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Long-Term Speech and Language Outcomes in Prelingually Deaf Children, Adolescents and Young Adults Who Received Cochlear Implants in Childhood

Chad V. Ruffin¹, William G. Kronenberger², Bethany G. Colson¹, Shirley C. Henning¹, and David B. Pisoni¹

¹DeVault Otologic Research Laboratory Department of Otolaryngology Head and Neck Surgery Indiana University School of Medicine Indianapolis, Indiana USA

²Department of Psychiatry Indiana University School of Medicine Indianapolis, Indiana USA

Abstract

This study investigated long-term speech and language outcomes in 51 prelingually deaf children, adolescents, and young adults who received cochlear implants (CIs) prior to 7 years of age and used their implants for at least 7 years. Average speech perception scores were similar to those found in prior research with other samples of experienced CI users. Mean language test scores were lower than norm-referenced scores from nationally representative normal-hearing, typically-developing samples, although a majority of the CI users scored within one standard deviation of the normative mean or higher on the Peabody Picture Vocabulary Test, Fourth Edition (63%) and Clinical Evaluation of Language Fundamentals, Fourth Edition (69%). Speech perception scores were negatively associated with a meningitic etiology of hearing loss, older age at implantation, poorer pre-implant unaided pure tone average thresholds, lower family income, and the use of Total Communication. Users of CIs for 15 years or more were more likely to have these characteristics and were more likely to score lower on measures of speech perception compared to users of CIs for 14 years or less. The aggregation of these risk factors in the > 15 years of CI use subgroup accounts for their lower speech perception scores and may stem from more conservative CI candidacy criteria in use at the beginning of pediatric cochlear implantation.

Keywords

cochlear implant; deafness; language; speech perception; children; prelingual hearing loss

The use of cochlear implants (CIs) in severe-to-profoundly deafened children to facilitate speech and language development via access to sound is now a well established medical intervention [Niparko et al., 2010]. A majority of early-implanted children are able to produce speech that is intelligible to normal-hearing listeners [Svirsky et al., 2000; Beadle et al., 2005] and score in the average range (within 1 SD of the normative mean) or better on a wide range of measures of speech perception and spoken language comprehension [Geers & Sedey, 2011]. However, CIs are not without limitations; speech perception scores obtained with a CI deteriorate significantly in noise [Svirsky et al., 2004], and mean language scores

Please direct all correspondence to Chad Ruffin, DeVault Otologic Research Laboratory, Department of Otolaryngology-Head and Neck Surgery, Indiana University School of Medicine, 699 Riley Hospital Drive, Research Wing 044, Indianapolis, IN, 46202. cvruffin@iupui.edu. Phone 317-274-1985. Fax: 317-274-4949..

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of samples of children and adolescents with CIs are lower than normative means and lower than mean scores of normal-hearing, typically developing peers [Geers & Sedey, 2011].

The most recent studies of long-term outcomes indicate that these speech and language achievements and limitations remain stable over 10 or more years of CI use [Geers et al., 2011; Geers & Hayes, 2011; Geers & Sedey, 2011; Davidson et al., 2011; Spencer et al., 2004; Uziel et al., 2007]. Long-term outcome studies that include cohorts of greater than 100 subjects [Uziel et al., 2007; Geers et al., 2011] as well as smaller cohorts [Spencer et al., 2004] report that a majority of adolescents and young adults who had used their CI for 10-15 years score in the average range or better on language outcomes and academic achievement skills. In these studies, positive prognostic factors for long-term speech and language outcomes include earlier age at implantation, a shorter length of pre-CI auditory deprivation, more pre-implant residual hearing, use of state-of-the-art CI technology and non-meningitic etiologies [Geers & Sedey, 2011; Uziel et al., 2007].

Examining speech and language outcomes in individuals who have been using their CI for over 15 years is of particular importance to assess the impact of expanded CI candidacy criteria that has occurred over the years. The population of users of CIs for over 15 years includes those who were implanted under criteria that restricted CIs to children with a profound hearing loss who were older than 18 months. As these children have matured, it is only now that we can evaluate speech and language outcomes of prelingually deafened adolescents and young adults who received their CIs in early childhood. These data are of enormous significance as they may demonstrate the efficacy of a CI for the development of speech and language from very early childhood to adulthood.

All of the currently published long-term studies of speech and language outcomes have reported findings on prelingually deaf children and adolescents who have used their CIs for 15 years or less [Beadle et al., 2005; Geers et al., 2011; Spencer et al., 2004; Uziel et al., 2007]. Extrapolating the outcomes of younger cohorts to this group is difficult. Most studies have combined long-term CI users implanted in late childhood (as late as 11-14 years of age) with those implanted in early childhood, despite important differences in language learning during different developmental periods of childhood [Beadle et al., 2005; Spencer et al., 2004; Uziel et al., 2007]. Furthermore, some long-term CI use studies included children with post-lingual deafness onset at older ages (as late as 7 years) [Beadle et al., 2005], while others combined long-term CI users with shorter-term (as few as 3 years) CI users [Spencer et al., 2004]. These methodological characteristics, which affect almost all existing studies of long-term CI use, limit the generalizability of findings to long-term CI users implanted in early childhood.

Only one long-term study of speech and language outcomes following CI required prelingual deafness, implantation in early childhood, and long-term (at least 7 years) CI use as inclusionary criteria for all subjects [see the research sample studied by Geers et al., 2011, and Davidson et al., 2011]. Hence, the research literature focusing on long-term speech-language outcomes exclusively in prelingually deaf children implanted in early childhood is sparse. Furthermore, long-term speech and language outcomes of children who have used their implants for 15 years or more have not been investigated at all. These data are only now becoming available as these children mature into young adults.

The present study aimed to fill these critical gaps in the understanding of speech-language outcomes in long-term CI users by addressing the following three questions: (1) What are the speech and language outcomes in prelingually deaf, long-term CI users who were implanted in early childhood? Only one prior study has addressed this question in a sample consisting exclusively of prelingually-deaf, long-term CI users implanted prior to age 7

years (Davidson et al., 2011). (2) Do speech and language outcomes in long-term CI users differ by duration of use, particularly in the cohort of CI users for 15 years or more? No prior research has investigated long-term outcomes in prelingually deaf children who used CIs for 15 or more years. (3) What demographic and hearing history factors are related to speech-language outcomes in long-term CI users? Because prior research has focused on a more restricted range of long-term CI use, little is currently known about differences in demographic and hearing history variables across a very wide duration of CI use (including users of CIs for 15 years and more) and the relations of these differences to speech and language outcomes.

Methods

Participants

Participants were 51 CI users who were required to have: (1) a prelingual onset of deafness, defined as >70 dB hearing loss in the better hearing ear sustained prior to age 3 years (see Geers, Brenner, & Tobey, 2011, for an example of use of this inclusion criterion); (2) had a failed trial of bilateral hearing aid use prior to cochlear implantation; (3) received a CI before age 7 years; and (4) used their CI for at least 7 years at the time of testing (Table 1). All participants consistently used a currently available, state-of-the-art multichannel CI system, and most were unilateral CI users (Table 1). Onset of deafness was defined as either the time at which the diagnosis of severe/profound hearing loss was made or the time of a known event such as meningitis that precipitated a severe/profound hearing loss. Two bimodal (CI with a contralateral hearing aid) CI users were tested with both devices for language measures and in the CI-only condition for speech perception measures; subjects with bilateral CIs were tested with both CIs activated. Analyses of the effects of bilateral cochlear implantation did not include these two bimodal subjects. None of the subjects had any reported co-morbid developmental or neurocognitive delays or disabilities other than hearing loss, and all participants were living in homes where English was used as the primary language. On a 1 (Mostly Sign) to 6 (Auditory Verbal) scale of communication mode (Geers, 2002), the sample mean fell in the Oral Communication range between 4 (Cued Speech) and 5 (Auditory Oral; Table 1). Etiology of hearing loss was as follows: unknown, N = 30; meningitis, N = 6; familial (presumed genetic because at least one other family member had a hearing loss, of unknown etiology), N = 8; auditory neuropathy, N = 3; Mondini malformation, N = 3; and large vestibular aqueduct, N = 1.

Procedure

Subjects were volunteers recruited from a database of all CI users in a large university-based CI clinic who had agreed to be contacted for research purposes. Subjects consented to the protocol approved by the university Institutional Review Board. Speech perception test stimuli for both noise and quiet were digital recordings presented over a high-quality loudspeaker at 65 dB SPL in a sound field within a sound-treated audio booth at 0° azimuth approximately 3 feet from the subject.

Measures

Several measures of speech perception (HINT Sentences for Children, Lexical Neighborhood Test, and Auditory-Visual Lexical Neighborhood Sentence Test) and language (Peabody Picture Vocabulary Test, Fourth Edition and Clinical Evaluation of Language Fundamentals, Fourth Edition) were used to provide a broad characterization of long-term outcomes. For the speech perception tests (each of which yields multiple scores), scores for the more difficult conditions of the test were used to reduce ceiling effects and to provide greater variability in the sample. Some subjects were unable to complete all tests

due to difficulty understanding or complying with the test; N for each measure is reported below.

HINT Sentences for Children—(HINT-C) [Nilsson et al., 1997] was used to assess open-set recognition of meaningful spoken English sentences. Ten sentences each were presented in quiet and in speech-shaped noise at +5 dB SNR. Scores were percent of correctly repeated words. The HINT-C in noise test (N=45) was used as the primary measure of sentence recognition in this study.

The Lexical Neighborhood Test—[Kirk et al., 1995] was used to measure open-set recognition of spoken monosyllabic words in quiet. Subjects repeated words from a 50 word list that contained lexically easy and lexically hard words. The percentage of correctly repeated lexically hard words (LNT Hard Words; N=50) was used to assess isolated spoken word recognition performance.

The Auditory-Visual Lexical Neighborhood Sentence Test—(AVLNST) [Holt et al., 2005] is an open-set measure of sentence recognition; subjects repeated 8 sentences presented in each of three modalities: auditory-only (sound without visual cues), visual-only (visual presentation of the speaker's face without audio), and audio-visual (auditory-plus-visual). The percent of keywords correct for each presentation modality and lexical competition conditions (easy vs. hard) were used to create a set of 6 scores based on combinations of these conditions (e.g., lexically easy auditory-only, lexically easy visual-only, lexically hard auditory-only, etc.). In this study, the AVLNST lexically hard versions of the auditory-only (N=49), visual-only (N=49), and audio-visual (N=50) scores were used as measures of speech perception in sentences for their respective presentation modalities.

The Peabody Picture Vocabulary Test, Fourth Edition—(PPVT-4) [Dunn & Dunn, 2007] is a test of one-word receptive vocabulary. Subjects choose one of four pictures matching a word spoken or simultaneously signed using Signed Exact English (depending on the subject's daily communication method). PPVT-4 standard scores (N=51) were reported in this study.

The Clinical Evaluation of Language Fundamentals, Fourth Edition—(CELF-4) [Semel & Secord, 2003] is a measure of expressive and receptive language. The CELF-4 subtests yield a normed Core Language Score (standard score; N=48) which was used as a measure of complex language processing skills.

Statistical Analysis

In order to investigate the relations between long-term CI use and speech perception and language outcomes, descriptive statistics (using SPSS, Version 19, IBM) for the demographic, hearing history, speech, and language variables were calculated for the entire sample and then for three subgroups based on duration of use: 7-9 years, 10-14 years, and 15 years or more. These subgroups were selected to provide a contrast with prior literature which focused on groups with 10 to 14 years of CI use. Investigation of subgroups with more (15+) and fewer (7-9) years of CI use allows for comparisons with the 10-14 year subgroup. Analyses of Variance (ANOVAs) were used to test for differences between the three duration of CI use subgroups on continuous variables; chi-square tests were used to test differences between the three duration of CI use subgroups on categorical variables. Follow-up t-tests were used to provide pairwise comparisons between the three duration of use subgroups, although when the overall ANOVA was not significant, significant t-tests comparing pairs of CI use subgroups should be interpreted with caution. Because nationally-representative norms based on large samples of normal hearing children are available for the

PPVT-4 and CELF-4, mean scores on those measures for the CI sample were also compared to norm-referenced mean scores (standard scores, with mean of 100 and SD of 15) using single-sample t-tests. Additionally, the percentage of subjects scoring within 1 SD of the normative mean or higher (i.e., standard score of 85 or higher; this value has been used by other groups to represent average or better performance; Geers & Sedey, 2011) was also reported to provide an estimate of the number of subjects with approximately average or better language skills as assessed by those measures. Norm-referenced scores are not available for the speech perception measures, but normal hearing, typically developing children routinely score at or near ceiling on these measures in the quiet. We provided values from similar studies in the Discussion for purposes of comparison with results from the present sample. Finally, correlations were calculated between the demographic, hearing history, and speech/language variables to investigate relations between demographic/hearing history characteristics and long-term speech-language outcomes in the CI sample.

In order to better understand the factors that underlie the differences in speech perception outcomes found between the very long-term CI users (e.g., 15+ years of CI use) and users of CIs for 14 years or less, ANCOVAs were performed with the speech perception scores (LNT, AVLNST, and HINT-C) as dependent variables, duration of CI use (subgroups for 7-10, 11-14, and 15+ years of use) as the independent variable, and key demographic and hearing history variables as covariates. The demographic and hearing history variables chosen as covariates for the ANCOVAs were variables that significantly differentiated between the 15+ years of use subgroup and one or more of the other subgroups (pre-implant PTA, age of onset of deafness, and meningitis vs. other etiology), as well as age at implantation. Age at implantation was included in these analyses because the comparison of the 15+ years of use subgroup and 7-9 years of use subgroup approached significance ($t(22)=1.78, p<0.089$) for age at implantation and because age at implantation has been found to be related to speech perception outcomes in other studies. Thus, these ANCOVA analyses assessed whether the differences found for the 15+ years of use subgroup could be accounted for by cohort-specific demographic and hearing history variables.

Results

Sample Characteristics

Most subjects ($N=27$) had used their CIs for 10-14 years (mean = 12.2 years; range = 7.1 – 22.4 years; Table 1). The three subgroups based on duration of CI use differed significantly on duration of CI use ($F(2,48) = 105.9, p < 0.001$); onset of deafness ($F(2,48) = 3.3, p < 0.05$); age at testing ($F(2,48) = 42.5, p < 0.001$); bilateral CI/bimodal user ($X^2(2) = 8.1, p < 0.05$); and meningitis ($X^2(2) = 15.5, p < 0.001$). Best PTA was significantly lower for the 15+ years of use subgroup compared to the 10-14 years of use subgroup, and onset of deafness occurred at older ages for the 15+ years subgroup compared to the 7-9 years subgroup ($p<0.05$). Additionally, each of the subgroups differed significantly ($p<0.05$) from each other subgroup in age at testing and duration of CI use. Users of CIs for 10-14 years scored higher on the Communication Mode Rating Scale (in the direction of auditory-verbal) than users of CIs for 7-9 years ($p<0.05$). None of the other demographic or hearing history variables were significantly different between groups.

Likely as a result of universal newborn hearing screening, the majority of children in all CI duration groups had deafness diagnosed at birth (82%, $N = 42$). Of the 9 subjects who became deaf after birth, $N = 4$ (15%) and $N = 5$ (45%) subjects were respectively in the 10-14 and the 15+ years of use subgroups. Six of these 9 subjects became deaf as a result of meningitis and therefore had onset of deafness at that time. The remaining 3 subjects who became deaf after birth had unknown etiology, although two of the three had family

members who were also deaf. Subjects used a variety of CI devices and processing strategies (Table 1)

Speech and Language Outcomes for All Subjects

The speech and language outcomes in the long-term CI use sample as a whole were as follows: The sample was able to identify far fewer words in the AVLNST Hard Visual-only condition than in the AVLNST Hard Auditory-only and Hard Auditory-Visual conditions (Table 2). LNT Hard-Word and HINT-C in Noise mean scores for the sample fell in the 60-71% range (Table 2). Across the entire study sample, both PPVT-4 ($t(50) = 2.98$, $p = 0.004$) and CELF-4 Core Language ($t(47) = 2.7$, $p = 0.01$) standard scores were significantly lower than normative mean scores. A majority of subjects scored at or above 1 SD below the normative mean on the PPVT-4 (62.7%), and the CELF-4 Core Language score (68.8%), compared to an expected 84% of the norm-referenced samples.

Speech and Language Outcomes by Duration of CI Use

Table 2 summarizes the speech and language outcomes by the duration of CI use. Across the three duration of CI use subgroups, a consistent pattern emerged for the speech perception scores, with the 15+ years of CI use subgroup scoring lowest on auditory speech perception measures and highest on visual speech perception measures (Table 2). The 15+ years of CI use subgroup scored significantly lower ($p < 0.05$) than the other two subgroups on AVLNST Hard Auditory and lower than the 10-14 years of CI use subgroup on LNT Hard Word and HINT-C in Noise. Conversely, the 15+ years of CI use group scored higher than the 7-9 years of CI use subgroup on AVLNST Hard Visual ($p < 0.05$).

However, ANCOVAs demonstrated that these differences in speech perception scores in the 15+ years of use subgroup were entirely explained by differences in several key demographic and hearing history risk factors in that subgroup. In these ANCOVAs, no differences were found between the three duration of use subgroups in LNT Hard Word ($F(2,43)=0.30$, $p=0.74$), HINT-C in Noise ($F(2,38)=0.85$, $p=0.43$), or AVLNST (Hard Auditory, $F(2,42)=0.66$, $p=0.52$; Hard Auditory-Visual, $F(2,43)=1.06$, $p=0.36$; Hard Visual, $F(2,42)=0.94$, $p=0.40$) scores after accounting for differences in meningitic etiology, pre-implant residual hearing, age of onset of deafness, and age of implantation. Additionally, no significant differences were found across the three subgroups for any of the language measures.

Demographic and Hearing History Factors Related to Speech and Language Outcomes

Correlations between speech-language and demographic/hearing history variables are shown for the entire sample in Table 3. In general, subjects with a longer period of CI use, a longer period of deafness prior to implantation, a lower family income, poorer residual hearing prior to implantation, a meningitic etiology of deafness, less emphasis on oral communication strategies in the home, and older age at both the time of testing and the time of implantation did more poorly on at least one of the auditory speech perception measures. Conversely, subjects with a longer duration of CI use and older age at implantation and testing did better on the AVLNST Hard Visual condition. The only variable that was related to language outcomes (PPVT-4 and CELF-4) was a positive correlation with family income (Table 3).

Discussion

This study examined long-term speech and language outcomes in a group of 51 prelingually deaf (>70 dB HL prior to age 3 years) children, adolescents and young adults who were implanted prior to age 7 and had used their implant for 7 years or more. Unlike prior studies,

this study used a sample consisting exclusively of prelingually-deaf, long-term CI users and included a subgroup of subjects who had used their CIs for 15 years or more. This latter subgroup is important to examine long-term speech and language outcomes of cochlear implantation from early childhood to adulthood. The findings obtained in this study replicated the delays in speech and language outcomes reported by other long-term studies and extended beyond existing research by reporting outcomes in those subjects with 15 or more years of CI use. This study also examined associations of speech-language outcomes with demographic and hearing history characteristics.

Speech and Language Outcomes for all Subjects

Our cohort achieved scores of 71-74% correct on the HINT-C in noise and AVLNST Hard Auditory tests and 60% correct on the LNT Hard Words. These results are similar to those reported by Spencer et al. (2004), Geers et al. (2008) and Davidson et al. (2011). On the two norm-referenced language tests (PPVT-4 and CELF-4), the number of long-term CI users scoring below average (less than 1 SD below the normative mean score) was at least double that of the normative group of normal-hearing children, and the observed mean standard scores of 90-91 were significantly lower than the expected standard scores for the normative sample (i.e., 100), although a majority of the long-term CI users in our sample scored within the average range or better (at or greater than 1 SD below the normative mean score) on the PPVT-4 (63%) and CELF-4 (69%). These findings are also consistent with the moderate language delays reported by other long-term outcome studies [Geers et al., 2011; Uziel et al., 2007].

Demographic and Hearing History Factors Related to Speech and Language Outcomes

The present findings also provide further support for the contribution of demographic and hearing history factors that have been associated with speech and language outcomes in prior short-term and long-term outcome research. For speech perception, the general pattern of findings was for etiology (meningitis), age at implantation, age at testing, and duration of deafness to be negatively related to auditory speech perception performance whereas lower pre-implant PTA thresholds, higher family income, and an auditory-oral communication mode were found to be positively correlated with better speech perception performance, even with up to 22 years of CI use. For language outcomes, higher income predicted stronger performance.

Speech and Language Outcomes by Duration of CI Use

The present investigation extends the findings of earlier long-term outcome studies to include subgroups with both shorter (7-10 years of use) and longer (> 15 years) durations of CI use than the typical 10-14 years of use evaluated in prior research. The wide range of CI use permitted us to investigate the relations between duration of use and speech-language outcomes in a sample of long-term CI users. The 15+ years of CI use subgroup exhibited LNT Hard Word, AVLNST Hard Auditory, and HINT-C in Noise scores that were significantly lower than at least one of the other subgroups, reflecting a general trend toward lower speech perception scores for the group of longest users. Furthermore, the 15+ years subgroup became deaf at older ages, had a greater proportion of meningitis-caused deafness, had poorer residual hearing prior to implantation, and was less likely to have bilateral implants (Table 1). It is notable that these demographic and hearing history variables were either significantly related or nearly significantly related to the speech perception scores in our sample (Table 3), suggesting that the longer CI user subgroup had a greater aggregation of demographic and hearing history risk factors for poor speech perception outcomes. Analyses comparing the duration of use subgroups while controlling for etiology, pre-implant residual hearing, age of onset of deafness, and age of implantation confirmed the presence of a cohort effect created by an aggregation of key demographic and hearing

history risk factors in the 15+ years of use subgroup. Controlling for age at implantation, best preimplant PTA, onset of deafness and meningitic etiology fully accounted for the lower performance by the 15+ years of CI use subgroup. This particular set of risk factors may be related to the conservative implant candidacy criteria in place at the time and postimplant performance expectations for those children who were among the first prelingually deaf children to receive multichannel CIs. This is a clinically important finding, because it suggests that the cohort of the longest CI users may be at greater risk for suboptimal speech perception outcomes as a result of aggregation of known demographic and hearing history risk factors. Other factors such as different exposure to processing strategies (e.g., older strategies) and devices, might also explain the differences found between the three duration of use subgroups, and this should be a topic of future research.

In sum, the findings of this study replicated delays in speech and language outcomes reported by other long-term outcome studies and significantly extended beyond prior research by using a sample that included only early-implanted, prelingually deaf, long-term CI users including those with 15 years or more CI experience. These results include the novel finding of poorer speech perception in subjects with 15 or more years of CI use (relative to 7-14 years of use), which was explained by the aggregation of key demographic and hearing history risk factors in the 15+ years of use group. This finding suggests that the cohort of very long-term (15+ years) CI users has different and important clinical and demographic characteristics relative to the 7-14 years of CI use subgroups. These characteristics and their relations with speech and language outcomes should be considered in clinical work with this cohort.

Although this study included subjects with a wide range of CI use, its limitations include cross-sectional design and potential volunteer bias. Additionally, although the relations between preimplant PTA and speech-language outcomes was investigated, information about aided PTA prior to cochlear implantation was not available in this sample (other than the criterion that all patients failed a trial with hearing aids prior to implantation). Because all patients used hearing aids prior to implant (with insufficient benefit) and only 2 patients used hearing aids (on the non-implanted ear) following implantation, it was not possible to statistically analyze the effect of hearing aid use on long-term speech and language outcomes in this sample, other than the finding that duration of hearing aid use prior to implantation was unrelated to long-term speech and language outcomes (Table 3). Future research with larger samples is needed to more comprehensively evaluate potential influences of bilateral CI use or bimodal CI-hearing aid use on long-term speech and language outcomes.

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References

- Beadle EAR, McKinley DJ, Nikolopoulos TP, Brough J, O'Donoghue GM, Archbol SM. Long-term functional outcomes and academic-occupational status in implanted children after 10 to 14 years of cochlear implant use. *Otol Neurotol.* 2005; 26(6):1152–1160. [PubMed: 16272934]
- Davidson LS, Geers AE, Blamey PJ, Tobey EA, Brenner CA. Factors contributing to speech perception scores in long-term pediatric cochlear implant users. *Ear Hear.* 2011; 32(1 Suppl):19S–26S. [PubMed: 21832887]

- Dunn, D.; Dunn, L. Peabody Picture Vocabulary Test. 4th ed. Pearson Assessments; Minneapolis, MN: 2007.
- Geers AE. Factors affecting the development of speech, language, and literacy in children with early cochlear implantation. *Lang Speech Hear Serv Sch.* 2002; 33:172–183.
- Geers AE, Hayes H. Reading, writing, and phonological processing skills of adolescents with 10 or more years of cochlear implant experience. *Ear Hear.* 2011; 32(1):49S–59S. [PubMed: 21258612]
- Geers AE, Sedey AL. Language and verbal reasoning skills in adolescents with 10 or more years of cochlear implant experience. *Ear Hear.* 2011; 32(1 Suppl):39S–48S. [PubMed: 21832889]
- Geers AE, Tobey E, Moog J, Breener CA. Long-term outcomes of cochlear implantation in the preschool years: From elementary grades to high school. *Int J Audiol.* 2008; 47(s2):S21–S30. [PubMed: 19012109]
- Geers AE, Brenner CA, Tobey EA. Long-term outcomes of cochlear implantation in early childhood: sample characteristics and data collection methods. *Ear and Hear.* 2011; 32(1 Suppl):2S–12S.
- Holt R, Kirk KI, Pisoni DB, Burckhartzmeyer L, Lin A. Lexical and context effects in children's audiovisual speech recognition. *JASA.* 2005; 118(3):1962–1962.
- Kirk KI, Pisoni DB. Lexical effects on spoken word recognition by pediatric cochlear implant users. *Ear Hear.* 1995; 16(5):470–81. [PubMed: 8654902]
- Niparko JK, Tobey EA, Thal DJ, Eisenberg LS, Wang N-Y, Quittner AL, Fink NE. Spoken language development in children following cochlear implantation. *JAMA.* 2010; 303(15):1498–1506. [PubMed: 20407059]
- Nilsson, MJ.; Soli, SD.; Gelnett, DJ. Development of the Hearing in Noise Test for Children (HINT-C). House Ear Institute; Los Angeles, CA: 1996.
- Semel, E.; Wiig, E.; Secord, W. Clinical Evaluation of Language Fundamentals. 4th ed. Pearson Assessments; Minneapolis, MN: 2003.
- Spencer LJ, Gantz BJ, Knutson JF. Outcomes and achievement of students who grew up with access to cochlear implants. *Laryngoscope.* 2004; 114(9):1576–1581. [PubMed: 15475785]
- Svirsky MA, Sloan RB, Caldwell M, Miyamoto RT. Speech intelligibility of prelingually deaf children with multichannel cochlear implants. *Ann Otol Rhinol Laryngol.* 2000; (Suppl.185):123–125. [PubMed: 10685560]
- Svirsky MA, Teoh SW, Neuberger H. Development of language and speech perception in congenitally, profoundly deaf children as a function of age at cochlear implantation. *Audiol Neurootol.* 2004; 9(4):224–233. [PubMed: 15205550]
- Uziel AS, Sillon M, Vieu A, Artieres F, Piron JP, Daures JP, Mondain M. Ten-year follow-up of a consecutive series of children with multichannel cochlear implants. *Otol Neurotol.* 2007; 28(5): 615–628. [PubMed: 17667770]

Table 1

Sample Description

	Duration of Cochlear Implant (CI) Use			
	All	7-9 Years	10-14 Years	15+ Years
N	51	13	27	11
Years of HA	1.7 (1.3)	1.2 (0.7)	1.9 (1.4)	1.9 (1.6)
Years of CI Use	12.2 (3.6)	8.4 (0.9)	11.8 (1.4)	17.7 (2.4)
Best Pre-Implant PTA	108.8 (10.3)	107.7(12.7)	106.9 (10.1)	114.6 (5.1)
Onset of Deafness (months)	3.5 (8.4)	0.0 (0.0)	3.1 (8.8)	8.5 (10.4)
Age at Implantation (months)	35.4 (19.9)	29.5 (16.6)	35.6 (21.9)	41.9 (17.5)
Deafness Duration (months)	31.9 (18.2)	29.5 (16.6)	32.5 (18.4)	33.4 (21.0)
Age at Testing (years)	15.2 (4.5)	10.8 (1.9)	14.8 (2.7)	21.2 (3.5)
Communication Model ¹	4.6 (1.0)	4.1 (1.3)	4.8 (0.7)	4.6 (1.2)
Income ²	7.1 (2.4)	7.2 (2.4)	7.2 (2.1)	6.3 (3.5)
Gender (N; Female/Male)	24/27	5/8	16/11	3/8
Bilateral CI/Bimodal User (N)	16	7	9	0
Meningitis (N)	6	0	1	5
<u>Implant Model/Processing Strategy (N ears)</u>				
CC Nucleus 22--SPEAK	10	0	1	9
ABC Clarion--CIS/MPS	4	1	3	0
ME Sonata--CIS	1	0	1	0
ABC CII--HiRes	1	0	1	0
CC Nucleus 24--SPEAK	1	0	1	0
CC Nucleus 24--ACE	39	13	24	2
CC Nucleus System 5--ACE	6	5	1	0
ME Combi 40+--CIS	3	1	2	0

¹ Communication Mode is coded on a scale from auditory-verbal = 6 to mostly sign = 1 (Geers, 2002).

² Income was coded on a 1 (under \$5,500/year) to 10 (\$95,000 and over/year) scale.

Note: Unless otherwise indicated, values are means accompanied by standard deviations in parentheses. ABC = Advanced Bionics Corporation; CC = Cochlear Corporation; ME = Med-El Corporation; N=number of subjects. PTA=unaided pre-implant pure-tone average (in dB HL). CI=cochlear implant. HA=hearing aid use prior to implantation.

Table 2

Speech and Language Outcomes by Duration of Cochlear Implant Use

	All	7-9 Years	10-14 Years	15+ Years	F
<u>Speech Perception Measures</u>					
LNT-Hard Word	60.4 (24.1)	61.5 (27.4)	66.2 (19.5)	45.5 (25.6)	3.1
AVLNST-Hard Auditory	74.7 (30.5)	78.5 (29.3)	82.7 (26.7)	51.5 (31.0)	4.8*
AVLNST-Hard A-V	85.0 (25.3)	78.9 (33.1)	88.2 (22.7)	84.9 (21.4)	0.6
AVLNST-Hard Visual	20.3 (21.6)	11.0 (15.6)	22.0 (25.1)	26.5 (15.7)	1.7
HINT-C in Noise	71.4 (23.9)	69.9 (28.3)	76.6 (18.7)	57.0 (28.2)	2.2
<u>Language Measures</u>					
PPVT-4 Standard Score	91.4 (20.6)	89.8 (22.8)	92.3 (20.6)	91.1 (19.9)	0.1
CELF-4 Core Language	90.1 (25.2)	94.5 (25.0)	88.5 (24.9)	89.5 (28.1)	0.2

Note: Unless otherwise indicated, values are means accompanied by standard deviations in parentheses. F-tests are the result of a one-way ANOVA comparison of duration of use groups. LNT=Lexical Neighborhood Test Hard Word; AVLNST=Auditory-Visual Lexical Neighborhood Sentences Test; A-V=Auditory-Visual; HINT-C=Hearing in Noise Test for Children (+5 dB). PPVT-4=Peabody Picture Vocabulary Test, Fourth Edition; and CELF-4=Clinical Evaluation of Language Fundamentals, Fourth Edition. N=number of subjects.

*
p<0.05

Table 3

Bivariate Pearson correlations between Demographic and Hearing History Variables and Speech-Language Scores

	LNT	AVL-A	AVL-AV	AVL-V	HINT	PPVT	CELF
Duration of HA	-0.05	-0.25	-0.05	0.18	0.18	0.11	0.09
Years of CI Use	-0.40**	-0.43**	-0.08	0.31*	-0.20	-0.02	-0.09
Best Pre-Implant PTA	-0.33*	-0.23	-0.20	-0.01	-0.37*	-0.19	-0.12
Onset of Deafness	-0.11	-0.16	0.07	0.09	-0.19	0.02	-0.02
Age at Implantation	-0.20	-0.36**	-0.17	0.29*	-0.08	0.03	0.02
Duration of Deafness	-0.17	-0.32*	-0.21	0.28	0.00	0.02	0.04
Age at Testing	-0.39**	-0.48**	-0.12	0.36*	-0.19	0.00	-0.06
Communication Mode	0.59**	0.50**	0.64**	0.02	0.24	0.10	-0.06
Income	0.42**	0.42**	0.31*	0.08	0.31	0.42**	0.40*
Gender	0.19	0.06	0.06	-0.11	0.10	-0.07	-0.09
Bilateral Implant	0.27	0.26	-0.03	0.23	0.23	-0.01	-0.05
Meningitis	-0.28	-0.29*	0.08	0.03	-0.34*	-0.08	-0.08

Note: LNT=Lexical Neighborhood Test Hard Word; AVL=Auditory-Visual Lexical Neighborhood Sentences Test – Hard Auditory (-A), Hard Auditory-Visual (-AV), or Hard Visual (-V); HINT=Hearing in Noise Test for Children (+5dB); PPVT=Peabody Picture Vocabulary Test Fourth Edition; CELF=Clinical Evaluation of Language Fundamentals Fourth Edition Core Language Score; PTA=unaided pre-implant pure-tone average (in dB HL). HA = hearing aid use prior to implantation. CI=cochlear implant.

*
p<0.05;

**
p<0.01