Published in final edited form as:

Laryngoscope. 2005 September ; 115(9): 1603–1611. doi:10.1097/01.mlg.0000171018.97692.c0.

Behavioral Assessment of Prelingually Deaf Children Before Cochlear Implantation

David L. Horn, MD, David B. Pisoni, PhD, Mary Sanders, PhD, and Richard T. Miyamoto, MD
DeVault Otologic Research Laboratory, Department of Otolaryngology—Head and Neck Surgery,
Indiana University School of Medicine, Indianapolis, Indiana, and the Department of Psychology,
Indiana University, Bloomington, Indiana, U.S.A.

Abstract

Objectives/Hypothesis—To determine whether scores from a behavioral assessment of prelingually deafened children who present for cochlear implant surgery are predictive of audiological outcomes

Study Design—Retrospective review of longitudinal data collected from 42 children with prelingual hearing loss who presented for a cochlear implant before age 5 years.

Methods—The Vineland Adaptive Behavioral Scales (VABS) was administered during the preimplant workup. Standardized scores reflect daily living skills, socialization, and motor development compared with a normative sample. Regression analyses were conducted to determine whether any subject variables were related to VABS scores. Mixed-model analyses were computed to determine whether preimplant VABS scores were predictive of longitudinal spoken-language data obtained after cochlear implant surgery.

Results—Motor scores tended to be higher than nonmotor scores. Nonmotor scores were significantly lower than the normative mean and decreased with testing age. Children with acquired deafness demonstrated lower motor scores than children with congenital causes. Children with higher motor scores demonstrated significantly higher performance on language, vocabulary, and word recognition tests than children with lower motor scores. Nonmotor domains were not as robustly related to spoken-language measures, although similar trends were observed

Conclusion—Profound deafness and language delay may confound the assessment of daily living skills and socialization in the population studied. Motor development appears to proceed normally in prelingually deafened children and is a preimplant predictor of spoken-language outcome in young infants and children with cochlear implants, a finding consistent with the large body of work establishing links between perceptual-motor and language development.

Keywords

Behavioral assessment; motor development; children; deaf; cochlear implant; individual differences; audiological outcome

© 2005 The American Laryngological, Rhinological and Otological Society, Inc.

Send Correspondence to David L. Horn, MD, DeVault Otologic Research Laboratory, Department of Otolaryngology—Head and Neck Surgery, Indiana University School of Medicine, 699 Riley Research Wing 044, Indianapolis, Indiana 46202, U.S.A.
dlhorn@iupui.edu.

Some of these findings were Presented in part at the International Conference on Newborn Hearing Screening, Cernobbio, Italy, 2004, and at the Biennial Meeting of the Society for Research in Child Development, Atlanta, GA, 2005.

INTRODUCTION

Cochlear implants have been approved for use in profoundly deaf children as young as 1 year of age.¹ Longitudinal studies of outcomes in deaf children have established that a cochlear implant (CI) leads to gains in spoken language.²⁻⁴ However, the ideal conditions under which these gains can be maximized remain poorly understood. Although several demographic factors, including age at implantation and modality of communication, have been found to affect CI outcomes in deaf children, a large portion of the variance remains unexplained.^{5,6} As a result, prediction of degree of benefit before implantation is an especially challenging dilemma for both clinicians and researchers.

In our department, a clinical psychologist evaluates each pediatric CI candidate with several normative behavioral measures. Although there is little doubt that gross developmental delay can impact spoken language acquisition with a CI,⁷ it is unclear whether such preimplant psychological measures are predictive of outcomes obtained from children who do not have gross neurological or developmental impairments. Children who are developmentally ahead of their age-matched peers may show more rapid spoken-language acquisition and attain greater audiological skills with a CI than children who are developing more slowly. However, three factors complicate the assessment of behavior in prelingually deafened (PLD) children. First, some normative measures may not be appropriate for the wide age range of children (infancy through teenage years) who present for a CI. Second, few psychological measures have been normalized on a population of children with hearing impairment. Because of the heterogeneity in the communication modalities, education methods, and home environments among PLD children, even hearing-impaired (HI) norms are of questionable value for assessing CI candidacy and predicting benefit. Third, although many psychological instruments claim to assess individual behavioral domains, language delays in HI may confound the measurement of a variety of behavioral domains. Thus, “delays” found in HI children must be interpreted in context, and any conclusions drawn about individual or groups of children must be made cautiously.

Knutson et al.⁸ reported audiological results from a study of 69 PLD children with cochlear implants who received preimplant psychological testing. Standardized caregiver behavioral reports and nonverbal intelligence tests were administered before CI surgery, and scores were correlated with a range of audiological outcome measures obtained at 1-year intervals after implantation. No predictive relations were found between any of the preimplant measures and postimplant audiological outcomes. However, three limitations make their results somewhat difficult to interpret. First, Knutson et al.⁸ did not report descriptive findings from the individual psychological measures obtained from children in their study. We do not know, for instance, how many children showed evidence of behavioral problems, nor do we know how performance on these measures compared with normative data. Without substantial variability in the preimplant predictor, it would be difficult to find significant correlations with outcomes. Second, the authors used correlations that examined only one interval of CI use at a time. These analyses do not take into account the longitudinal changes in spoken language skills that develop over subsequent intervals of CI use. Third, their results are difficult to apply to children implanted at younger ages because age at implantation varied from 2 to 15 years in their sample.

In a more recent study by Kutz et al.,⁹ 18 PLD pediatric CI candidates were evaluated before implantation using several neuropsychological and behavioral instruments. Kutz et al.⁹ found that normative scores of their participants were highest for measures that assessed motor development and lowest for those which assessed communication skills. Most of the measures correlated negatively with chronological age, with the exception of motor development. Kutz et al.⁹ concluded that the behavioral delays seen in their sample were due

to language delays that were more severe in older PLD children. The authors argued that motor development was less affected by hearing loss and language delay than other behavioral domains.

There are four important limitations to the study by Kutz et al.⁹ First, children with neurological impairment or developmental delay were not explicitly excluded. If such children were included, this may have biased the results. Second, the authors did not specify whether normative scores were from normal-hearing (NH) or HI populations. This is important because some of the measures used provide supplemental norms from HI children at residential schools for the deaf. Third, the authors only examined the effect of chronological age on the psychological measures without examining other factors, such as degree of hearing loss or mode of communication, that have been shown to influence audiological outcomes.¹⁰ Fourth, Kutz et al. did not examine whether these preimplant measures were predictive of postimplant audiological outcomes.

The present study was designed to replicate and expand the findings of Kutz et al.⁹ with a larger, more closely defined group of PLD children. Children with known or suspected neurological impairment or developmental delay were excluded. Preimplantation behavioral functioning was assessed using the Vineland Adaptive Behavioral Scales (VABS),¹¹ one of the preimplant measures used by Kutz et al.⁹ Standard scores from NH tables of the VABS were used to assess preimplant adaptive behavioral functioning. The effects of a number of patient variables on VABS standard scores were investigated. The hypothesis that preimplant behavioral functioning would be related to postimplant speech perception and spoken language outcomes with a CI was investigated.

MATERIALS AND METHODS

Participants

After Institutional Review Board approval was obtained, preimplant evaluations and longitudinal spoken-language data collected at the DeVault Otologic Research Laboratory of the Indiana University School of Medicine were reviewed. Forty-two PLD children were identified with bilateral severe or profound hearing loss diagnosed by age 3 years who presented for a CI before age 5 years and had consented to participate in chart-review studies. All children used either oral English communication (OC) or a combination of oral and manual English (TC). Five children were excluded from the study because of a diagnosis (or a documented clinical suspicion) of developmental delay, cognitive impairment, or neurological sequelae. The characteristics of the remaining 37 children included in the study are shown in Table I.

Procedures

All children received a preimplant psychological assessment from a clinical psychologist. Although the psychological measures administered varied with age, clinical concerns, and behavioral limitations of each child, all children in the study were assessed using the VABS.¹¹ This measure consists of a series of more than 250 statements describing specific behaviors across four domains: daily living skills, socialization, motor, and communication (Table II). Caregivers respond to each statement based on whether the child exhibits the behavior consistently, occasionally, or not at all. Age-based standard scores are computed from each domain raw score based on normative data obtained from 3000 NH, typically developing children.¹¹ A score of 100 (SD = 15) reflects mean performance at any given age.

The VABS was administered by a licensed clinical psychologist in a structured interview with each child's caregivers. The communication domain was not scored because most of the

behaviors are auditory biased. Therefore, only standard scores from the motor, daily living skills, and socialization domains were used in our analyses.

Several spoken-language measures (collected longitudinally at various times before and after implantation) were available for these children. Three measures were selected based on their age appropriateness and availability in the study sample. The Grammatical Analysis of Elicited Language (GAEL-P) measures closed-set spoken word recognition.¹² Children were initially familiarized with 30 objects presented and named in the audiovisual modalities. During testing, sets of four familiarized objects were presented and a target object name was presented live-voice, auditory-only, by the experimenter. Children were given a correct score if they chose the named object.

Receptive and expressive language skills were assessed with the *Reynell Developmental Language Scales* (third edition).¹³ The receptive scales (RDLS-rec) measure 10 different skills including spoken-word recognition, sentence comprehension, and verbal comprehension of ideational content. The expressive scales (RDLS-exp) assess skills such as spontaneous production of speech and picture description. The RDLS-rec and RDLS-exp scales were administered in the child's preferred communication mode.

Vocabulary knowledge was measured with the Peabody Picture Vocabulary Test (PPVT).¹⁴ In this closed-set, forced-choice test, children were presented with a vocabulary item through their preferred mode of communication. Children then chose from four pictures, one of which correctly corresponded to the meaning of the word. Experienced clinicians administered each of the above measures in a quiet, well-lit room.

Scores from the spoken-language measures were grouped into one of four intervals of CI use: before implantation and 1 year, 2 years, and 3 years after implantation. As is common in longitudinal clinical studies, not all children were tested on each measure at each time interval. This occurred for two reasons. First, many of the children became fatigued during the testing day and were unable to complete all of the measures. Second, some of the children moved away from the geographic area and were unable to attend laboratory sessions as frequently as every 6 months. Four children had not yet received a CI; therefore, spoken-language data from 33 children in the sample was available at the time of the present study. Table III shows the number of patients tested on each outcome measure at each interval of testing.

To determine whether preimplant VABS scores were predictive of postimplant performance on spoken-language measures, we used the SAS mixed procedure (Cary, NC). This statistical method is ideal for analyzing longitudinal clinical outcome data in which each subject is not tested at each time interval.¹⁵ The SAS mixed procedure uses a maximum-likelihood estimation method to create a model without eliminating any participants.¹⁵ Scores from subjects tested at two or more time intervals are used to compute an estimation of the mean outcome score at each time interval. Scores from all subjects (including those tested at only one interval) are used to compute the variance of the mean outcome score at each time interval. With the SAS procedure, systematic selection biases can be minimized by using data from all children, even those who were not tested at each interval, in the test design.¹⁵

RESULTS

Table IV provides a summary of the descriptive data for each VABS domain. Variance was high for all three domains, although most scores fell within 2 SD of the population mean (Fig. 1). The results of paired-sample *t* tests showed that mean motor domain score (95.7) was significantly higher than mean daily living skills score (89.6) ($t[1,36] = 2.32, P = .026$).

The other domain comparisons did not reach significance. One-sample *t* tests revealed that mean daily living skills domain ($t[1,36] = -4.44, P < .0001$) and socialization domain ($t[1,36] = -3.26, P = .002$) scores were significantly lower than 100. In contrast, mean motor domain score was not significantly different from 100 ($t[1,36] = -1.85, P > .05$).

A series of stepwise regression analyses was carried out to determine whether individual domain scores were related to any of the subject variables. In these analyses, unaided PTA, communication mode, and age at VABS testing were included as independent variables (regressors). Cause was coded as either acquired deafness ($n = 4$) or congenital/unknown ($n = 33$) as a regressor in the analyses. Of the children who had acquired deafness, one child became deaf from ototoxicity at 6 months of age, 2 children from early postnatal meningitis, and 1 child from perinatal cytomegalovirus (CMV) infection. We did not include age at implantation as a regressor because it was highly correlated with age at VABS testing ($r = 0.995, P < .0001$). The regressor variables showed only low to moderate bivariate correlations (r values < 0.50). Each VABS domain was treated as the dependent variable in a stepwise regression (entry and removal criteria, 0.05 and 0.10, respectively).

Table V shows the final regression models for each VABS domain score. For motor domain, only the cause variable was a significant regressor. Children with documented acquired causes of deafness showed lower motor domain scores overall than children with congenital or unknown causes. For both daily living skills and socialization domains, the only significant regressor was chronological age at VABS testing. In this case, children who were older at test displayed lower daily living skills and socialization domain scores than children who were younger at test.

For each VABS domain, children were divided into two groups based on a median split (from median scores as shown in Table IV). The participants in each median split group varied from domain to domain. Children in the high groups had preimplant VABS scores that fell above 50% of the sample, whereas children in the low groups had scores below the 50th percentile. Using a median split design, spoken-language outcomes could be compared between each group. If a given domain is predictive of spoken-language outcomes, children in the high group should show higher scores on spoken-language measures than children in the low group.

Table VI shows the relative demographic characteristics of each VABS split group. Predictably, high and low groups all differed significantly in their mean standard score for each domain. With respect to the age variables, children in the high socialization domain group were significantly older at implantation and VABS testing and were deaf for longer periods than children in the low socialization domain group. No other split groups differed significantly with regard to the age variables. The high groups tended to contain a smaller proportion of OC children than the low groups, although these differences did not reach significance.

As described previously, the SAS mixed procedure was used to determine whether preimplant VABS scores were predictive of postimplant performance on speech and language outcome measures. For each outcome measure, a mixed model was constructed in which interval of CI use was the repeated-measure variable and VABS split group was the between-subjects variable. To control for potential confounders of age at implantation and communication mode, we included both variables as between-subjects factors in each mixed-model analysis. Therefore, the SAS mixed procedure could be used to test for effects of each VABS split group with age at implantation, communication mode, and duration of CI use controlled for in the model.

Statistical results from the 12 models for each VABS domain outcome-measure pair are shown in Table VII. Main effects of chronological age, duration of CI use, and communication mode are not discussed in detail because the primary interest of the present study was to determine whether VABS domain scores were independently related to spoken language outcomes. A main effect of “group” in a model indicates that average performance between children in the high and low median split groups on spoken language measures differ significantly. The directions and degrees of these differences are shown in Figs. 2 to 5, which display the least-squares means obtained from the SAS mixed procedure. The least-squares means reflect the mean outcome score for each split group when the other variables in the model (i.e., age at implantation, duration of CI use, communication mode) are held constant.

For all VABS domains, children in the high group tended to show higher spoken-language scores than children in the low groups (Figs. 2-5). However, these differences did not consistently reach significance (Table VII). Children in the high daily living skills domain group demonstrated significantly higher performance on the GAEL-P and had greater mean PPVT language quotients than children in the low daily living skills domain group. However, no effect of daily living skills domain split group was found for RDLS-rec or RDLS-exp language quotients. The high socialization domain group demonstrated higher GAEL-P and RDLS-exp scores than the low socialization domain group, although no effect of socialization domain group was found for RDLS-rec or PPVT.

In contrast to the results from the daily living skills and socialization domains, the effect of split group on spoken-language outcomes was more robust for the motor domain. The high motor domain group demonstrated significantly better performance on all four spoken-language measures than children in the low motor domain group. For the GAEL-P, estimated mean score of children in the high motor domain group was 60.5% words correct compared with 34.1% for children in the low motor domain group (Fig. 2). Children in the high motor domain group also demonstrated language and vocabulary skills that were closer to their chronological-age peers than children in the low motor domain group as shown by the differences in mean RDLS-rec, RDLS-exp, and PPVT language quotients between the two groups (Figs. 3-5).

DISCUSSION

Children in the present study demonstrated higher VABS domain scores (Table IV) than the deaf children tested by Kutz et al.⁹ The difference was most pronounced for the daily living skills and socialization domains (mean standard scores, 83 and 82, respectively, in Kutz et al.⁹). These differences may be due to the inclusion of children with neurological impairments or developmental delays in the study of Kutz et al.⁹ In addition, the children tested by Kutz et al.⁹ were older, on average, than the children in the present study. The negative correlations between age and VABS domains may have led to a difference in overall mean VABS scores between the two studies.

Similar to the results reported by Kutz et al.,⁹ we found that mean motor domain was more typical than the other domains of the VABS compared to the normative population. This finding is in contrast to earlier literature describing delays in motor skills of HI children compared with NH children.¹⁶ However, the earlier studies involved children attending residential schools for the deaf who used American Sign Language rather than oral or manual English. The earlier studies did not report or attempt to control for cause of deafness or other potential confounders such as neurological impairment or age at diagnosis. The present findings, taken together with those of Kutz et al.,⁹ suggest that HI children who

present for a CI in infancy or early childhood do not display evidence, on average, of general motor impairment.

The results of our multivariate analyses replicated an important finding of Kutz et al.⁹ that nonmotor VABS domains were negatively related to chronological age at testing. That is, children who were older at testing showed greater delay in socialization and daily living skills than children who were younger at testing. These results suggest that motor development proceeds more typically in these PLD children than other developmental domains. Age at testing and duration of auditory deprivation are highly correlated in this population of PLD infants and children ($r = 0.96$, $P = .000$). As a result, the correlations between age at testing and VABS domain scores could easily be restated in terms of duration of deprivation: longer periods of auditory deprivation are associated with greater delays in socialization and daily living skills behaviors.

However, these conclusions must be qualified because several daily living skills and socialization domain items may be inappropriate for assessing HI children. Of the first 60 daily living skills domain items (encompassing expected behaviors up to 8 y of age), 7 items involve children performing a common chore when asked. Although language modality is not specified, it is possible that deaf children may not perform behaviors such as putting toys away and cleaning a room because of communication difficulties rather than a true delay in the development of daily living skills. An additional 3 of the first 60 daily living skills domain items involve expressive language skills to indicate body states or abstract knowledge. Failure of deaf children to demonstrate these behaviors may be due to delay in language development rather than daily living skills per se.

Of the first 42 items from the socialization domain, 9 items involve receptive or expressive language skills. Only one of these items, “responds verbally and positively to good fortune of others,” assumes spoken-language skills; the remaining eight items involve labeling of people and emotions or using social language skills, such as asking permission or apologizing. As in the previously discussed daily living skills domain items, failure of deaf children to demonstrate any of these social behaviors may be due to language delay related to hearing loss rather than a delay specific to the socialization domain. Although the VABS allows “not applicable” scores for some items, the items discussed in the present study were scored with a zero, regardless of the individual circumstances or sensory impairment of a given child.¹¹ In contrast, none of the items in the motor domain involve expressive or receptive language.

What clinical relevance do the VABS domains have for PLD infants and children who present for a CI? We do not know whether development of daily living skills and socialization behaviors will continue to be delayed in deaf children after implantation or whether these children will catch up to the behaviors of their NH peers. The effects of early auditory deprivation and spoken-language delay may be far reaching, and it is of great clinical and theoretical importance to understand how early access to spoken language with a CI affects the social, emotional, and cognitive development of PLD children. Indeed, evidence has begun to accumulate that early experience with a CI has an impact on the development of cognitive and behavioral skills in deaf children.¹⁷⁻²¹

The only demographic factor, other than chronological age, that was a significant predictor of VABS scores was the acquired/congenital cause variable. Children with acquired causes of hearing impairment demonstrated lower motor domain scores than children with congenital causes. Two of the three children in the group with acquired causes were deaf as a result of bacterial meningitis in infancy, and this confounding factor may be responsible for the result. Meningitis and other central nervous system infections have been widely

reported to affect motor development.²² We failed to find evidence that degree of hearing loss or communication mode had any impact on VABS scores.

An important goal of the present study was to determine whether preimplant VABS scores were predictive of postimplant spoken-language scores. The results of the mixed-model analyses revealed several new preimplant predictors of performance on a range of spoken-language measures. Moreover, the pattern of results revealed that not all VABS domains were related to all spoken-language skills. Motor development was significantly related to performance on spoken-word recognition, receptive language, expressive language, and vocabulary knowledge tests obtained over a 3-year period after implantation. Children in the low motor domain group demonstrated, on average, lower spoken-word recognition scores and lower age-adjusted language and vocabulary skills than children in the high motor domain group. In contrast, the daily living skills and socialization domains were not as robustly related to spoken-language measures, although several significant relations were noted. These two domains may be less predictive than the motor domain because they are more influenced by auditory deprivation and delay in spoken-language skills in PLD children. As a preimplant measure, socialization and daily living skills domains may underestimate the developmental potential of PLD children to overcome spoken-language delays after cochlear implantation.

Links between motor development and perceptual and linguistic skills have been widely reported in the developmental literature with both NH and HI children.²³⁻²⁵ In NH children, motor development assessed in infancy has been shown to be strongly related to language outcomes in later childhood.²⁴ To our knowledge, the present study is the first investigation to demonstrate that preimplant measures of motor development are predictive of postimplant language outcomes in a HI population of infants and young children who have received a CI.

Recently, Horn et al.²⁶ reported results from an older group of 42 PLD children with cochlear implants (mean age at implantation, 5 y) who were tested before implantation using the Beery Test of Visual-Motor Integration (VMI).²⁷ The VMI test required children to copy two-dimensional line drawings of increasing complexity, and scores were based on published developmental norms. Performance on this measure was significantly correlated with postimplant measures of open-set speech perception, auditory sentence comprehension, and speech intelligibility. The VMI test results provide further converging evidence that preimplant motor and perceptual-motor functions are predictive of postimplant spoken-language outcomes. Like the VABS, the VMI may be especially useful in assessing PLD children because no auditory processing is required.

One explanation for the correlation between motor development and spoken-language acquisition in PLD children with cochlear implants is that motor and language systems share common cortical processing resources. This hypothesis is not new. Lenneberg,²⁸ one of the first theorists to propose a biological explanation for the links between motor and language systems, argued that developmental correlations between motor and language milestones reflected common underlying rates in brain maturation. Recently, a number of studies have explored the basic neural mechanisms behind these links. These findings suggest an articulatory or motor-based representation of speech in which brain areas traditionally known to be involved in regulating motor behavior are recruited during language processing tasks.^{29,30}

The present findings are consistent with these recent accounts suggesting close links between perceptual-motor and language systems and indicate common underlying neural mechanisms behind individual differences in motor development and spoken-language

development in HI children with cochlear implants. More research is needed to better understand which motor and perceptual-motor skills are related to audiological measures of outcome, as well as process measures of neural information processing and capacity. The present study provides the first behavioral evidence that preimplant assessment of motor and perceptual-motor skills may be clinically useful in predicting audiological benefit in PLD children who present for a CI.

Acknowledgments

The authors thank Rebecca Davis for technical support, Sujuan Gao for statistical assistance, and Aimee Horn, Tonya Bergeson-Dana, and Rachael Frush-Holt for assistance in editing the manuscript.

Supported by NIH-NIDCD Training Grant T32 DC00012 and NIH NIDCD Research Grant RO1 DC00064 to Indiana University.

BIBLIOGRAPHY

1. Gates G, Miyamoto R. Cochlear implants. *N Engl J Med*. 2003; 349:435–445.
2. Miyamoto RT, Svirsky M, Kirk KI, Robbins AM, Todd S, Riley AR. Speech intelligibility of children with multichannel cochlear implants. *Ann Otol Rhinol Laryngol*. 1997; 168:35–36.
3. Svirsky M, Robbins A, Kirk K, Pisoni D, Miyamoto R. Language development in profoundly deaf children with cochlear implants. *Psychol Sci*. 2000; 11:153–158. [PubMed: 11273423]
4. Tyler RS, Fryauf-Bertschy H, Kelsay DM, Gantz BJ, Wood-worth GP, Parkinson A. Speech perception by prelingually deaf children using cochlear implants. *Otolaryngol Head Neck Surg*. 1997; 117:180–187. [PubMed: 9334763]
5. Sarant J, Blamey P, Dowell R, Clark G, Gibson W. Variation in speech perception scores among children with cochlear implants. *Ear Hear*. 2001; 22:18–28. [PubMed: 11271973]
6. Pisoni D, Cleary M, Geers A, Tobey E. Individual differences in effectiveness of cochlear implants in children who are prelingually deaf: new process measures of performance. *Volta Rev*. 2000; 101:111–164.
7. Pyman B, Blamey P, Lacy P, Clark G, Dowell R. The development of speech perception in children using cochlear implants: effects of etiologic factors and delayed milestones. *Am J Otol*. 2000; 21:57–61. [PubMed: 10651436]
8. Knutson J, Ehlers S, Wald R, Tyler R. Psychological predictors of pediatric cochlear implant use and benefit. *Ann Otol Rhinol Laryngol*. 2000; 185:100–103.
9. Kutz W, Wright C, Krull K, Manolidis S. Neuropsychological testing in the screening for cochlear implant candidacy. *Laryngoscope*. 2003; 113:763–766. [PubMed: 12671445]
10. Geers A, Brenner C, Davidson L. Factors associated with development of speech perception skills in children implanted by age five. *Ear Hear*. 2003; 24:24–35.
11. Sparrow, S.; Balla, D.; Cicchetti, D. Vineland Adaptive Behavioral Scales: Survey Form Manual. American Guidance Service; Circle Pines, MN: 1984.
12. Moog, J.; Kozak, V.; Geers, A. Grammatical Analysis of Elicited Language: Presentence Level. Central Institute for the Deaf; St. Louis: 1983.
13. Reynell, JK.; Huntley, M. Reynell Developmental Language Scales. NFER-Nelson; Windsor, UK: 1985.
14. Dunn, L. Peabody Picture Vocabulary Test. 3rd ed.. American Guidance Service; Circle Pines, MN: 1997.
15. Schafer J, Graham J. Missing data: our view of the state of the art. *Psychol Methods*. 2002; 7:147–177. [PubMed: 12090408]
16. Wiegersma P, Van der Velde A. Motor development of deaf children. *J Child Psychol Psychiatry*. 1983; 24:103–111. [PubMed: 6826667]
17. Horn D, Davis R, Pisoni D, Miyamoto R. Behavioral inhibition and clinical outcomes in children with cochlear implants. *Laryngoscope*. 2005; 115:595–600. [PubMed: 15805866]

18. Horn D, Davis R, Pisoni D, Miyamoto R. Development of visual attention skills in prelingually deaf children who use cochlear implants. *Ear Hear.* in press.
19. Schlumberger E, Narbona J, Manrique M. Non-verbal development of children with deafness with and without cochlear implants. *Dev Med Child Neurol.* 2004; 46:599–606. [PubMed: 15344519]
20. Smith L, Quittner A, Osberger M, Miyamoto R. Audition and visual attention: the developmental trajectory in deaf and hearing populations. *Dev Psychol.* 1998; 34:840–850. [PubMed: 9779732]
21. Pisoni, D.; Cleary, M. *Springer Handbook of Auditory Research: Auditory Prosthesis.* Zeng, FG., editor. 2004.
22. Carter J, Neville B, Newton C. Neuro-cognitive impairment following acquired central nervous system infections in childhood: a systematic review. *Brain Res Brain Res Rev.* 2003; 43:57–69. [PubMed: 14499462]
23. Taylor R, Richards S, Moody S. Concurrent validity of the motor domain of the Vineland Adaptive Behavior Scales. *Perceptual Motor Skills.* 1990; 71:685–686.
24. Siegel LS, Saigal S, Rosenbaum P, Morton RA, Young A, Berenbaum S, Stoskopf B. Predictors of development in preterm and full-term infants: a model for detecting the at risk child. *J Pediatr Psychol.* 1982; 7:135–148. [PubMed: 6180158]
25. Bachara G, Phelan W. Visual perception and language levels of deaf children. *Perceptual Motor Skills.* 1980; 51:272.
26. Horn, D.; Davis, R.; Pisoni, D.; Miyamoto, R. Eighth International Cochlear Implant Conference. Miyamoto, R., editor. Elsevier; Indianapolis, IN: 2004. p. 332-335.
27. Beery, K. *The VMI Developmental Test of Visual Motor Integration.* 3rd ed, revised. Modern Curriculum Press; Cleveland: 1989.
28. Lenneberg, E. *Biological Foundations of Language.* John Wiley & Sons; New York: 1967.
29. Wilson M. The case for sensorimotor coding in working memory. *Psychonomic Bull Rev.* 2001; 8:44–57.
30. Wilson S, Saygin A, Sereno M, Iacoboni M. Listening to speech activates motor areas involved in speech production. *Nat Neurosci.* 2004; 7:701–702. [PubMed: 15184903]

Fig. 1. Distributions and mean values for preimplant VABS domain scores. Large circles represent the raw data means; dots represent individual standard scores. Error bars indicate SD of the sample. Dotted lines indicate the mean and +2 SD of the normative population.

Fig. 2.

Predicted mean Grammatical Analysis of Elicited Language (GAEL-P) percentage correct score as a function of preimplant Vineland Adaptive Behavioral Scales domain split group. Circles represent least-squares means from the SAS mixed models (light circles represent low split group and dark circles represent high split group). Differences between light and dark circles indicate the expected mean scores of each split group as if the other variables in the models (age at cochlear implantation, duration of cochlear implant use, communication mode) were held constant. SE bars are shown. Asterisks indicate significant effects of group ($P < .05$).

Fig. 3.

Predicted mean *Reynell Developmental Language Scales*, receptive (RDLS-rec) language quotient score as a function of preimplant Vineland Adaptive Behavioral Scales domain split group. Circles represent least-squares means from the SAS mixed models (light circles represent low split group and dark circles represent high split group). Differences between light and dark circles indicate the expected mean scores of each split group as if the other variables in the models (age at cochlear implantation, duration of cochlear implant use, communication mode) were held constant. SE bars are shown. Asterisks indicate significant effects of group ($P < .05$).

Fig. 4.

Predicted mean *Reynell Developmental Language Scales*, expressive (RDLS-exp) language quotient as a function of preimplant Vineland Adaptive Behavioral Scales domain split group. Circles represent least-squares means from the SAS mixed models (light circles represent low split group and dark circles represent high split group). Differences between light and dark circles indicate the expected mean scores of each split group as if the other variables in the models (age at cochlear implantation, duration of cochlear implant use, communication mode) were held constant. SE bars are shown. Asterisks indicate significant effects of group ($P < .05$).

Fig. 5.

Predicted mean Peabody Picture Vocabulary Test (PPVT) language quotient as a function of preimplant Vineland Adaptive Behavioral Scales domain split group. Circles represent least-squares means from the SAS mixed models (light circles represent low split group and dark circles represent high split group). Differences between light and dark circles indicate the expected mean scores of each split group as if the other variables in the models (age at cochlear implantation, duration of cochlear implant use, communication mode) were held constant. SE bars are shown. Asterisks indicate significant effects of group ($P < .05$).

TABLE I**Demographic Characteristics of Sample.**

Mean unaided PTA (dB HL)	105.2, SD = 16.9	Range: 58.3–118.4
Mean age of onset (mo)	0.4, SD = 1.5	Range: 0–6.0
Mean age at preimplant evaluation (mo)	22.7, SD = 13.7	Range: 5.0–63.0
Mean duration of deprivation (mo)	29.2, SD = 14.5	Range: 10.0–67.0
Mean age of CI activation (mo)	29.5, SD = 14.4	Range: 10.0–67.0
Mode of communication (CM)	15 OC, 22 TC	
Gender	18 female, 19 male	
Cause or origin	33 congenital (26 unknown, 2 genetic, 2 LVA, 2 AN, 1 Mondini); 4 acquired (1 meningitis at 4 mo, 1 meningitis at 6 mo, 1 ototoxicity at 6 mo, 1 perinatal CMV)	

Pure-tone average (PTA) refers to average decibels hearing loss (dB HL) threshold at 500, 1000, and 2000 Hz. Age of hearing loss was estimated from age at diagnosis and clinical history. CI = cochlear implant; CM = communication mode; OC = oral English communication ; TC = combination of oral and manual English ; LVA = large vestibular aqueduct syndrome; AN = auditory neuropathy; CMV = cytomegalovirus infection.

TABLE II

Vineland Adaptive Behavioral Scales: Sample Items.

Domain	Sample Items
Daily living skills (D)	Opens mouth when spoon with food is presented
	Asks to use the toilet
Socialization (S)	Distinguishes caregiver from others
	Shows anticipation of being picked up by caregiver
Motor (M)	Sits supported for at least 1 minute
	Transfers object from one hand to another

TABLE III

Number of Subjects Tested at Each Interval of Cochlear Implant Use.

Outcome Measure	Interval of CI Use			
	Preimplant	Year 1	Year 2	Year 3
PPVT	4	17	13	8
RDLS-rec	9	22	16	9
RDLS-exp	9	22	16	8
GAEL-P	14	21	14	7

CI = cochlear implant; PPVT = Peabody Picture Vocabulary Test; RDLS-rec = *Reynell Developmental Language Scales*, receptive; RDLS-exp = *Reynell Developmental Language Scales*, expressive; GAEL-P = Grammatical Analysis of Elicited Language.

TABLE IV

Mean, Median, and Standard Deviation of Vineland Adaptive Behavioral Scales Domain Standard Scores.

Domain	Mean Standard Score	Median Standard Score	Standard Deviation
Daily living skills	89.6	88.0	±14.2
Socialization	91.7	88.0	±16.0
Motor	95.7	97.0	±14.5

TABLE V

Final Stepwise Regression Models for Each Vineland Adaptive Behavioral Scales Domain Score.

Dependent Variable	Predictor Variables	Rsqr	Excluded Variables
Daily living skills (D)	Age: $\beta = -0.512$, $t(1,34) = -3.48$, $P = .001$	0.241	CM, PTA, cause
Socialization (S)	Age: $\beta = -0.614$, $t(1,34) = -4.54$, $P = .0001$	0.359	CM, PTA, cause
Motor (M)	Cause: $\beta = 0.437$, $t(1,34) = 2.83$, $P = .008$	0.167	CM, PTA, age

For each predictor variable, standardized coefficient (β) and t test and P values are given. Age = age at Vineland Adaptive Behavioral Scales testing; CM = communication mode (oral English communication [OC] = 0, combination of oral and manual English communication [TC] = 1); pure-tone average (PTA) = unaided PTA (decibels of hearing loss) before implantation; Cause = congenital vs. acquired (congenital = 1, acquired = 0); Rsqr = adjusted R square.

TABLE VI

Vineland Adaptive Behavioral Scales Median Split-Group Characteristics.

	Split Group	SS	PTA	CM (%)	Depr	Age Test	Age CI	Cause
D	High	100.4 (9.6)	105.3 (16.5)	23	27.6 (17.6)	22.2 (18.4)	28.0 (17.6)	1 meningitis
	Low	81.0 (9.0)	103.0 (18.3)	50	30.2 (12.4)	25.4 (10.3)	30.5 (12.3)	1 ototoxic
S	High	104.5 (10.7)	105.7 (16.6)	33	21.3 (13.9)	17.4 (14.5)	22.0 (14.1)	1 meningitis, 1 ototoxic
	Low	78.7 (8.6)	102.4 (18.3)	44	35.8 (11.5)	29.7 (10.8)	35.8 (11.5)	All congenital
M	High	106.3 (8.4)	105.1 (17.7)	28	36.1 (17.0)	30.0 (16.2)	36.1 (17.0)	All congenital
	Low	87.4 (12.0)	103.0 (17.5)	53	23.4 (8.8)	19.2 (9.5)	24.0 (9.0)	1 meningitis, 1 ototoxic

Split groups are based on Vineland Adaptive Behavioral Scales (VABS) domain median values from original sample (Table IV). Values given in bold indicate significant difference between high and low groups based on independent-samples *t* tests (*P* < .05). Standard deviations are given in parentheses. SS = mean standard score; PTA = pure-tone average; CM = communication mode; Depr = mean duration of deprivation (mo); Age Test = mean age at VABS test (mo); Age CI = mean age at implantation of cochlear implant (CI) (mo); Cause = congenital/unknown or acquired.

TABLE VII

Results of SAS Mixed Models: Main Effects of Vineland Adaptive Behavioral Scales Median Split-Group Spoken-Language Outcome Measures.

Spoken Language Outcome Measures				
	GAEL-P	RLDS-Rec	RDLS-Exp	PPVT
D	F(1,21.5) = 5.02, P = .036*	F(1,18.5) = 2.08, P = .167	F(1,17.2) = 2.03, P = .172	F(1,14.5) = 7.39, P = .016
S	F(1,19.6) = 5.77, P = .026	F(1,18.4) = 1.38, P = .256	F(1,18.3) = 5.06, P = .037	F(1,14.5) = 1.94, P = .184
M	F(3,35.3) = 6.74, P = .017	F(1,18.9) = 4.94, P = .039	F(1,17.6) = 6.80, P = .018	F(1,4.7) = 6.28, P = .011

F statistics for main effects of Vineland Adaptive Behavioral Scales (VABS) group (high or low) for each SAS mixed model. GAEL-P in percentage correct; RDLS-Rec, RDLS-Exp, and PPVT in language quotient. Significant main effects are bolded. F statistics for other variables (duration of CI use, age at implantation, communication mode) and interactions between variables are omitted for simplicity. No significant interactions involved the VABS group variable except for an interaction between D split group and Use (children in the high group showed greater improvement in GAEL-P score with cochlear implant use than children in the low D split group (F(3,30.1) = 3.99, P = .017). GAEL-P = Grammatical Analysis of Elicited Language; RDLS-Rec = *Reynell Developmental Language Scales* receptive; RDLS-Ex = *Reynell Developmental Language Scales* expressive; PPVT = Peabody Picture Vocabulary Test.