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Effects of Early Auditory Experience on the Spoken Language of Deaf Children at 3 Years of Age

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Abstract

Objective: By age three, typically developing children have achieved extensive vocabulary and syntax skills that facilitate both cognitive and social development. Substantial delays in spoken language acquisition have been documented for children with severe-profound deafness, even those with auditory oral training and early hearing aid use. This study documents the spoken language skills achieved by orally educated three-year-olds whose profound hearing loss was identified and hearing aids fitted between 1 and 30 months of age and who received a cochlear implant between 12 and 38 months of age. The purpose of the analysis was to examine the effects of age, duration and type of early auditory experience on spoken language competence at age 3.5.

Design: The spoken language skills of 76 children who had used a cochlear implant for at least 7 months were evaluated via standardized 30-minute language sample analysis, a parent-completed vocabulary checklist, and a teacher language-rating scale. The children were recruited from and enrolled in oral education programs or therapy practices across the United States. Inclusion criteria included: presumed deaf since birth, English the primary language of the home, no other known conditions that interfere with speech/language development, enrolled in programs using oral education methods, and no known problems with the cochlear implant lasting over 30 days.

Results: Strong correlations were obtained among all language measures. Therefore, principal components analysis was used to derive a single Language Factor score for each child. A number of possible predictors of language outcome were examined, including age at identification and intervention with a hearing aid, duration of use of a hearing aid, pre-implant PTA threshold with a hearing aid, PTA threshold with a cochlear implant, and duration of use of a cochlear implant/ age at implantation (the last two variables were practically identical since all children were tested between 40 and 44 months of age). Examination of the independent influence of these predictors through multiple regression analysis revealed that pre-implant aided PTA threshold and duration of CI use (i.e., age at implant) accounted for 58% of the variance in Language Factor scores. A significant negative coefficient associated with pre-implant aided threshold indicated that children with poorer hearing before implantation exhibited poorer language skills at age 3.5 years. Likewise, a strong positive coefficient associated with duration of implant use indicated that children who had used their implant for a longer period of time (i.e., who were implanted at an earlier age) exhibited better language at age 3.5 years. Age at identification and amplification was unrelated to language outcome, as was aided threshold with the cochlear implant. A significant quadratic trend in the relation between duration of implant use and language score revealed a steady increase in language skill (at age 3.5)

for each additional month of use of a cochlear implant after the first 12 months of implant use. The advantage to language of longer implant use became more pronounced over time.

Conclusions: Longer use of a cochlear implant in infancy and very early childhood dramatically affects the amount of spoken language exhibited by three year old profoundly deaf children. In this sample, the amount of pre-implant intervention with a hearing aid was not related to language outcome at 3.5 years of age. Rather, it was cochlear implantation at a younger age that served to promote spoken language competence. The previously identified language-facilitating factors of early identification of hearing impairment and early educational intervention may not be sufficient for optimizing spoken language of profoundly deaf children unless it leads to early cochlear implantation.

The first three years in a child's life are critical for acquiring information about the world, communicating with family, and developing a cognitive and linguistic foundation from which all further development unfolds. If a child is able to develop age-appropriate spoken language skills, he or she will be more likely to be prepared to enter a preschool or kindergarten setting ready to participate fully in all activities and to engage in meaningful social interactions with teachers and peers. It has been shown that children who are deprived of sufficient amounts and/or quality of language input in their earliest years are at risk for poor outcomes in both language and academic endeavors later in childhood (Hart & Risley, 1995). It has also been shown that poor language skills and/or poor parent-child communicative interactions early in life are associated with concurrent socio-emotional and behavioral problems (Prizant & Meyer, 1993; Baltaxe, 2001) and have been associated with later deficits in language development (Rescorla, 2002; Scarborough, 1990; Ziegler, Pech-Georgel, George, Alario & Lorenzi, 2005; Snow, 1984), reading (Scarborough & Dobrich, 1990; Nathan, Goulandris & Snowling, 2004), lower verbal intelligence (Hart & Risley, 1995), poorer social-emotional development and self-esteem (Greenberg & Kusche, 1993) and some psychiatric diagnoses (Toppelberg & Shapiro, 2000). Clearly, it is to the advantage of every child to form a solid foundation in a primary language. Most, though not all, deaf children are born to hearing parents who use spoken language. Thus speech is the most efficient means of communication within those families and the local community. This paper addresses the concerns of those families and professionals who are interested in facilitating the development of a primary spoken language for severely-profoundly deaf children.

Language skills of three-year olds with and without hearing loss

The literature on the language development of typically developing, hearing children provides benchmarks regarding the mean vocabulary size and sentence length produced by children of middle-socioeconomic class who are three years of age. Though there is wide variability among children at this age, one might expect a three-year-old to be able to produce 900 - 1,000 different words and to use those words to produce sentences that are, on average, 3-4 words in length and include a subject and a verb (Owens, 2005). In previously published work from our own laboratory, for example, we found that in a 30-minute play session with a parent, the typical hearing child at 3.5 years of age produced approximately 210 different words and produced utterances that were an average of 3.2 words in length (Nicholas, 2000). In contrast, profoundly deaf children have demonstrated a much lower level of lexical and syntactic skills. When the same 30-minute play session was examined for 3-year-old orally educated profoundly deaf children without cochlear implants we documented an average of 35 different words in utterances that were an average of 1.5 words in length (Nicholas, 2000). This low level of lexical and grammatical proficiency put them at a huge disadvantage compared to chronologic age-mates and left them unable to fully participate in, and benefit from, typical preschool activities without a high degree of communicative support.

The impact of early cochlear implantation on spoken language development

There is a strong emphasis in the clinical literature upon getting language input to children with hearing loss at the earliest possible ages for the purpose of the prevention or remediation of delay (Ramkalawan & Davis, 1992; White & White, 1987; Yoshinaga-Itano, Sedey, Coulter, and Mehl, 1998). These studies indicate that early diagnosis and hearing aid fitting are associated with improved language outcomes for children with a wide range of hearing losses. For children with profound hearing loss, research has documented significant benefits of cochlear implantation over conventional amplification for improving speech and language acquisition (Osberger, Maso, & Sam, 1993; Geers & Moog, 1994). The age of cochlear implantation for children with severe-profound deafness has been increasingly lowered, based on the assumption that the earlier the input is experienced the greater the benefit will be to the child. As a result, the proportion of children implanted at age two or younger has increased dramatically. Because of the widespread acceptance of the possibility that critical/sensitive periods for speech perception and/or language exist, researchers have been interested in the extent to which younger cochlear implantation improves the acquisition of these skills (Dawson et al., 1992; Nikoloupoulos, O'Donoghue, & Archbold, 1999; Richter, Eissele, Laszig, and Lohle, 2002; Connor & Zwolan, 2004; Kirk, Miyamoto, Ying, Perdew & Zuganelis, 2002; Spencer, 2004; Holt, Svirsky, Neuburger & Miyamoto, 2004; Svirsky, Teoh, & Neuburger, 2004). It is known that neural organization in the young child is measurably altered in the circumstance of auditory deprivation (Sharma, Dorman, & Spahr, 2002) but whether or not this alteration is permanent or is amenable to reversal with enough subsequent exposure to spoken language is not known. Recent work has shown, however, that changes in the neural responding within central auditory pathways occur shortly after cochlear implantation in infants and appear to be closely related to early communicative behaviors that develop at the same time (Sharma et al., 2004).

The lowering of the age of potential cochlear implantation provides an opportunity for evaluating spoken language development during the first three years of life for children who have used a cochlear implant for two or more years. Such data are of clinical and theoretical interest. From a clinical standpoint, parents considering a cochlear implant for their child must have up-to-date information on the potentially greater benefits of early implantation so that these may be weighed against the expected outcome of later implantation or continued use of hearing aids. From an educational standpoint, educators of deaf children need to know whether to revise expectations and preschool curricula for their students as greater achievements are documented for this new cohort of deaf children who may have substantial auditory experience by the time they are three years old. From a theoretical standpoint, a deaf child's ultimate achievement in communication and spoken language under circumstances of very early auditory input may have implications for theories of acquisition that stress the importance of auditory experience in infancy.

There are two potential advantages for preschool-aged children who have received a cochlear implant during infancy. One advantage is the longer duration of auditory stimulation by the time they are 3-4 years old. The other advantage is that auditory input during the first two years of life (i.e., a potential critical/sensitive period) may be particularly conducive to more rapid progress in spoken language. In most studies examining the effects of early cochlear implantation, no attempt is made to separate the influence of these two factors. However, some studies have indicated that children who receive early cochlear implantation exhibit faster rates of language acquisition than do children implanted later. Svirsky, Robbins, Kirk, Pisoni, & Miyamoto (2000) have shown that language growth rates of children who receive implants before 5 years of age are very close to growth rates of hearing children once the deaf child has received an implant. Differences in language performance between children with implants and their hearing age-mates, they concluded, may be due primarily to the existing delay in

performance at the time of implantation. Ideally, therefore, implantation should occur not only early enough for normal language progress to be achieved, but also before delays are present. When cochlear implantation is initiated at a younger age, more language progress may be apparent over a given duration of use than would occur if implantation were postponed until the child was older. In addition, children implanted younger have the advantage of improved auditory experience and spoken language during a critical developmental period. This advantage was apparent when speech perception and language development was compared over the same developmental period for children implanted between 16-24 months, 25-36 months and 37-48 months of age (Svirsky, Teoh & Neuberger, 2004). Children implanted *before* the age of 2 years exhibited advantages in both areas of competence over those receiving the implant at 2 or 3 years of age.

The critical variable for optimum success may be the time interval between the onset of deafness and receipt of a cochlear implant. A study that analyzed outcomes at age 8 and 9 years for children with congenital hearing losses and for children who lost their hearing between birth and 35 months of age concluded that, if the desired result is for both speech and spoken language levels to fall within the range of hearing age-mates, the advantage appears to lie with those children who have a shorter duration of deafness, whether the deafness was congenital or acquired (Geers, 2004). For congenitally deaf children at the same age, of course, duration of deafness is equivalent to age at implant.

Importance of pre-implant audition for spoken language development

At the same time that age at implantation is decreasing, children with greater amounts of residual hearing are being considered cochlear implant candidates. Such children have been observed to achieve even better results than those with very profound pre-implant thresholds (Eisenberg, Kirk, Martinez, Ying & Miyamoto, 2004; Cowan, Deldot, Barker, et al, 1997; Gantz, Rubenstein & Tyler, 2000; Dolan-Ash, Hodges & Butts, 2000; Zwolan, Zimmerman-Phillips, Asbaugh, et al, 1997). On the one hand, these children may benefit from more intact auditory structures available for electrical stimulation through a cochlear implant. On the other hand, very early use of hearing aids in children with residual hearing may act as a bridge to provide auditory access to language until the child receives an implant. Therefore, their experience with hearing aids before implantation may provide them with more advantages of early auditory stimulation than more profoundly deaf hearing aid users with similar age at implantation.

A recent study by Kishon-Rabin, Taitelbaum-Swead, Ezrati-Vinacour & Hildescheimer (2005) demonstrated that duration of cochlear implant use was not necessarily the most important factor in explaining language progress. About half of 24 infants in that study performed as predicted given the duration of use of their implant but the other half did not. The authors concluded that the latter group did not gain sufficient auditory information from their previously worn hearing aid to lay an adequate foundation for vocalizations that could later be enhanced and expanded with the use of a cochlear implant. In a related study of German-speaking pediatric cochlear implant recipients, Szagun (2001; 2004) investigated the relative importance of both pre-operative hearing ability and of age at implantation. Outcome measures were MLU derived from spontaneous language samples and productive vocabulary as assessed by a parent-response questionnaire. Age at implantation ranged from 14-46 months and children were compared to a group of hearing children matched at the study outset for vocabulary level. Analyses revealed different results for the grammar (MLU) and the vocabulary outcome measures. Age of implantation was significantly correlated with higher MLU values but not with vocabulary scores. Pre-operative hearing levels were significantly related to both grammar and vocabulary measures and explained a larger percentage of variance than age at implant.

Importance of early diagnosis and intervention

Simultaneous with the increasing acceptance and prevalence of the cochlear implant surgery, there has been a movement in the United States and other countries to pass legislation that requires hearing screening procedures for all newborn infants. Yoshinaga-Itano et al. (1998) demonstrated that providing a diagnosis and appropriate intervention services within the first six months of life led to deaf children having significantly better language outcomes than those who were identified at a later age. Likewise, Robinshaw (1995) found that 12 profoundly deaf infants who were diagnosed and fit with hearing aids by 6 months of age used communicative vocalizations similarly to five hearing children of the same chronological age and significantly more than 12 children with similar hearing loss who had been diagnosed between 2-3 years of age. At the present time, a majority of states mandate such universal hearing screening and the average age for diagnosis of a significant hearing loss in the United States has been reduced substantially (Dalzell et al., 2000). Such early diagnosis provides an opportunity not only for the earlier introduction of sound via hearing aids and for specialized auditory training, but also for earlier consideration of cochlear implantation should the child be an otherwise appropriate candidate and the parents desire this option. This early diagnosis of severe-to-profound hearing loss has raised new questions about how soon cochlear implant surgery can safely and effectively be conducted and what disadvantages are associated with waiting months or even years to determine implant candidacy.

Along with earlier identification and widespread use of cochlear implantation has come an increasing prevalence of enrollment in educational programs that emphasize the use of audition and speech in communicative development, with the expectation that many deaf children today will be increasingly better equipped to benefit from instruction in spoken language (Marschark & Spencer, 2006). Being able to master spoken language skills that will allow children to comfortably and competently participate in mainstream schools and other activities with minimal amounts of outside support has begun to take a higher priority in many educational settings (Geers, 2004). As a result, there has been a large increase in the proportion of deaf children who are being educated in mainstream settings within five years of surgery (Niparko & Blankenhorn, 2003; Geers & Brenner, 2003).

Early diagnosis, therefore, has the potential for setting in motion a series of events that are likely to result in improved spoken language outcomes by three years of age. An early diagnosis likely leads to fitting of hearing aids at a younger age and longer duration of improved auditory perception through amplification. It also makes possible an earlier and longer period of speech and language instruction as well as the opportunity for earlier cochlear implantation.

Purpose of the present study

The purpose of the present study was to examine the relative contributions of both audiological intervention (duration of use of both a hearing aid and a cochlear implant) and auditory perceptual experience (as measured by aided sound field thresholds) on spoken language outcomes when the child is 3.5 years of age. While other studies have examined the duration of implant use or corresponding age-of-implantation effects, the results of those studies are confounded by the fact that those children who are getting a cochlear implant at the youngest ages may also have the advantage of earlier diagnosis, earlier hearing aid intervention, and earlier educational intervention. This paper directly examines the relative contribution of pre-implant experience. We hypothesize that there is a linear relation between age at implant and language competence at three years of age; i.e., better language skills at age three are predicted for each month of cochlear implant use. The fact that children who are implanted later tend to have better residual hearing to begin with potentially detracts from the duration of use/age of implantation effect. Children with better aided thresholds before cochlear implantation would

be expected to exhibit better language outcomes than children with similar implant experience but with more profound hearing losses. Once the variability accounted for by the degree of pre-implant auditory perceptual ability is removed, we are likely to see an even stronger relationship between age at implant/duration of use and language outcome.

Unique aspects of this study include:

- (1) A sample of children who were all 3;6 years old (± 2 month) when tested. This allows us to examine the effects of longer duration of auditory experience on children for whom maturation and developmental status is the same.
- (2) A sample of children who participated in intervention programs using exclusively spoken language. A significant impact of instructional communication mode on language outcomes has been documented (Geers, Nicholas, and Sedey, 2003; Kirk et al., 2002). Including only children from oral communication settings eliminates this source of variability from the analysis.
- (3) Comprehension and production of exclusively spoken language. Previous studies have included a variety of communication modalities in both test administration and in scoring responses. Evaluation of spoken language with all children in the present study provides an unambiguous interpretation of the effects of cochlear implantation on spoken language outcomes.
- (4) Evaluation of language from direct observation as well as from teacher- and parent-report. A convergence of language measures derived from spontaneous spoken language samples, parent report, and teacher ratings may provide a broader and more representative picture of a young child's communicative abilities than any single language test.

Analyses will be accomplished in two stages. First, spoken language outcome will be predicted from two pre-implant variables: (a) length of time from receipt of hearing aid to cochlear implant surgery and (b) the sound-field threshold values obtained while the child was using a hearing aid. Next, with the variance from those factors statistically accounted for, we will determine how much additional variance can be explained by the duration of cochlear implant use and the sound-field thresholds obtained with the use of a cochlear implant.

METHOD

Participants

Group characteristics are summarized in Table 1. The sample includes 76 children from across the United States and Canada who received a cochlear implant between the ages of 12-38 months of age and were 3;6 years old (± 2 months) at the time of testing. The children's hearing loss was diagnosed, amplification fitted and intervention initiated all within a very short interval (average interval = 1 month), so all three of these variables are summarized as age at amplification, which occurred at an average age of 12 months. They had used a hearing aid for an average of 11 months before receiving a cochlear implant. Duration of cochlear implant use at time of test ranged from 7 to 32 months. No participants had developmental or medical conditions other than their hearing loss that would be expected to interfere with speech and language development. All children scored within 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). The children had been consistently enrolled in an auditory-oral or an auditory-verbal program. All children came from families in which English was the primary language or the only language spoken to the child. All hearing losses were presumed to be congenital as children were excluded from the study if there was any evidence or suspicion that the child had once had normal hearing or a progressive hearing loss. The children had

received a cochlear implant between 1998 and 2003. 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. Finally, 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.

Participants were recruited from 23 different U.S. states as well as 1 Canadian province. Host sites were 14 schools for the deaf, 4 hospitals, 3 county child development centers, 4 public schools, and 7 auditory-verbal therapy practices. 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.

Procedure

Each participant was videotaped in a 30-minute play session with his or her own parent in a quiet room. The session was a semi-structured time in which the parent was instructed to communicate with the child in a manner that was consistent with their everyday interactions. Four sets of toys, one set introduced every 7-8 minutes, were provided to the child-parent dyad for purposes of stimulating conversation. A more complete description of the toy boxes and procedure can be found in Nicholas and Geers (1997). In addition, each parent completed the MacArthur Communicative Development Inventory: CDI (Words and Sentences form; Fenson et al., 1993) and the child's teacher or therapist completed the Scales of Early Communication Skills for Hearing Impaired Children (Moog & Geers, 1975).

Dependent variables

Measures derived from the language sample—All spoken words produced by the children and parents were transcribed from the videotape by an experienced teacher of deaf children. Criteria for judging a word to be intelligible were: same number of syllables, matched on at least one vowel, matched on at least one consonant. The transcription procedures follow the CHAT format of the Child Language Data Exchange System (CHILDES; MacWhinney, 2000). A second teacher of the deaf reviewed each of the videotapes with its transcript and made any necessary corrections due to omission or error.

A number of language measures of interest in this study were derived from the language sample and are referred to in the tables as the “CLAN variables” as they were derived and counted utilizing the CLAN programs of the CHILDES (MacWhinney, 2000). The CLAN variables were: Total Number of Words, Number of Different Word Roots, Mean Length of Utterance, Number of Bound Morphemes per Word and Number of Different Bound Morphemes. These were counted from the transcripts of the 30-minute play session. All of these children were learning spoken language exclusively, only spoken language was included in the dependent variable counts, and all references in this paper to a “word” refer to a spoken word. These five measures provide for a description of several important aspects of a young child's emerging language skill (Miller, 1981). The Total Number of Words provides a measure of the amount of talk generated by the child within the confines of the 30-minute play session. The Number of Different Word Roots is a measure of the breadth of the child's vocabulary. This variable differs from a simple vocabulary count in that it includes words that contain a single free (root) morpheme such as “look” (root of *look-s*, *look-ed*, *look-ing*) as a single item in the vocabulary, thereby decreasing the possibility of over-estimating the breadth of the child's vocabulary. The Mean Length of Utterance (in Words) was included as a crude measure of syntactic development and, consistent with other researchers, it is our practice to exclude repetitions,

false starts, and abandoned utterances in the calculation of this measure. A bound morpheme was defined as any grammatical tag or marker that cannot function independently and is attached to a free morpheme or other bound morpheme. This definition included inflectional suffixes such as -s, -es, -'s, -ing, -ed, -er ("bigger"), derivational suffixes such as -ly, -ist, -er ("painter"), -ness, -ment, as well as contractions such as -'s (is), -'nt (not), -ll (will), -'re (are), -'m (am), and -'us (us). The Number of Bound Morphemes per Word provides a sense of how often a child is using bound morphemes and Number of Different Bound Morphemes indicates the breadth of the child's mastery of bound morpheme types.

For the purposes of examining transcriber reliability, eight of the language samples (10%) were independently transcribed by the two the transcribers mentioned above. Results are presented Table 2. There was a very close correspondence between the frequency of occurrence of each of the five dependent variables that were derived from the language sample.

Measures derived from parent report—The MacArthur Communicative Development Inventory (CDI: Words and Sentences Form; Fenson et al., 1993) is an instrument developed primarily to document the productive vocabulary and early grammatical skills of typically developing, hearing children who are between the ages of 16-30 months of age. The inventory consists of 680 different words arranged in 22 semantic categories. A respondent (usually a parent) indicates which words the child is known to have produced with recognizable speech. Other parts of the inventory assess the child's use of irregular word forms (seen as a natural and positive developmental step), the length of three longest utterances recently spoken, and the complexity of the grammar in recent spontaneous language. As all of the deaf children in this study were learning language through auditory-oral means, spoken language was the only communication modality assessed. The dependent measures obtained from this assessment instrument were as follows: Vocabulary Raw Score (possible range 0 - 680), Irregular Words Raw Score (possible range 0 - 25), Sentence Complexity Raw Score (possible range 0 - 37), and Length of Longest Sentence Raw Score (no limit on score). Raw scores were used since the children were assessed at a chronological age much older than those in the normative sample. Scores on the CDI are reported for 75 of the children (one parent did not return the language rating form).

Measures derived from teacher ratings—Ratings of language comprehension and production skills were obtained from teachers or speech/language therapists on the Scales of Early Communication Skills for Hearing-Impaired Children (SECS; Moog & Geers, 1975). This rating scale provides hierarchical lists of receptive and expressive language skills that are rated by the teacher (see Appendix A). The test manual reports inter-rater reliability coefficients that range from .76 to .91. Raw scores were used in the analysis, since all children were approximately the same age when their teachers rated them. However standard scores based on a normative sample of 3-year old severely-profoundly deaf children prior to the use of cochlear implants in children are also reported.

RESULTS

Means and standard deviations on all of the language measures are presented in Table 3. These scores were generally higher than those obtained from profoundly deaf three-year-olds in oral education programs before the advent of cochlear implants. This was particularly evident in the average SECS standard score ratings, which were 1 and 1.5 standard deviations above the previous average for receptive and expressive language scales, respectively (Moog & Geers, 1975). The average Total Number of Words, Different Root Words and Bound Morphemes observed was also substantially higher than had been observed in previous studies of 3-year-olds with profound hearing loss (Nicholas, 2000).

Table 4 provides a summary of the correlation coefficients obtained between all language measures. All variables correlated 0.51 or higher ($p < .001$), demonstrating the validity of these measures that were derived from three different sources: parent report, teacher rating and direct observation of the child. The relatively high correlation coefficients obtained among the measures suggested that these outcome variables could be reduced to a single standardized score using principal components analysis. This approach is motivated by the belief that the collection of measures taps some common ability and that a single summary score would be more economical than multiple scores (see Strube, 2003). Principal components analysis forms the summary score by creating a weighted linear combination of the original variables (which have been standardized). The weights are derived to insure that the principal component preserves as much of the original score variance as possible, and when relevant to insure that multiple principal components are independent. This approach is valid provided that the principal component represents the original variables well. This occurs when the single principal component accounts for the majority of variability in the set of original variables, as indexed by the proportion of original variable variance accounted for by the principal component. To say that a principal component accounts for 60% of the original variable variance means that 60% of the information in the set of original variables is represented in the single principal component score. Generally, components that account for over 50% of the original variable variance are considered to be excellent summary scores. Each measure's principal component loading or correlation with the overall principal component score is listed in Table 5. The principal component score accounts for 77% of the total variance in the language measures and therefore serves as the Language Factor score. The Language Factor score is a standardized score with a mean of 0 and a standard deviation of 1.0. The range of values in this sample is from -1.84 to $+2.63$.

Table 6 provides the correlations between the Language Factor Score and the independent variables: Pre-implant aided pure tone average (PTA) threshold, age first aided, months of hearing aid (HA) use, age at implantation, post-implant PTA threshold, and duration of implant use. Language Factor scores were found to increase significantly with younger age at amplification (i.e., diagnosis and intervention; $r = -.54$) as well as younger age at cochlear implantation ($r = -.62$). Language scores increased with longer duration of implant use ($r = .63$), but there was no such association between language outcome and duration of hearing aid use ($-.07$). Duration of hearing aid use prior to cochlear implantation was not significantly associated with the language outcome.

Interesting relations were also documented among the predictor variables: (a) children identified and aided at an early age were also more likely to receive a cochlear implant at a younger age ($r = .69$), (b) children who continued using hearing aids for longer periods of time before cochlear implantation tended to be those with better aided thresholds ($r = .34$), and (c) children implanted at younger ages were those who did not receive as much benefit from a hearing aid ($r = .40$). Thresholds measured with a cochlear implant did not show significant correlations with any predictor variable.

A multiple regression analysis examined the independent contribution of each independent variable with the influence of the other independent variables held constant. The number of independent variables was reduced to four non-redundant predictors that were entered in an hierarchical fashion in the following order: Pre-implant aided PTA threshold, Duration of HA use, Post-implant PTA threshold, Duration of CI use. Results are presented in the top panel of Table 7. Together these four independent variables accounted for 58% of the variance in Language Factor scores, with both aided PTA threshold and duration of CI use being significant predictors. The significant negative coefficient associated with pre-implant aided thresholds indicates that children with poorer hearing before implantation exhibit poorer language skills at age 3.5 years. Likewise, the strong positive coefficient associated with duration of implant

use indicates that children who have used their implant for a longer period of time (i.e., implanted younger) exhibit better language at age 3.5.

The best estimate of the relation between duration of implant use and language test scores, with the influence of pre-implant aided threshold controlled for statistically, is depicted in Figure 1. The 95% confidence limits in Language Factor scores are plotted for each duration of implant use. These error bars reflect greater uncertainty at the ends of the distribution due to the smaller number of subjects relative to the middle of the distribution. When this relation was tested for curvilinearity (bottom panel of Table 7), a significant quadratic effect was detected. The curvilinear effect indicates that the simple slope relating duration of CI use to the Language Factor score changed as duration of implant use increased. In other words, duration of implant use was more highly related to language outcome at higher levels of duration compared to lower levels. Follow-up analyses of the predicted simple slopes for each level of duration of use were used to identify the point at which the simple slope was significantly different from zero, in this case at 11-12 months of use. This result indicates that the effect of cochlear implant use on language outcome is not apparent until after about a year of device use, after which there is a steady increase in language skill measured at age 3.5 for each additional month of use of a cochlear implant. This relation became more pronounced with longer implant use and did not reach asymptote even approaching 32 months of use.

As an aid to understanding the level of conversational discourse produced by children with differing Language Factor scores, three examples are included in Appendix B. Small portions of conversation are presented from the children with the lowest, median, and highest Language Factor scores. Along with each are audiological and surgical data as well as a listing of the three longest sentences produced in the full 30-minute language sample.

DISCUSSION

Summary of Results

The dependent measures of language used in this study illustrated strong convergence in depicting language skills achieved by severely-profoundly deaf 3-year olds. Measures derived from direct observation were in good agreement with measures derived from parent report and from teacher ratings. This finding supports the validity of the weighted Language Factor Score used in this study as a reliable estimate of spoken language outcome.

Use of a cochlear implant in infancy appears to dramatically affect the amount of spoken language benefit derived from the auditory input experienced by the children in this sample. These results suggest that the previously identified language-facilitating factors of early identification of hearing impairment and early educational intervention (Yoshinaga-Itano et al., 1999) alone may not be sufficient for developing spoken language competence in profoundly deaf children by in the preschool years. In this sample, the amount of pre-implant intervention with a hearing aid did not affect spoken language outcome at age 3.5 years. Rather, it was cochlear implantation at a younger age that served to reduce the gap between a deaf child's chronological age and his or her language level. Furthermore, children who exhibited more pre-implant residual hearing and therefore received more benefit from a hearing aid exhibited even better language after the same period of cochlear implant use than children with less hearing.

Because the sample of children in this study was limited to those in oral educational settings, it is unknown whether or not these results would generalize to children who are in settings that utilize other language-teaching methods, i.e., Total Communication or Bilingual/Bicultural.

Issues Requiring Further Research

Separating age at implant from duration of implant use—There was a linear relationship between implant experience and language development, at least for children who had used an implant for a year or more. An additional advantage of longer implant experience was auditory stimulation at a younger age. This report does not aim to compare the relative influence of age at implantation and duration of implant use. Because all of the children in this study were examined when they were 3.5 years of age and were implanted at different chronological ages, they must have differing lengths of implant experience at the time of data collection. The relative influence of age of implantation and duration of use will be examined when these children are observed a second time, when they are 4.5 years of age. At that time, the amount of variance in outcome score associated with age at implant, duration of use and age at test can be separated.

Exploring language advantages for implantation below 12 months of age—This study examined language skills of children implanted as young as 12 months of age. However, implants are currently being used in selected instances for children as young as 7 months. Because of the apparently special receptivity of the auditory system to phonological input during the second half of the first year of life (see Kuhl, 2000 for a review) there are reasons to expect that even greater gains may be realized by those who have access to auditory input before 12 months of age (the youngest age at implant sampled in this study). However the increased risks associated with surgery combined with the increased possibility of misdiagnosing a profound hearing loss at such young ages may argue against further reduction in candidacy age guidelines. Furthermore, speech perception results reported by Holt et al. (2004) found no advantage for children implanted at 6-12 months of age compared to those implanted at 12-24 months. The speech perception advantage provided by very early implantation may also appear in the children's spoken language and speech development. Therefore the benefits of cochlear implantation for children under 12 months of age deserves further study, particularly a detailed analysis of their development of phonemes and phonological aspects of language.

Examining longer durations of cochlear implant use—This study included children who had up to 32 months of implant experience. An area of continuing interest is whether the advantages of earlier implantation will be maintained over a relatively long time course. At least one previous study (Geers et al., 2003) found that children implanted between 2-4 years of age did not differ among themselves in language performance measured at ages 8-9 years. Because that study did not include language measurements from the participants when they were preschoolers it is impossible to know whether children implanted at younger ages exhibited an advantage that was subsequently lost or whether children implanted at any point during the preschool years exhibited an equal “early implant” benefit. Other important reasons for studying the outcomes of these children at school age are: (a) determining whether early language advantages lead to greater achievement in literacy skills as these have been traditionally more difficult for deaf children to acquire than for hearing children, and (b) documenting whether language skills of these children, including semantic, syntactic and pragmatic competence, will eventually catch up with their hearing age-mates and, if so, how long that will take.

CONCLUSION

The results of this study indicate that when cochlear implant use is initiated early, children are able to make significant use of the auditory input and are able to reap language-learning benefits that are clearly not available to those with limited auditory input. By the age of 3.5 years, deaf children who have used a cochlear implant for at least a year exhibit a spoken language

advantage that increases with each month of previous cochlear implant use. This is important because at this age the majority of children have entered into nursery school, daycare, or other settings in which they must interact with both age-mates and adults other than their parents. While it is possible that children who receive an implant later may eventually catch up to this group in terms of language skills, valuable time will have been lost in the development of social and cognitive skills which are usually developing in preschool aged children via the medium of spoken language.

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APPENDIX A

Scales of Early Communication Skills for Hearing-Impaired Children

Ratings are made based on general observation of the child's language in both elicited and natural situations. Each item is rated as established, absent or emerging. In order to accurately rate a child, it is necessary to read the test manual where the criteria for rating language behavior is thoroughly described. The following items summarize the overall categories of language behaviors that are included on the receptive and expressive language scales.

Receptive Language

- I.** Demonstrates awareness that the mouth and/or voice convey information
- II.** Demonstrates comprehension of a few words or expressions
- III.** Demonstrates the ability to learn new words
- IV.** Demonstrates the ability to acquire new comprehension vocabulary in phrases and sentences.
- V.** Demonstrates comprehension of successive phrases and sentences

Expressive Language

- I.** Demonstrates awareness that vocalizations are used to communicate
- II.** Demonstrates the ability to use a few syllables, words or expressions
- III.** Demonstrates the ability to learn new expressive vocabulary
- IV.** Demonstrates the ability to acquire new expressive vocabulary fairly readily
- V.** Demonstrates the ability to join two or three words together
- VI.** Demonstrates the ability to combine verbs and nouns in phrases and sentences
- VII.** Demonstrates the ability to use sentences containing a modifying word or phrase
- VIII.** Demonstrates the ability to use sentences containing more than one type of modifying word or phrase
- IX.** Demonstrates the ability to use sentences containing more than one verb form

APPENDIX B

Examples of Conversation While Parent and Child Set up Wooden Train Tracks Children are 3;6 years of age (± 1 month)

CHILD A -- Lowest Language Factor Score (LFS) in Participant Sample

Pre-implant aided PTA: 80 Unaided: 101 Age at CI surgery: 32 mos. Duration of CI use: 9 mos. LFS: -1.843

Child: (makes train noises)	Mom: There we go. That might work.
Child: (unintelligible) Uh-oh.	Mom: Well, that's about as good as it's going to get.
	Mom: Uh-oh.
Child: Uh-oh.	Mom: There you go, there you go. Push.
Child: (unintelligible)	Mom: Choo-choo!
Child: Uh-oh.	Mom: Baby, I know. Just, just.... it'll go.
Child: (noises)	Mom: You going to fix it?
Child: (points to track)	

Three longest utterances in a 30-minute language sample: Bye-bye, bye-bye. No. Baby.

CHILD B -- Median Language Factor Score (LFS) in Participant Sample

Pre-implant aided PTA: 55 Unaided: 111 Age at CI surgery: 15 mos. Duration of CI use: 29 mos. LFS: 0.012

Child: Oh, this go there.	Mom: Wow, nice job! (claps)
Child: I want train.	Mom: You want the train?
Child: (nods)	Mom: Oh, OK. I'll give you some pieces.
Child: I'll hold.	Mom: You going to help?
Child: (nods)	Mom: OK.
Child: This go there?	
Child: This working?	Mom: Does that work, you think?
Child: Yeah.	

Three longest utterances in 30-minute language sample: Uh-oh, he's broke down. No, he go in bed. These go right there.

CHILD C Highest Language Factor Score (LFS) in Participant Sample

Pre-implant aided PTA: 55 Unaided: 90 Age at CI surgery: 12 mos. Duration of CI use: 31 mos. LFS: 2.633

Child: OK, so the trains can – goes right here, goes right here, OK?	Mom: OK
Child: So you have to listen to me, OK?	Mom: OK, I'm listening to you.

Child: So we have to put these away.	Mom: (unintelligible)
Child: Have to spread these out.	
Child: Put these in the boxes.	
Child: OK, so we have to make this an oval like this, OK?	Mom: A what?
Child: A oval.	Mom: An oval?
Child: Yeah.	Mom: I think this is a circle.

Three longest utterances in 30-minute language sample:

This is the left right here and the people goes around the town.

OK, now the people goes to stand there with that noise and now (makes train noises).

OK, the train's coming to get the animals and people.

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Figure 1.

The language principal component score is depicted as a function of duration of implant use. A significant curvilinear (quadratic) effect was detected for duration of implant use. After 11-12 months of implant use, language scores increase with longer duration of implant use and this relation becomes more pronounced over time.

Table 1

Participant Characteristics (n = 76)

	Mean	Standard Deviation	Range
Unaided PTA (dB, HL)	107.19	10.81	77-120
HA PTA (dB, HL)	65.01	15.50	32-110
Age first aided (months)	12.13	8.04	1-30
Duration of HA use (months)	11.0	6.27	0-30
Age at Implant (months)	23.16	7.73	12-38
Age at Test (months)	42.75	1.16	40-45
CI PTA (dB, HL)	30.21	5.19	20-43
Duration of CI use (months)	19.76	7.64	7-32

Note: PTA = Pure tone average threshold in the sound field at 500, 1K and 2K Hz in decibels re: Hearing Level; HA = hearing aid; CI = cochlear implant

Table 2
Comparison of frequency counts of the five dependent variables (from transcripts) utilized in the statistical analyses.

Total Number of Words		Number of Different Root Words		Total Number of Bound Morphemes		Number of Different Bound Morphemes		Mean Length of Utterance	
Transcriber	Transcriber	A	B	A	B	A	B	A	B
Child		A	B	A	B	A	B	A	B
1	438	459	86	89	13	10	4	1.84	1.83
2	359	395	112	117	29	27	8	2.10	2.39
3	613	627	183	192	56	45	11	3.06	3.00
4	127	130	66	62	5	6	4	1.58	1.64
5	275	218	72	54	0	0	0	1.09	1.05
6	554	679	125	147	49	69	8	2.58	2.87
7	619	552	168	151	18	14	6	2.40	2.18
8	478	376	116	111	26	35	5	1.65	1.57
Mean	432.88	429.50	116.00	115.38	24.50	25.75	5.75	2.04	2.07

Table 3

Scores of Cochlear Implant Users on Language Measures

	N	Score	Mean	Standard Deviation	Range
Utterances per 30-Minute Language Sample			278.08	79.95	110 - 502
CLAN variables	76	Total Words	421.89	273.10	33 - 1316
	76	Different Root Words	110.92	52.75	9 - 251
	76	Bound Morphemes	26.99	28.82	0 - 127
	76	Different Morphemes	4.88	3.33	0 - 12
	76	Mean Length Utterance	1.82	.67	1 - 3.83
CDI variables	75	Vocabulary	362.43	182.41	8 - 679
	75	Irregular Words	6.64	6.90	0 - 25
	75	Sentence Complexity	13.16	11.95	0 - 37
	75	Longest Sentence	4.99	3.46	0 - 18.67
SECS variables	76	Receptive Scaled Score *	59.43	6.75	42 - 67
	76	Expressive Scaled Score *	65.97	9.29	34 - 82

* Scaled scores re 3-year old hearing aid users (Mean=50; SD = 10)

Note: CLAN = Child Language Analysis programs for quantification of direct observation variables (MacWhinney, 1995); CDI = Communicative Development Inventory; CDI (Words and Sentences form; Fenson et al., 1993); SECS = Scales of Early Communication Skills for Hearing Impaired Children (Moog & Geers, 1975).

Table 4

Intercorrelations Between Language Measures

	1	2	3	4	5	6	7	8	9	10	11
1 CDI Vocabulary	-----	.83	.87	.76	.59	.87	.67	.84	.71	.79	.79
2 Irregular Words		-----	.87	.75	.51	.68	.64	.74	.77	.81	.68
3 Sentence Complexity			-----	.80	.51	.77	.64	.78	.73	.81	.70
4 Longest Sentence				-----	.52	.69	.63	.66	.73	.72	.69
5 SECS Receptive					-----	.70	.54	.57	.52	.53	.61
6 Expressive						-----	.71	.83	.70	.75	.83
7 CLAN Total Words							-----	.84	.85	.82	.92
8 Different Root Words								-----	.85	.84	.89
9 Different Bound Morphemes									-----	.84	.89
10 Bound Morphemes										-----	.83
11 Mean Length of Utterance											-----

Note: CLAN = Child Language Analysis (MacWhinney, 1995); CDI = Communicative Development Inventory: CDI (Words and Sentences form; Fenson et al., 1993); SECS = Scales of Early Communication Skills for Hearing Impaired Children (Moog & Geers, 1975); All correlations significant at $p < .001$

Table 5

Principal Component Loadings of Language Factor Variables

Variable	Component
CLAN: Number of Different Root Words	.932
CLAN: Number of Different Bound Morphemes	.928
CLAN: Mean Length of Utterance	.912
CDI: Vocabulary	.906
CLAN: Number of Bound Morphemes	.892
SECS: Expressive	.886
CLAN: Total Words	.876
CDI: Sentence Complexity	.875
CDI: Irregular Words	.854
CDI: Longest Sentence	.821
SECS: Receptive	.665

Note: CLAN = Child Language Analysis (MacWhinney, 1995); CDI = Communicative Development Inventory: CDI (Words and Sentences form; Fenson et al., 1993); SECS = Scales of Early Communication Skills for Hearing Impaired Children (Moog & Geers, 1975)

Table 6

Intercorrelations Between Predictor Variables and Language Factor Score

	Age HA	Dur HA	HA PTA	CI PTA	Age CI	Dur CI	Lang Factor
Age HA	-----	-.44**	-.12	-.01	.69**	-.67**	-.54**
Duration HA		----	.34**	.19	.35**	-.36**	-.07
HA PTA			----	.06	.40**	.39**	-.14
CI - PTA				----	.14	-.13	-.07
Age CI					----	-.99**	-.62**
Duration CI						----	.63**
Language Factor							-----

**
p < .001

Note: PTA = Pure tone average threshold in the sound field at 500, 1K and 2K Hz; HA = hearing aid; CI = cochlear implant; Dur = Duration; Lang = Language

Table 7

Multiple Linear and Curvilinear Regression of Four Independent Variables to Predict Language Factor Score

LINEAR ANALYSIS				
Source	Unstandardized Regression Coefficient (B)	t-ratio	p<	Partial η^2
Aided PTA	-.030	-5.078	.001	.27
Duration HA	.011	0.069	.800	.01
CI – PTA	.0089	0.582	.563	.00
Duration CI	.110	9.554	.001	.57
CURVILINEAR ANALYSIS				
Aided PTA	-.0290	5.02	.001	.27
Duration HA	.0130	1.00	.320	.01
CI – PTA	.0078	.520	.600	.00
Duration CI	-.0069	-.120	.900	.00
Duration of CI Use ²	.0031	2.08	.041	.06

Note: Variables listed in order of entry into the hierarchical analysis; PTA = Pure tone average threshold in the sound field at 500, 1K and 2K Hz; HA = hearing aid; CI = cochlear implant