteristics that may influence outcome include age of the child when deafness is identified and amplification and habilitation is initiated, the communication mode used with the child and the type of classroom/therapy employed. Characteristics of the implant itself include generation of technology used, the age of the child when implant stimulation is initiated, and the amount of time the child has used the implant. These factors interact in unpredictable ways, so that isolated correlations between predictor variables and outcome scores may be difficult to interpret. Results for two independent samples of orally-educated children tested by different laboratories were compared using multiple regression analysis to illustrate interactions among predictor variables. Four predictor variables accounted for a similar proportion of variance (23% and 24%) in receptive vocabulary (PPVT) outcome scores in each sample. A unique predictor was then added to each analysis. The addition of pre-implant aided threshold not only increased the total variance accounted for to almost 40%, but also increased the effect of implant age as a predictor variable. A different result was observed in the other sample, were the added predictor variable was nonverbal IQ, where the estimated contribution of implant age was reduced. The current analysis suggests that future analyses minimally control for independent contributions of implant age, nonverbal IQ, and pre-implant aided thresholds when examining expected outcomes. Children in both samples who received a cochlear implant sometime between their first and second birthday achieved age-appropriate oral receptive vocabulary levels during preschool.

Keywords

Predicting Outcomes; Age at Implant; Aided Threshold

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One goal of early intervention for children with hearing loss is successful educational integration with hearing peers at the earliest age possible. It is generally believed that the primary obstacle to meeting this goal is delayed language and reading skill development based in part on auditory deprivation in infancy. Because the average rate of verbal development in deaf children is slower than that of hearing age-mates, the gap between these groups widens with age (1); (2). Thus catching up becomes increasingly difficult as deaf children mature, requiring a faster-than-normal pace of development to close the gap. In response to this dilemma, there has been a strong emphasis on getting language input to children with hearing loss at the earliest possible ages, so that the gap does not develop in the first place (3). For children with profound hearing loss, this often has meant using sign language to take advantage of the unimpaired visual modality for language exposure. For families pursuing an oral approach without using sign language, the rate of spoken language development is affected by degree of aided speech perception ability (1;4) and intensity of instruction (5). However the level of speech perception ability provided by hearing aids to profoundly deaf children is rarely sufficient to support normal rates of spoken language development, no matter how early such intervention is initiated and regardless of the intensity of instruction. For these children, a number of studies have documented significant benefits of cochlear implants over hearing aids in facilitating auditory perception of speech and speeding the development of spoken language (6–8). With this new technology, more children are exhibiting speech and language skills closely approximating those of hearing age-mates, facilitating their successful integration into a mainstream educational setting.

Use of cochlear implants by profoundly deaf children, while providing greatly improved auditory information over conventional amplification, does not restore normal auditory sensitivity or discrimination. Even long-term use of a cochlear implant from a young age does not always result in closing the language gap between deaf children and their hearing peers. For example, only about half of a large nationwide sample of children implanted during the preschool years had achieved age-appropriate levels of speech intelligibility, language and reading skills and participated fully in mainstream education with hearing peers by age 8–9 years (9). The variability in spoken language outcomes remained high following 4 to 7 years of cochlear implant use.

Here we will review research to identify cochlear implant characteristics and intervention practices that have been found to be associated with language outcomes. We begin with a list of subject characteristics that have been found to influence language development in deaf children independent of cochlear implantation. Then the contributions of implant technology and clinical practice to post-implant outcomes levels will be explored. Finally, we will illustrate how the complex interaction of these factors can obscure identification of the relative benefits of early cochlear implantation for language development.

Intrinsic Characteristics

A first step in assessing cochlear implant benefit is to determine, based on the existing literature, those intrinsic characteristics that might account for significant variance in performance outcomes, so that their influence can be controlled in an analysis. In observational research, children are not randomly assigned based on factors such as their cognitive ability, family circumstances, or pre-implant characteristics that may affect their response to cochlear implantation. Furthermore, these variables are not independent, so strong correlations among them can cause problems with interpretation of outcome results. The danger is that an overly simplistic analysis will result in mistakenly attributing to one variable (e.g. age at implant) an impact that is influenced by another variable (e.g., family socio-economic status). Studies that do not account for these factors when they co-vary with an intervention variable of interest may either overestimate or underestimate the true impact

of the targeted variable. The following list includes intervening variables that have been identified as potential sources of outcome variance.

Gender

Girls with cochlear implants have been found to exhibit higher scores than boys on tests of speech perception (10) speech production (11), language (12) and reading (13). Therefore, girls might be expected to reach age-appropriate language and reading levels sooner than boys. Because gender may not be equally distributed within a cochlear implant sample (14), removing any gender-related variance is advisable before identifying implant-related factors that are associated with significantly improved outcomes.

Cognitive Ability

Cognitive ability in deaf children is typically measured using tasks that do not require linguistic knowledge. Various studies have quantified this variable with norm-referenced scores on non-verbal reasoning, memory, visual attention and/or motor tasks or by simply counting the number of additional diagnosed disabilities. The degree of delay/number of disabilities has been associated with rate of growth in a number of post-implant outcome measures, particularly those that use higher level speech processing abilities such as word recognition and comprehension (10;15;16). Even in a sample with no additional diagnosed disabilities, in which most of the children scored within or above the average range for hearing peers, performance on non-verbal cognitive tasks predicted significant variance in speech perception (17), speech production (11), language (18); (19) and reading (13)outcomes. It is particularly important to control for cognitive ability when examining the effects of different types of intervention on language development after implantation, since children with higher cognitive scores may be more likely to be enrolled in oral intervention programs {Geers, 2003 43 /id]. In such circumstances, performance advantages that are associated with greater cognitive ability may mistakenly be attributed to communication mode. Because of test reliability issues, diagnosing cognitive delays and additional disabilities is more difficult at younger ages. Therefore the contribution of cognitive factors may not be estimated as well in children for whom outcomes are measured at young ages. In this case, development of motor and self help skills from parent report have been used to screen for cognitive delay (20) and to predict response to cochlear implantation (21).

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Family Environment

Family socio-economic status (SES) is most often estimated from parent education, occupational skill level or income. Such factors have been found to predict communication skills in children with normal hearing (22) as well as those with hearing loss (23). Children with cochlear implants tend to come from more affluent and well-educated families (14), giving them an advantage in comparisons with non-implanted children. Furthermore, within the cochlear implanted population, socioeconomic variables are associated with a variety of measured outcomes (9;10) and may co-vary with factors such as age at implant (e.g., more affluent and educated parents may seek a cochlear implant sooner following diagnosis of hearing loss) and type of intervention (e.g., affluent families may be more likely select an oral communication option).

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Age at Onset of Hearing-Loss

Children who experience a period of normal hearing prior to the onset of profound hearing loss have been found to achieve better speech perception, speech production and spoken language outcomes whether they receive hearing aids or cochlear implants (24). This advantage is particularly marked for children for whom spoken language competence has been established before the onset of hearing loss (i.e., around 3 years of age or later) (10).

However, even in a group of children whose hearing loss was acquired between birth and 36 months, onset age was found to predict significant variance in language and reading outcomes (9;25). Unless the sample under investigation is restricted to children with onset at birth, the age at onset should be considered in analysis of post-implant outcomes. A related variable is duration of profound deafness prior to cochlear implantation. It has been reported that more children implanted within a year after the onset of deafness achieved age-appropriate speech and language scores compared to children with more than a one year delay between onset of deafness and cochlear implantation (25).

Pre-implant Hearing

For many years, only children who received no measurable benefit from hearing aids were considered candidates for cochlear implantation. More recently, cochlear implant candidacy criteria have been expanded to include children who achieve some open set speech perception with a hearing aid (26). Children with greater residual hearing prior to cochlear implantation may make use of early auditory input with hearing aids to achieve vocal and lexical development that is rarely achieved by those with more profound deafness (27). Residual hearing may also reflect a more intact auditory system available for electrical stimulation through a cochlear implant. As a result, children with better pre-implant thresholds, particularly when measured with hearing aids, achieve better average results than children implanted at the same age with poorer thresholds (20;28). Cochlear implantation may be postponed for children who get more benefit from hearing aids. Therefore, if age at implantation is found to be a significant predictor after removing variance due to preimplant aided hearing, the finding would be especially impressive. This would mean that age at implantation would be a robust predictor despite the fact that those implanted earlier would have been predicted to have done worse, based on their hearing history (20).

Implant Characteristics

Once the impact of the relevant intrinsic characteristics on the measured outcome has been determined and associated variance removed, factors associated with cochlear implantation may be considered. Many of these factors are subject to change as technology improves and the implant candidacy criteria are broadened. Because profound hearing loss in children is a relatively low-incidence condition and the subject population is geographically widespread, researchers may accumulate data over a number of years and/or locations to achieve a sufficiently large number of subjects or to follow development longitudinally. This practice makes it particularly critical to examine variance that may be associated with changes or differences in technology and clinical practice.

Generation of Technology

The technology of cochlear implants has been evolving since they were first introduced, including improved electrode arrays and speech coding strategies(26). In some cases, children with more recent implant technology exhibit better speech and language outcomes (29). They are also more likely to have been implanted at younger ages (8). In large sample studies in which outcomes are examined for children implanted over a decade or more, the year of implant surgery may provide a gross estimate of the generation of technology used at initial stimulation. However, because speech coding strategies may be upgraded as new technology becomes available, more detailed information may be needed to truly account for the contribution of processor characteristics to speech and language outcomes. For example, children initially implanted with the Nucleus 22 M-PEAK coding strategy exhibited better auditory, speech and language outcomes the earlier they were upgraded to the SPEAK coding strategy (9;29). Since SPEAK was introduced, however, studies comparing newer

technologies in groups of children have not documented a significant advantage for any electrode array or coding strategy(8).

Device Function

Some children may not obtain optimal benefit from their implant due to inadequate mapping, incomplete electrode arrays or internal device failure. Limiting the subject population to children with complete insertion or function of electrode insertion and no loss of implant stimulation that exceeds a specified period (20) may help control the impact of these factors on outcome. An alternative approach quantifies parameters that are set by the audiologist to maximize the child's perception of speech, such as the number of active electrodes in the child's map, the child's ability to discriminate between adjacent electrodes, the size of the dynamic range from threshold to comfortable listening level and the range over which the child perceives growth of loudness (17;30). These metrics can only be compared within specific electrode arrays, however, since devices differ in electrode configuration and in the units representing dynamic range. For example, within the Nucleus-22 device, coding strategy and mapping parameters have been found to account for approximately 20% of total variance in speech perception (17;31), speech production (11) and language (12) outcomes.

Duration of implant use

Post-implant outcome may be influenced by the amount of time the implant device is used on a daily basis and the number of months of experience with the implant at the time of testing. Amount of daily use has been quantified using parent questionnaires and found to affect speech perception outcome scores (32). Virtually all studies have demonstrated improved auditory, speech and language outcomes after cochlear implantation compared to the pre-implant abilities, and increasing levels of performance with greater amount of implant experience. However, only a few studies have compared improvements following cochlear implantation to those observed in similar children who do not use cochlear implants (6;8). Thus it is difficult to separate improvements that are due to longer cochlear implant use from those associated with maturation and intervention.

Age at implant

One of the most dramatic changes in cochlear implant candidacy criteria has been a reduction in the recommended surgery age to 12 months. The source of the advantage for younger cochlear implantation appears to be threefold. First, the amount of auditory experience accumulated at any given test age (i.e., duration of cochlear implant use) is greater as implant age decreases. Second, children who receive a cochlear implant as infants, before they fall too far behind, may benefit from a smaller language gap to close in relation to hearing age-mates. This is especially true for children implanted between 12 and 24 months when compared to those implanted at two years or later (33;34). Finally, receiving an implant within a critical period for neural development may allow pathways to develop that might otherwise be permanently altered due to auditory deprivation (35). The speech and language of children implanted during this critical period is expected to exceed that of later-implanted children with the same duration of implant use (8;36). When equated for duration of implant use, language quotient scores of children who received an implant at 12 to 18 months of age were reportedly higher than those of children implanted at two years of age. However, almost identical expected language performance was predicted for any given duration of use when children were implanted at 24 months of age or later (20).

Approaches to intervention/habilitation

Classroom Placement

Even before cochlear implants were available, mainstream placement during the preschool years was associated with better language and academic outcomes, at least for deaf children learning spoken language (37). The proportion of children enrolled in mainstream classes has been shown to increase with each year of cochlear implant use (38). Amount of mainstream class experience was a significant predictor of reading (13) and speech production (11) skill level for children with 4 to 6 years of cochlear implant experience. However, educational mainstreaming may be a result rather than a cause of intelligible speech and age-appropriate reading levels, since better-performing students can be expected to integrate with hearing age-mates earlier.

Educational Communication Mode

Communication modes that are based in English are most often dichotomized into oral communication (OC) approaches, that do not use sign language, and total communication (TC) approaches that use both speech and sign. Although there is evidence that children enrolled in OC programs demonstrate better speech perception, speech intelligibility and language levels post implant than those in TC programs (12;39–42), higher vocabulary levels have been documented in children from TC settings(8) (29). Higher pre-implant vocabulary in sign language may be due in part to differences from test norms associated with accepting sign responses (8). However, a vocabulary advantage post-implant for very early implanted children in TC settings has been demonstrated with speech-only test administration (29;43).

Approaches to Experimental Design and Analysis

The multitude of factors affecting outcomes achieved following cochlear implantation in children complicates the task of discovering clinical practices that contribute to age-appropriate language development. Statistical techniques, like multiple regression analysis, have been used to compensate for the lack of random assignment in cochlear implant study designs (44). Another approach uses propensity scores (45), which equates the groups compared on identified covariates (8). Structural equation modeling (SEM), an extension of multiple regression analysis, may be used to confirm the interaction of multiple factors in a theory-based model. In addition to these analytic techniques, sample selection may be used to eliminate some sources of variability. Nonetheless, it is probably unrealistic for an outcome study to control for all possible contributing variables and results will vary depending on the sample characteristics and factors included in the analysis. For example, the size of the effect of earlier implantation on outcome scores varies with the range of implant ages examined, the age at which outcomes are measured and the covariates entered into the analysis. Documented age at implant effects range from none at all (9) to quite large effects (8;20;46). Identifying factors that are consistently associated with favorable outcomes requires confirmation from several studies.

The effects of including different sets of intervening variables on spoken language outcomes following cochlear implantation can be illustrated by comparing results from two recently completed studies of children implanted at young ages {Nicholas, 2007 677 /id](47). Both studies documented receptive oral vocabulary scores on the *Peabody Picture Vocabulary Test-PPVT {Dunn, 1997 634 /id}* in children implanted at young ages. Administration of the PPVT involves presenting a picture to elicit a pointing response, so no verbal response is required. Administration of the PPVT involves presenting a picture to elicit a pointing response, so no verbal response is required. Standard scores (mean = 100; SD = 15) are

based on large carefully-selected normative samples of typically-developing hearing children of comparable age and therefore reflect the size of any language gap. Vocabulary development has been shown to be an important predictor of reading outcomes in deaf children, both with (46) and without (4) cochlear implants.

Both studies had used multiple regression analysis to examine variance in PPVT scores accounted for by child, family and implant characteristics. Co-variates were identified that contributed independently to individual differences in vocabulary level achieved by implant recipients in each study. Both studies sought to determine when children with cochlear implants might be expected to catch up with hearing age-mates as a function of the age of cochlear implantation.

Participants

Children in both studies had been consistently enrolled in auditory-oral or auditory-verbal programs representing a broad geographical region throughout North America. These programs placed a major emphasis on the development of listening and oral language skills. Children in both samples came from middle and upper middle class families in which both parents had normal hearing. None had been diagnosed with conditions other than their hearing loss that would be expected to interfere with speech and language development. The children had received a cochlear implant between 1998 and 2003 and therefore used a similar generation of implant technology. Measured participant characteristics are summarized in Table 1. The two samples differed significantly on parent education level ($F = 4.51$; $p = 035$), age at implant ($F = 7.06$; $p = .009$; and age at test ($F = 328.19$; $p = .001$).

Sample 1 Characteristics {Nicholas, 2007 677 /id}

Sample 1 included 74 children (37 boys and 37 girls) who received a cochlear implant between the ages of 12–38 months of age and were 54 months old (± 2 months) at the time of testing. Duration of cochlear implant use at time of test ranged from 18 to 45 months with an average duration of 30 months. All hearing losses were presumed to be congenital as no children were included in the study if there was any evidence or suspicion that the child had once had normal hearing or a progressive hearing loss. Spoken English was the primary language or the only language used with the child. 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 (49). Intelligence quotient scores were not included in the analysis, due to the variety of tests and normative samples represented. Most of the children (N=59) were enrolled in special education preschool programs at the time of testing, 9 were in mainstream preschools and 6 were home schooled. Better ear thresholds with hearing aids prior to cochlear implantation were reported by the children's audiologists. Three frequency average thresholds at 500, 1000 and 2000 Hz ranged from 32 to 100 dB, with an average of 65 dB, SPL. Forty-seven of the children had received a Nucleus-24 implant from the Cochlear Corporation, 28 had a Clarion 1.2 or CII cochlear implant from the Advanced Bionics Corporation, and one child had a Med-El cochlear implant. All children had a full insertion of the electrode array at the time of surgery and none had experienced an interruption of implant use that lasted for more than 30 consecutive days.

Sample 2 (47)

The sample included 126 children (67 boys and 59 girls) who received a cochlear implant between 11 and 59 months of age and were 5 or 6 years old at time of testing (average age 5 years 10 months). All children were enrolled in classes for children with hearing loss at the time of testing, with hearing children included (reverse mainstreaming) for 30 participants.

Duration of cochlear implant use ranged from 12 to 70 months with an average duration of 3 years 4 months. Onset of profound hearing loss was reported to have occurred at birth or before 6 months of age. Seventy of the children had received a Nucleus-24 implant from the Cochlear Corporation, fifty had a Clarion 1.2 or CII cochlear implant from the Advanced Bionics Corporation, and three children had a Med-El cochlear implant. All children had functioning implants at the time of testing. Pre-implant hearing data were not available for a sufficient number of children to be included in the analysis. All children were administered the nonverbal subtests of the *Wechsler Preschool and Primary Scale of Intelligence* (50). Nonverbal IQ scores ranged from 80 to 140 with a mean of 107.6.

Methods

Study 1

Program administrators at school and therapy centers were asked to review their rosters for children who had received a cochlear implant before their third birthday and who met the study criteria. The parents 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 data collection on a language test battery in that setting. The PPVT was administered at age 4.5 years.

Study 2

School administrators were asked to review their files for specific language test results (including the PPVT) from children between 5;0 and 6;11 years of age who had used a cochlear implant for at least 1 year. If test results were not available and the child was still in the appropriate age range and parent consent could be obtained, a research team member traveled to the child's school and completed data collection in that setting.

Outcome Variable

The receptive vocabulary outcome measure for both samples was the PPVT Standard Score. Because standard scores are referenced to hearing age-mates (Mean = 100; SD = 15), they are corrected for chronologic age. The two samples did not differ significantly in vocabulary score (85 in Sample 1 and 87 in Sample 2). Whether children were tested at 4, 5 or 6 years of age, on average they scored within one standard deviation of the mean for hearing age-mates. This represents a marked improvement over results reported for profoundly deaf children in an oral education setting prior to the advent of cochlear implants (1).

Predictor Variables

Both studies included a set of common predictor variables: gender, age at test, age at implant, age at first hearing aid fitting and grade completed by the most highly educated parent. In addition, each study included a predictor variable that was unique to that sample. Study 1 included pre-implant better ear aided PTA threshold (500, 1K, 2K Hz). This variable provided an estimate of the amount of benefit each child received from hearing aids prior to receiving a cochlear implant. Study 2 included Performance IQ from the Wechsler Preschool and Primary Scale of Intelligence –WPPSI (50). This variable provided an estimate of nonverbal learning ability based on a normative sample of age-matched hearing children (mean =100; SD =15). This sample was restricted to children with IQs within or above the average range and the group average nonverbal IQ was 107.

Results

Inter-correlations of Variables

Table 2 provides inter-correlation matrices for predictor and outcome variables for each of the two samples. In Sample 1, higher vocabulary outcome scores were associated with higher parent education (r =.304), earlier hearing aid use (r = −.331), younger age at implant (r = −.434) and better pre-implant aided hearing (r – .223). In Sample 2, higher vocabulary outcome scores were associated with higher parent education (r = .323), younger test age (r = −.181), younger age at implant (r = −.262) and higher nonverbal IQ (r = .480). Children implanted at younger ages tended to have higher IQs (r = −.214 in sample 2) and first received hearing aids earlier (r = .715 for implant age and age HA in Sample 1 and .322 for Sample 2). They also received less benefit from hearing aids (r = −.383 for implant age and aided PTA in Sample 1).

Higher parent education and young age at implantation were positively associated with vocabulary outcome in both samples, but several associations were unique to one sample or the other. For example, age at test ranged over a two-year span in Sample 2 and 5 year olds obtained higher vocabulary standard scores in relation to hearing age mates than 6 year olds. In Sample 1, test age ranged over only 4 months, and was unrelated to vocabulary score. Because of the varied and complex associations among predictors, multiple regression analysis is required to identify independent sources of variance in each sample.

Common Predictors

A multiple regression analysis (level 1) was used to examine the independent contribution of predictor variables that were common to both samples. This analysis determined the amount of independent variance in vocabulary outcome score accounted for by each predictor after controlling for the contributions of the other three variables. Results are summarized in Table 3. Twenty-three percent of the variance in vocabulary scores was predicted by these four characteristics in Sample 1 and 24% in Sample 2. Only age at implant stimulation contributed significant independent variance in Sample 1 (p = .054). Parent Education (p = .000), age at implant (p =.002) and age at test (p =.054) were significant independent predictors of variance in vocabulary scores in Sample 2

Adding Unique Predictors

Another analysis (level 2) re-examined the independent contribution of each of the four common predictors when a unique predictor was added to the analysis (Aided PTA threshold in Sample 1, Nonverbal IQ in Sample 2). Results are summarized in Table 3. In sample 1, when pre-implant aided PTA threshold was included, 39.6% of the total variance in vocabulary score was predicted, with pre-implant PTA providing an additional 16% of explained variance. When the variance in outcome score accounted for by pre-implant hearing threshold was controlled along with the other three predictor variables, the independent contribution of implant age as an outcome predictor increased substantially (B increased from −.760 to −1.522). Removing variance associated with pre-implant aided hearing level helped to offset the beneficial effects of early hearing on vocabulary scores of later implanted children and thus augmented the benefits of early cochlear implantation.

In Sample 2, adding the unique contribution of nonverbal IQ to the four common predictors resulted in an additional 10% of explained variance, thus accounting for a total of 34% of variance in vocabulary score. In this case, the effects of parent education level, test age and implant stimulation age were all reduced by including IQ in the analysis. This is not surprising, because of the high correlation between IQ and vocabulary score (r = .480) and the moderate correlations between IQ and parent education (r = .249) and test age (r = −.

187), indicating that the IQ predictor shared considerable variance with these other predictors. Nevertheless, higher vocabulary outcome scores were still significantly associated with higher parent education level and younger age at implant, even when the variance due to IQ was removed.

Vocabulary as a Function of Implant Age

Figure 1 depicts the expected PPVT standard score for each age at implant stimulation represented in Sample 1, with pre-implant PTA threshold set at the sample mean of 65 dB, HL. Error bars indicate the 95% confidence interval around each expected mean. On this graph, a standard score of 85 or higher indicates vocabulary knowledge within on standard deviation of the mean for hearing age-mates. Considering the full 95% confidence interval, we can expect that 4.5 year old children implanted by 22 months of age will score within this average range. Children with pre-implant aided hearing levels better than 65 dB (who often get implant surgery at later ages) can be expected to achieve a normal vocabulary level with somewhat shorter durations of use.

Figure 2 provides expected PPVT standard scores for each age at implant stimulation represented in Sample 2, with parent education level set at the sample mean of 15.6 years and nonverbal intelligence set at the sample mean of 107.6. In this sample, a mean vocabulary standard score of 85 or higher can be expected for 5–6 year old children implanted by 27 months of age. . Children whose parents have completed a 4-year college or graduate program and those with nonverbal IQs above 107 might be expected to reach age-appropriate vocabulary levels somewhat sooner.

Conclusions

A variety of variables have been associated with speech and language outcomes in children who receive cochlear implants. It is not surprising that the literature provides contradictory evidence regarding the effects of these factors on post-implant outcome. Results from the two samples described here illustrate the complexity of relationships among predictor variables. Both samples consisted of children who were of preschool age, deaf from birth or shortly thereafter, enrolled in oral education settings, with nonverbal development within or above the average range. Both groups had the benefit of early amplification and intervention followed by cochlear implantation with a similar generation of processing strategies. Their rehabilitation took place in settings which emphasized parent involvement in spoken language development. The two samples were tested on the same vocabulary outcome measure, the PPVT, and achieved almost identical average standard scores, within the low-average range relative to hearing age mates.

Vocabulary scores of these two similar subject samples were analyzed in relation to four common predictor variables: gender, parent education, age first aided, age at test, and age at implant. The amount of variance in vocabulary score associated these characteristics was quite similar in the two samples (23% and 24%). In both samples, most of the variance in vocabulary was predicted by age at implant stimulation, though parent education was also positively associated with vocabulary scores.

In a second analysis, a unique predictor was added to each regression: pre-implant aided threshold in Sample 1 and WPPSI performance IQ in Sample 2. When pre-implant aided threshold was added to the analysis, the relation of implant age to vocabulary outcome was strengthened from barely significant ($p<.054$) to highly significant ($p<.000$) in Sample 1. A combination of pre-implant aided hearing and age at implant stimulation accounted for almost 40% of the variance in PPVT receptive vocabulary score at age 4.5. Children with more pre-implant residual hearing tended to receive a cochlear implant at somewhat older

ages. The early hearing aid benefit may offset any detrimental effects on vocabulary acquisition of waiting until the child is older for cochlear implantation. Therefore, the full contribution of implant age to vocabulary level was only apparent after variance due to pre-implant hearing had been removed.

A different result was observed when the added predictor variable was nonverbal IQ rather than pre-implant aided hearing. The predicted variance in vocabulary scores increased from 24% to 34% with the addition of IQ, and the estimated contribution of other variables (e.g., age at implant) was reduced. This occurred because children with higher IQs tended to receive an implant at younger ages ($r = -.214$). Because children with higher IQs also developed better vocabulary ($r = .480$), the apparent effect of implant age on vocabulary was exaggerated until variance due to IQ was removed.

Understanding the benefits of early cochlear implantation in children requires consideration of a range of potential influences and how they may interact to affect language development. Intrinsic characteristics such as gender, nonverbal intelligence, family environment, age at onset of deafness and pre-implant hearing may pre-dispose a child to better or poorer outcomes with a cochlear implant. Research designs that take as many of these factors as possible into account when examining effects of implant technology, clinical practice or habilitation strategy provide the most accurate estimates of expected post-implant outcome. Studies such as the two examples presented here illustrate that children with specified intrinsic characteristics (congenital or very early onset deafness, normal cognitive ability, strong family participation) can be expected to achieve age-appropriate oral receptive vocabulary levels during preschool (4 to 6 years of age) if they receive a cochlear implant sometime between their first and second birthday (± 3 months). Children who have the benefit of aided residual hearing prior to receiving an implant (i.e., 65 dB or better aided thresholds) and those with higher nonverbal intelligence (i.e., IQ = 107 or higher), may be expected to achieve age-appropriate levels at younger test ages or with somewhat later age at stimulation.

Future research is needed to examine language levels observed in samples that differ from those reported here (e.g., children from bi-lingual or less-affluent family environments, those with multiple disabilities, those using other communication modes instead of or in addition to speech, children with updated speech processing strategies or bilateral implants). The current analysis suggests that future analyses should control, at minimum, for age at implant stimulation, nonverbal IQ, and pre-implant aided thresholds when examining expected outcomes. The relatively large proportion of unexplained variance in the studies reported here indicates that additional variables may be identified that contribute to post-implant outcome and their inclusion may further expand our knowledge. It will be critical that studies include a sufficiently large sample size to achieve adequate power from the analysis after controlling for a number of predictor variables. Multivariate analyses can then serve to identify intervention practices that will provide the most benefit to well-specified groups of children following cochlear implantation.

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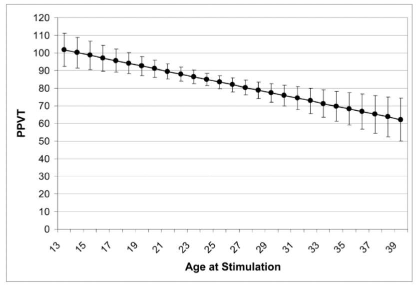
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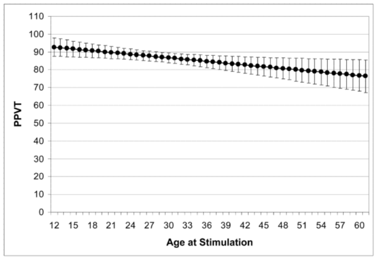
Age at Stimulation

Figure 1.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Age at Stimulation

Figure 2.

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Table 1

Sample Characteristics

	Sample 1(N=74)			*Sample 2 (N=126)*		
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**
Age at Implant (Months)	24.16**	7.92	12 – 38	28.21	11.60	11.59
Performance IQ (WPPSI)	WNL			107.65	13.63	80–140
Pre-CI Aided PTA (dB, HL)	64.63	14.74	77–120	NA		
Age at Test (Months)	54.99***	1.37	52–56	70.04	7.06	60 – 83
Age first HA (Months)	12.34	8.06	1–20	11.57	7.85	1–40
Parent Education (Years)	16.22*	2.0	10 – 20	15.62	1.87	10 – 20
PPVT Standard Score	84.74	19.33		87.27	18.65	

Significant differences between samples:

* $p<.05$;

** $p<.01$,

*** $p<.001$

WNL = Within Normal Limits

NA = Not Applicable

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Table 2

Intercorrelation Matrices for each Test Sample

Sample 1 (N=74)

Score	**Parent Education**	**Age HA**	**Age at Test**	**Age at Implant**	**Aided PTA**	**PPVT Standard Score**
Gender	.109	−.046	.109	.045	−.046	−.102
Parent Education	-	−.188	−.019	**−.310.** *(.004)*	−.027.	**.304** *(.004)*
Age HA		-	.036	**.715** *(.000)*	.170.	**−.331** *(.002)*
Age at Test				.027	.041	.005
Age at Implant					**−.383** *(.000)*	**−.434** *(.000)*
Aided PTA						**−.223** *(.028)*

Sample 2 (N = 126)

Score	Parent Education	Age HA	Age at Test	Age at Implant	Nonverbal IQ	PPVT Standard Score
Gender	.021	**−.154** *(.042)*	−.054	−.026	−.089	−.133
Parent Education	-	.001	.119	*.042*	**.249** *(.002)*	**.323** *(.000)*
Age HA		-	.116	**.322** *(.000)*	.005.	.048
Age at Test				**.300** *(.000)*	**−.187** *(.018)*	**−.181** *(.022)*
Age at Implant					**−.214** *(.008)*	**−.262** *(.002)*
Nonverbal IQ						**.480** *(.000)*

(Significance level of correlation coefficient)

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Table 3

Level 1 Regression Analyses to Predict PPVT Standard Score from 5 Common Characteristics in 2 Samples of Children

	Sample 1 (N=74)				Sample 2 (N=126)			
Parameter	**Regression Coefficient (B)**	**Standard Error**	**t**	**Sig.**	**Regression Coefficient (B)**	**Standard Error**	**t**	**Sig.**
Gender	−4.519	4.167	−1.085	.282	−5.040	3.002	−1.679	.096
Parent Education	1.993	1.089	1.830	.072	3.551	0.799	4.445	**.000**
Age HA	−0.184	0.367	−0.077	.618	0.319	0.202	1.578	.117
Age at Test	0.464	1.507	0.308	.759	−0.431	0.222	−1.944	**.054**
Age at Implant	−0.760	0.387	−1.962	**.054**	−0.441	0.141	−3.136	**.002**
R^2	**.235**				**.241**			

Table 4

Level 2 Regression Analyses to Predict PPVT Standard Score from Five Common Characteristics and One Unique Characteristic in each Sample

	Sample 1 (N = 74)				Sample 2 (N=126)			
Parameter	**Regression Coefficient (B)**	**Standard Error**	**t**	**Sig.**	**Regression Coefficient (B)**	**Standard Error**	**t**	**Sig.**
Gender	−4.267	3.731	−1.144	.257	−3.786	2.827	−1.339	.183
Parent Education	1.220	0.992	1.230	.223	2.597	0.782	3.323	**.001**
Age HA	0.191	0.340	0.562	.576	0.259	0.190	1.363	.175
Age at Test	0.737	1.351	0.546	.587	−0.274	0.211	−1.296	.198
Age at Implant	−1.522	0.391	−3.895	**.000**	−0.332	0.134	−2.469	**.015**
Nonverbal IQ					0.467	0.111	4.218	**.000**
Pre-Implant PTA (dB)	0.599	0.142	−4.223	**.000**				
R^2	**.396**				**.340**			