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Article 1: Long-Term outcomes of cochlear implantation in early childhood: Sample characteristics and data collection methods

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Precis

Articles contained in this monograph describe the communication performance of 112 teenagers who received multichannel cochlear implants between the ages of 2 and 5 years. Children were first tested during the elementary school years when they were 8 or 9 years of age. They also were tested as adolescents when they were between 15 and 18 years old. Characteristics of the population are described including their modes of communication and educational environments. Child, family and educational variables that will be explored in the following articles as possible predictors of successful outcomes are introduced.

INTRODUCTION

Cochlear implantation, as a field, has made substantial progress over the nearly twenty years since multichannel cochlear implants (CIs) were approved by the Food and Drug Administration (FDA) in the early 1990's for use in children. Significant improvements were made to the external and internal hardware components, signal processing strategies used to electrically represent acoustic signals, and to the methods used to document the influence of the devices on communication development in children with severe-profound hearing losses. During the early years of cochlear implantation, many investigators focused on important issues associated with safety and efficacy under ideal circumstances of service delivery (Clark, Cohen, & Shepherd, 1991). Following the establishment of implantation safety, investigators turned their attention to the impact the devices provided for developing spoken language skills (Clark, 2003). Investigators from around the world documented improved speech perception (Blamey & Sarant, 2002; Ching et al., 2005; Eisenberg et al., 2006; Galvin, Mok, Dowell, & Briggs, 2007; Gordon, Tanaka, & Papsin, 2005; Kirk, Hay-McCutcheon, Sehgal, & Miyamoto, 2000), speech production (Geers, 2004; Moog & Geers, 1999; Osberger, Maso, & Sam, 1993; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000; Tobey & Geers, 1995; Tobey et al., 2000), language (Geers, 2004; Hay-McCutcheon, Kirk, Henning, Gao, & Qi, 2008; Svirsky et al., 2000; Svirsky, Teoh, & Neuburger, 2004; Tomblin, Barker, & Hubbs, 2007) and reading skills (Crosson & Geers, 2001; Geers, 2003; Geers, 2004) in young children receiving CIs relative to children with similar hearing losses who continued to use tactile aids or conventional hearing aids (Geers & Tobey, 1995; Miyamoto et al., 1991; Most, Rothem, & Luntz, 2009; Osberger et al., 1990; Osberger et al., 1991; Osberger et al., 1993). As data amassed, investigators probed the influence of a number of factors on the level of outcomes achieved. Better outcomes were documented in children who were female, those with a higher parental occupation skill level, those with better hearing and longer duration of CI use and those with an onset of hearing impairment after 3 years (Stacey, Fortnum, Barton, & Summerfield, 2006). Significant advantages also were found for children taught using spoken language only (Geers et al., 2000; Stacey et al., 2006; Kirk, Miyamoto, Ying, Perdew, & Zuganelis, 2003) and for those children who received a CI by 2 years of age (Connor, Craig, Audenbush, Heavner, & Zwolan, 2006; Nicholas & Geers, 2006). Criteria for implantation shifted significantly as evidence supported implantation at younger ages and as an appropriate intervention for children with greater degrees of residual hearing (Waltzman & Roland, Jr., 2005; Tomblin, Barker, Spencer, Zhang, & Gantz, 2005; Ching et al., 2005; Nicholas & Geers, 2007). Throughout all these changes, however, a recurring theme continues to interest researchers and clinicians alike; namely, how closely does information from CIs allow young children with severe-profound hearing losses to acquire communication skills commensurate with typical hearing children?

The answer to this question varies depending upon the representativeness of the sample studied—an issue largely ignored in most studies of CI effectiveness during ideal or typical situations. Children with CIs tend to have more affluent families and fewer additional disabilities than non-implanted children with profound sensor-neural hearing loss (SNHL) (Fortnum, Marshall, & Summerfield, 2002). As a result of these characteristics, CI users might be expected to achieve higher language and academic skills than the general population of individuals with profound SNHL. However, it is clear that children with prelingual profound SNHL typically fail to achieve age-appropriate language and reading scores even with affluent families and above-average intelligence (Geers & Moog, 1989), In addition, children with CIs who participate in research studies are not representative of the general population of implanted children, since less affluent families, poor performers and nonusers may be less likely to assent to testing and participation in studies. Some studies address this issue by including all qualifying children implanted sequentially at one or more selected implant centers, but participation is then restricted to particular centers, which also may not represent children implanted nationwide (Niparko et al., 2010). Furthermore, subject attrition in longitudinal studies may be greater for less successful CI users. Therefore, it is important to consider the representativeness of the sample in interpreting the results.

The current study is based on a sample of children who participated in an initial investigation begun in the mid 1990's. This early study examined the speech perception, speech production, language and reading outcomes associated with a large cohort of some of the very first children to receive a CI in North America (Geers & Brenner, 2003; Geers, 2006). Outcomes were examined when the children were 8 – 9 years of age and in the early stages of elementary education. CI children included in this early elementary study (hereafter referred to as CI-E subjects) had no previously-diagnosed additional disabilities, were born deaf or acquired profound hearing loss before 3 years of age, and received a CI by five years of age. Parents of these children spoke only English at home and almost all the parents had normal hearing.

All applicants who met the sample selection criteria were invited to attend a 3-day summer research camp in St. Louis (Geers & Brenner, 2003). All expenses were paid, including transportation, hotel accommodations and daily entertainment activities for the child and one accompanying adult so that cost would not prohibit any families from participating in the study. Additional family members could attend, but needed to pay their own transportation costs and activities fees. This requirement could have limited the ability of low-income families to attend a camp. Approximately 15 children and their parents attended each data collection camp. A total of 12 camps were held between 1997 and 2000. Testing took place 2.5 hours each day for 3 days. All children were tested under similar conditions by a consistent group of examiners on an identical battery of tests.

Important characteristics of the sample were described in detail in a previous publication (Geers & Brenner, 2003) and are reviewed here. A total of 181 eight and nine year olds (90 boys; 91 girls) were recruited from CI Centers across North America. Participants resided in 33 different states and 5 Canadian provinces and the sample was not heavily represented by any one geographical region or implant center. They used the technology and met the candidacy criteria in place between 1990 and 1996 when they received their devices (National Institutes of Health, 1995). All but two of the children used the Nucleus 22-channel CI (Cochlear Americas, 13059 E. Peakview, Centennial, CO 80111), the only device available to children until 1995, when two of the participants received Clarion devices (Advanced Bionics Corporation, 25129 Rye Canyon Loop, Valencia, CA 91354). None of the children demonstrated significant amounts of pre-implant residual hearing as indicated by speech perception testing in their individual clinics. During the time the children received their devices, candidacy requirements stipulated a hearing aid trial period of at least 6 months with no evidence of open set speech perception before a child was eligible to receive a CI.

The CI-E participants were distributed across the most common educational environments available in North America, including both public and private schools, both special education and mainstream classrooms, and both oral communication (OC) modes and modes of communication augmented with signed language (referred to here as simultaneous communication, or SC). Each child's classroom communication mode was described with a rating scale completed by the parents. A rank between 1 and 6 was assigned to each year for 5 years following cochlear implantation. Ratings between 1 and 3 were assigned to Simultaneous Communication (SC) programs. In mostly sign programs, sign-only was used for communication during some of each day and assigned a rating of “1”. In speech and sign programs, speech almost always occurred simultaneously with each signed word and sign-only or speech-only were rarely used (this condition was assigned a “2”). In speech emphasis programs, speech-only was used for communication during some of each day in addition to portions of the day which included sign, and this condition was assigned a rating of “3”. Ratings between 4 and 6 were applied to oral communication (OC) programs if sign language was never used. Cued speech programs, a formal system of manual cues (Cornett, 1967) used to facilitate lipreading, was assigned a “4”. Auditory-oral programs, where the child was encouraged throughout the day to both lipread and listen to the talker, were assigned a “5”. Auditory-verbal programs where the child was taught to rely on listening alone to understand speech was assigned a “6.” Ratings were averaged over a 5-year period to summarize the amount of emphasis on speech and audition in each student's program (MODEAVG) over the preschool and early elementary school years. The MODEAVG could range from 1.0 for those who spent all five years in an exclusively sign setting to 6.0 for those who were in auditory-verbal programs over that period of time – with intermediate average values (e.g., 3.5) possible for those who changed settings over the years. Average ratings for 92 children were 4.0 or higher, indicating they were in exclusively OC settings, and 89 children had MODEAVG ratings below 4.0, indicating they had spent at least some time in SC settings. Therefore, although the participants were not selected based on communication mode, there was approximately equal OC and SC representation.

The sample included approximately 18% of the total available population of prelingually deaf 8-9 years old children who received a CI in the U.S. between 1990 and 1996 who were 5 or younger when they were implanted. The group average nonverbal intelligence quotient (PIQ = 102; SD = 14.5) was close to the normative mean compared to either hearing or deaf age-mates. The median parental education was 15 years (high school and 3 years of college) and median household income level was between $50,000 and $65,000. The median household income for the general American population during that time period was $50,303 (DeNavas-Walt, Proctor, & Lee, 2006).

The analysis used for this study incorporated one of the first attempts to use multivariate statistical techniques to examine the effects of a large number of intervening variables thought to influence performance in pediatric cochlear implant recipients. These variables were considered in a hierarchical model representing three distinct domains: child and family characteristics, implant characteristics and educational intervention (Strube, 2003). The first goal of this approach was to establish the influence of individual predictor variables on the level of auditory, linguistic and academic performance achieved by children using CIs at age 8 or 9 years. The second goal was to control for the effects of these variables at each stage of the analysis. As a result, for example, the influence of an intervention approach, like communication mode, was examined after controlling for the influence of the child's IQ, family education and income, age at implant and implant processor characteristics.

Outcomes were measured across a variety of skills. Speech perception results averaged around 50% correct for open-set word lists through listening alone and nearly 80% through lipreading and listening together; however; scores for individual children ranged from 0 to 100% correct (Geers, Brenner, & Davidson, 2003). Speech intelligibility performance averaged nearly 64% reflecting the contributions of individual consonant accuracy averaging close to 68% (Tobey, Geers, Brenner, Altuna, & Gabbert, 2003). More than half of the children demonstrated language skills similar to typical hearing children of comparable ages on measures of verbal reasoning, narrative ability, utterance length, and lexical diversity (Geers, Nicholas, & Sedey, 2003). Significant predictors of high levels of spoken communication skills included higher PIQ, female gender, longer use of the updated SPEAK processing strategy, a fully active electrode array, greater dynamic range, and steeper growth of loudness. After controlling for the influence of these variables, an additional 10% of the unexplained variance in spoken word recognition, speech, and language scores was independently accounted for by classroom communication mode, with OC students performing higher than those from SC classrooms. In addition, this study documented individual differences in the speed and efficiency with which phonological and lexical representations of spoken words were maintained in and retrieved from working memory. These cognitive skills were associated with speech and language levels exhibited at CI-E (Pisoni & Cleary, 2003).

Over half of the children at ages 8 and 9 years of age scored within the average range for their age in reading compared with normative data for typical hearing children. This finding is in contrast to a previously published survey reporting the average reading levels associated with deaf teenagers when graduating from high school was comparable to third or fourth grade readers (Traxler, 2000). Reading competence was associated with higher PIQ, higher family socio-economic status, female gender and later onset of deafness (between birth and 36 months) (Geers, 2003). After variance due to these child and family characteristics was removed, reading competence was associated with mainstream educational placement, use of an updated implant speech processor, use of a CI map with a wide dynamic range, and specific cognitive abilities that included longer memory span and use of phonological coding strategies. Reading outcome was most highly predicted by linguistic competence and, secondarily, by speech production skill.

The Follow-up Study

In order to further explore how access to auditory information via a cochlear implant influenced communication development, the current study was initiated in the mid 2000's to re-examine communication outcomes in this group of early-implanted children when they were teenagers in high school (CI-HS). The studies contained in this monograph provide detailed analyses of a follow-up study conducted with 112 of the original group of CI-E children tested at 8-9 years of age. The students in this follow-up study had more than 10 years of experience with their implant devices at time of testing.

Data collection camps were similar to those held for the CI-E sample (Geers & Brenner, 2003), including paid accommodations for 4 nights for a CI-HS student and an accompanying adult, 3 mornings of testing for the students and education programs for the parents, with recreational activities in the afternoons and evenings. All testing took place in St. Louis by experienced pediatric audiologists, speech-language pathologists and teachers of the deaf. The test battery for the CI-HS teenagers covered a wide range of skills and abilities, including speech perception, speech production and intelligibility, language and communication, memory and phonological processing, reading and written language, and aspects of self-esteem and social skills. When possible, the test battery replicated skills assessed in the elementary grades by administering the same test at both ages. However, it was often necessary to adapt the measure for the higher skill levels measured in adolescents or adopt new measures with age-appropriate norms. Detailed descriptions of each test in the battery are included in subsequent articles in this monograph.

In addition to standardized tests of speech, language, and reading, we also included questionnaires to provide insight into the social development of these teenagers and the extent to which they feel part of the hearing community, deaf community, or both communities. We also sampled the domain of executive function, including aspects of working memory, phonological awareness and verbal rehearsal speed to examine the degree to which they underlie language and academic development.

Each article in this monograph addresses specific hypotheses regarding outcomes documented in this follow-up study. In general, we hoped to learn whether speech, language and reading skills, which were so close to age-mates with normal hearing in elementary grades, kept pace with normal development or fell further behind hearing peers by their high school years. Although some investigators examined performance in adolescents with more than three years of CI experience (Vermeulen, vanBon, Schreuder, Knoors, & Snik, 2007; Wheeler, Archbold, Gregory, & Skipp, 2007), relatively little research focuses exclusively on prelingually deaf teenagers with more than 10 years of CI experience (but see Spencer, Gantz & Knutson (2004); Beadle et al (2005) and Uziel et al.(2007)). Teenagers using CIs since preschool have the opportunity to capitalize on the full potential of information from the devices during their elementary and high school years. This monograph provides an in-depth look at their skills and attitudes as they transition from childhood into the adult world. These individuals represent a new era in deaf education, since they are among the first to have used a multi-channel CI from preschool age through adolescence.

The objectives of this introductory article are to: 1) describe sample characteristics and discuss the extent to which the CI-HS sample is representative of the larger sample tested at CI-E; 2) describe how sample characteristics changed over time for the 112 students tested at CI-E and CI-HS.

METHODS

Letters were mailed to the last known address for all families in the original sample whose child was between 15 and 18 years of age inviting them back for a follow-up summer research camp in St. Louis. This included 181 participants in the original study and three pilot subjects who participated in a preview camp in 1996. The first twenty-nine students attended a camp session as teenagers in 2004. Mailings were repeated in 2006, 2007 and 2008 until it was apparent that all of the original CI-E participants who were available and interested in participating had been recruited. A total of 112 participants and their families returned for follow-up testing during one of the four summers and these students comprised the CI-HS sample (62% of the original sample). Of the 72 families who did not return, current addresses were not located for 22 families and 49 families were unable or unwilling to travel to St. Louis to participate in follow-up testing. Questionnaires were mailed to these 49 students for completion at home and 21 were returned. As a result, we report follow-up data for 73% of the original sample during their high school years (62% via testing; 11% via questionnaires). All participants signed an assent form and parents signed a consent form approved by the Institutional Review Board of The University of Texas at Dallas.

Participants

CI-HS Sample—Background characteristics of the CI-HS sample are included in Table 1. Twenty-four of the students had onset of deafness after birth: 10 students during the first year of life, 8 students in the second year, and 8 students between 24 and 36 months of age. Duration of deafness pre-implantation (time elapsed between birth or onset age and CI) ranged from 4 months to 5 years and 4 months.

Comparison Groups—Throughout this monograph, we compare performance of teenagers with CIs with typically-developing hearing age-mates. When normative samples are available from standardized tests, standard scores are used. These scores represent a student's relative standing compared to the mean and standard deviation of the age-appropriate normative sample of typically developing children (NS-TD). Test developers attempt to obtain normative samples that are representative of the population in general. Standard scores are typically used by schools and clinicians to determine the need for special services. They provide a means of comparing relative standing of an individual student across different abilities and different measures. Furthermore, using standard scores controls for differences in chronologic age among study participants, and is therefore considered ideal for this analysis. One drawback to using standard scores is the family socio-economic status of students in this study was above average, so the children might be expected to achieve slightly higher than the mean values obtained from more representative normative samples (Nittrouer, 2010). We recognize the standard scores may underestimate the magnitude of performance when compared to a similar socio-economic group, but such scores provide an important benchmark for children with hearing loss (Nicholas & Geers, 2007).

Normative data were not available for some tasks employed in this study and it was necessary to use raw scores to represent relative abilities. In these instances, in order to provide an appropriate comparison group, a control group of 46 teenagers (NHC-HS) from public high schools in the St. Louis metropolitan area was recruited by distributing flyers at church and neighborhood functions. Students were offered $50 to participate in a 3-hour battery of tests and questionnaires. All students passed a hearing screening at 15 dB HL from 250-8000 Hz in both ears.

Table 1 summarizes the mean and standard deviation of sample characteristics in the NHC-HS group. They were similar to the CI-HS group in age at test, highest parent education, and family size. Intelligence level was estimated in the NHC-HS group with the Peabody Picture Vocabulary Test (PPVT) (Dunn & Markwardt, 1989) and for the CI-HS group by the Performance Scale of the Wechsler Intelligence Scale for Children (WISC-P) (Wechsler, 1991). The mean PPVT standard score (109.6) in the NHC-HS group was significantly higher than the mean WISC-P score (103.1) in the CI-HS group ($t(1, 155) = -2.4$, $p<.02$) based on the NS-TD sample. This result indicates that the NHC-HS group might be more cognitively/developmentally advanced than the CI-HS group. Reading levels were estimated with two subtests of the Test of Reading Comprehension – (TORC-3) (Brown, Hammill, &

Wiederholt, 1995), General Vocabulary and Paragraph Comprehension. Mean scaled scores were close to the average for the NS-TD group (i.e., 10), indicating that the NHC-HS group was fairly typical academically.

Measuring Sign Enhancement

The CI-E study documented the communication mode used in each child's classroom during the preschool and early elementary years (i.e., MODEAVG described above). However, regardless of the mode used by the teacher, some students primarily rely on speech while other students' language is best when sign and speech are used together. Recognizing that parental or participant reports of classroom communication mode may not fully describe the extent to which any student makes use of SC to augment spoken communication, in this study, we used test results at CI-E and CI-HS to create metrics reflecting the extent to which a student's language improved when sign language was added to spoken language (i.e., sign enhancement). An estimate of sign enhancement at the CI-E test session was derived from two spontaneous language samples obtained at age 8 or 9 (Geers et al., 2003). One language sample was collected in an SC interview conducted by a clinician skilled in various sign systems. No limitations were imposed on the child's communication mode and both signed and spoken productions were transcribed and counted in the language analyses. An OC interview also was conducted that focused exclusively on the CI-E child's ability to converse with a person who did not know sign language. Only the child's intelligible spoken words were transcribed and counted in the analysis. Sign enhancement was estimated by dividing scores on the following measures obtained in the OC interview with those obtained in the SC interview: different words per minute, words per utterance (MLU in words), Index of Productive Syntax (IPSyn) (Scarborough, 1990): sentence Complexity and noun phrases. A value of 1.0 means that the scores were the same and the child performed no better with a combination of speech and sign than with speech alone. A value greater than 1.0 reflects either variation associated with measurement error, interference with oral communication when sign is used, or both. A value less than 1.0 reflects an advantage of using sign in addition to oral communication.

A different method was used to estimate sign enhancement at the CI-HS test sessions because language samples were not obtained when the students were teenagers. Each CI-HS teenager's improvement in vocabulary comprehension when sign was used in addition to spoken language was estimated by comparing their scores on two separate administrations of the PPVT (Dunn & Dunn, 1997). Form IIIA was given as standardized, using only speech (OC condition). Form IIIB was presented using sign or finger spelling in addition to speech (SC condition). Results are expressed as standard scores (mean = 100; SD = 15) in relation to the normative sample of typically-developing (NS-TD) age-mates. Sign enhancement was expressed as the difference between the standard score in the SC administration and the OC administration.

Questionnaires were used to assess each CI-HS student's typical communication mode. Parents responded to the question: “How does your child usually communicate?” Students responded to the question: “How do you communicate when you go out by yourself?” If either respondent indicated use of speech and sign (none reported using sign language exclusively), he/she was categorized as using SC.

RESULTS

Sample Characteristics

Table 2 compares CI-E characteristics (at age 8 or 9) of the 112 CI-HS students who returned for testing as teenagers with the 72 students who did not return. The groups did not

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differ in age of implantation, PIQ on the WISC-III (Wechsler, 1991) or their classroom communication mode rating averaged over preschool and early elementary years (MODEAVG). However, significance testing of the means presented in Table 2 indicates that students participating in the CI-HS study demonstrated higher speech perception scores on the BKB sentences (Bamford & Wilson, 1979), higher reading scores on the Peabody Individual Achievement Test- PIAT (Dunn & Markwardt, 1989) and higher speech intelligibility scores on the McGarr Sentences when they were 8-9 years of age than those participants who did not return for follow-up. Minority representation was 14.3% of the CI-HS sample compared to 5.6% of non-participants, indicating successful minority recruiting for the follow-up study.

Table 3 compares the distribution of PIQ scores in the CI-HS sample with the NS-TD age-mates for the WISC-III (Wechsler, 1991). The distribution of PIQ scores in the CI-HS group is similar to that observed in the general population, but with slightly higher proportions at the extremes of the distribution (± 2 SD = 7.2% compared to 4% in the general population) and a slightly higher proportion (54.4%) above the median of 100.

Grade placement of most of the CI-HS teenagers was appropriate to their chronologic age: Two percent of the CI-HS teenagers were in 9th grade, 28% were in 10th grade, 49% were in 11th grade and 22% were in 12th grade. Table 4 summarizes the types of special services reported by teenagers for the school year just completed. Seventeen students (15%) reported receiving no special services in their mainstream classes.

Changes Occurring between CI-E and CI-HS

Table 5 compares characteristics of the 112 students at the CI-E and CI-HS test sessions. The average interval between these test sessions was 8 years. Very little change was observed in demographic characteristics (e.g. highest level of parent education, family size) and the mean PIQ remained nearly identical at the two administrations. However, there was a statistically significant 1 point decrease in the scaled score on the Block Design subtest of the WISC-III [$F(1,111) = 22.37$, $p < .0001$].

Families completed a questionnaire that asked them to indicate the range in which their family income fell for the preceding tax year, and all but four families provided this information. Canadian dollars were converted into a US scale using the published conversion factor into American dollars and then determining the range it fell into. The rankings assigned to each income range are summarized in Table 6 along with the median value for the 112 students included at both CI-E and CI-HS. Median income was considerably above the national average by the time those children reached high school age.

Figure 1 summarizes the classroom placement of the 112 students at their first test session in early elementary grades (CI-E) and the second test session in high school (CI-HS). Sixty-three percent of the CI-HS students were fully mainstreamed with hearing age-mates at 8 -9 years of age. By the time they were in high school, 76% of the CI-HS participants were fully mainstreamed, with an additional 20% of the sample mainstreamed for part of the school day and only 5% of the sample still in full-time special education classrooms.

The distribution of the 112 CI-HS students in terms of their classroom communication mode ratings (acquired from a parent report) when they received a CI and for four years following implantation are summarized in the first 5 columns of Table 7. In general, little change in overall communication mode was observed over the period immediately following receipt of a CI. There was a small increase in the number enrolled in OC classrooms (61 to 64) as CI experience increased. In addition, there was a gradual increase in the number of children whose SC program emphasized speech. There also was some increase in the number of children using an auditory-verbal approach within OC methodologies. The last column of Table 7 is an estimate of the typical communication mode students used in high school based on questionnaire responses. Of the 40 students categorized as using SC in high school, 5 students (12.5%) had previously attended OC programs. Of the 72 CI-HS students categorized as using speech exclusively to express themselves, 17 students (24%) had previously attended SC programs.

Table 8 summarizes the mean sign enhancement values obtained from OC and SC language samples at the CI-E test session. Sign enhancement ratios below 1.0 indicate better performance on language outcome measures in the SC as compared to the OC interviews. Students with sign enhancement ratios of 1.0 or higher were either not using sign at all or the use of sign language was not adding to the diversity and/or complexity of their spoken language at age 8-9 years.

Figure 2 summarizes the relation between average classroom communication mode (MODEAVG) over the first 5 years of CI use and the sign enhancement ratio measured for the CI-E group at age 8 and 9 years. There is a tendency for children who spent at least some of their early years in SC classrooms (i.e., MODEAVG <4.0) to use better language when their sign productions are included. However, there are also children who have been exposed to sign in their classrooms whose language is about the same in speech alone as when they use SC. The CI-E "sign enhancement ratio" reflects the child's actual performance rather than assuming that his/her preferred mode is the same as that used in the classroom.

Individual standard scores obtained by the CI-HS students on the two administrations of the PPVT are plotted in Figure 3. For most CI-HS children, SC and OC standard scores were within one standard deviation (15 standard score points) of each other. However, thirteen students showed more than a 1 SD improvement in test score when the words were presented in sign and speech together compared to three students who scored better in an OC than in an SC administration of the PPVT. A difference score was determined by subtracting the standard score in the OC condition from the score in the SC condition. The mean difference was 3.4 standard score points in favor of the SC administration over the OC administration. This difference score was used to estimate sign enhancement for the CI-HS group and is plotted against the sign enhancement ratio obtained at CI-E in Figure 4. Even though these estimates of sign enhancement were obtained about 8 years apart in time and covered different aspects of communication (expressive language in the CI-E group and receptive vocabulary in the CI-HS group), there was good correspondence between these estimates ($r=.47$; $p<.0001$), indicating stability in these estimates of sign enhancement over time.

DISCUSSION

Representativeness of the Study Sample

In interpreting the results of this study, it is important to take into consideration characteristics of the individuals and families who participated. Below we discuss a number of factors that may impact the outcomes in the original CI-E sample of 181 and in the follow-up sample characteristics of 112 students at both CIE and CI-HS.

CI-E Sample—Although the original sample was large, geographically diverse and exhibited many of the characteristics of children implanted at that time, the families who sought a CI for their child when the device was first available and traveled to St. Louis to participate in a data collection camp were advantaged in several respects. First, their child's hearing loss was identified and aided at a relatively early age (average 1 year 3 months) and they received a CI during the preschool years. This early auditory input provided an advantage in spoken language development compared to the general population of children with profound SNHL (Yoshinaga-Itano, 2006) and those children implanted after age 5 (Connor et al., 2006). The families were English-speaking; the majority were of white ethnicity and the parents had more education and higher incomes than the general population. Questionnaire responses indicated the families tended to be intact with both a mother and a father who involved their deaf child in family activities on a regular basis. Presence of a father in the home encourages both language and academic development in children with hearing loss (Calderon & Greenberg, 2003). Children with hearing loss who are from affluent families acquire spoken language skills more quickly whether they use a CI (Niparko et al., 2010) or not (Easterbrooks, O'Rourke, & Todd, 2000). However, it is important to note that family incomes above the national average have also been documented in other large samples of children with CIs (Fortnum et al., 2002), suggesting that the income advantage seen here may be a general characteristic of children receiving a CI rather than selection bias operating in this particular sample. All of the children reported fairly consistent use of their CI, probably because families of nonusers or extremely inconsistent users chose not to respond to our invitation.

Follow-up CI-HS Sample—The 112 adolescents who returned for follow-up testing had significantly higher speech perception, speech intelligibility and reading scores when they were in elementary grades than the 72 students who did not return. It may be that families who felt their children were performing reasonably well were more likely to return for follow-up testing. Some of the families who declined to participate may have done so because their child was either no longer using the CI or they did not achieve the level of outcomes with the device that the family had hoped.

For the 112 who did return for follow-up, we saw that family income increased by approximately $30,000 (more than 30%) over the 8 year interval. Possible causes for this increase over time were wage inflation and career advancement. According to the U.S. Census Bureau, the median household income of white non-Hispanic families (approximately $55,500) showed negligible increase between 1998 and 2008 indicating minimal wage inflation over that period (DeNavas-Walt et al., 2006). The average age of parents in this sample increased from 39 to 47 years over this interval, a factor that was probably associated with career advancement and increased income. However the amount of increase was considerably greater than was observed in the general population. US Census data for 2008 indicate that there was roughly a 4% increase in household income between 35-39 year olds ($62,399) and 45-49 year olds ($64,753). Thus, families participating in this study represent greater upward mobility, which could have a positive impact on their expectations for achievement gains in their children. The impact of any or all of these factors could have resulted in overestimating the contribution of early implantation and long-term CI use to the high achievement levels of these children, outcomes greater than might be anticipated from a broader, more representative sample.

On the other hand, these results may underestimate the positive effects of early cochlear implantation on language achievement in current CI users. The CI-HS students who participated in this study received their device more than 10 years ago and did not have some of the advantages available to more recently implanted children. It could be argued that this group of CI students is no longer representative of current clinical practice in pediatric cochlear implantation. Technological advances have resulted in improved electrode arrays and speech processing strategies (Spencer & Tomblin, 2006). A reduction in recommended age of cochlear implantation to 12 months has led to earlier implantation which is associated with accelerated language progress in the youngest recipients (Nicholas & Geers, 2007). Children with greater pre-implant thresholds are now considered good candidates for a CI and bimodal and bilateral implantation may result in even better results

(Nittrouer, 2010). However, these practices have not been adopted long enough for recipients to reach adolescence.

To address this issue of possible sample bias we included as many contributing background characteristics as possible in the multiple regression analyses (e.g., PIQ, parent education/ family income, gender, duration of CI use). However, we can never be 100% certain that all possible sources of selection bias were controlled. It is likely that the current CI-HS sample does not represent the entire population of children receiving CIs and conclusions regarding causality are not possible in the absence of a fully randomized design. Nevertheless, the longitudinal nature of the design provided an opportunity to explore multiple pathways of influence from early predictors to later communication skill. The variance partitioning in the hierarchical multiple regression analysis provides is especially powerful when determining pathways of influence. Such analyses allow us to explore associations between communication mode and cognitive processes in the development of speech perception, speech intelligibility, language and academic achievement over time, while controlling for sample characteristics associated with outcome level (Strube, 2003).

Rationale for Current Investigation

Following a sample of early-implanted children from elementary grades into their high school years provides a unique opportunity to examine long-term benefits derived from early generations of CI technology and the clinical standards in place at that time (ASHA, 2003). These data provide a frame of reference against which to judge improvements achieved with current technologies and practices when those recipients reach an equivalent duration of use. It has been noted that "for the first time in the history of the education of deaf individuals, achievements in speech and language development in this population are changing faster than researchers can keep up." (Spencer & Tomblin, 2006). As a result, we do not have a good sense of what outcomes to expect and how these outcomes may be influenced by the choice of sensory aids, communication mode or educational settings. It is important to learn how well early CI recipients are integrated into hearing society and to what extent they identify with the Deaf or hearing communities and feel comfortable moving between these groups. This broad sampling of children from educational environments across North America who were tested near the beginning and end of the standard academic grades should provide insight into these questions.

The articles in this monograph detail results obtained from the 112 CI-HS teenagers on a comprehensive seven-hour test battery. Where possible, we examine change in performance on identical measures administered in early elementary grades (CI-E) and high school (CI-HS). A primary function of this report is to describe how closely the students' skills and attitudes resemble their hearing age-mates (based on results from either the NS-TD or NHC-HS groups). We anticipated that this new generation of high school students with profound SNHL would more closely approach speech and language levels of hearing age mates than was true for the previous generation of SNHL children that did not have access to CI technology, but that not all of the CI-HS students in this study would exhibit skills commensurate with typically developing hearing age-mates. The ultimate goal of the following articles is to identify factors associated with more successful outcomes in children who receive cochlear implant technology.

Glossary of Terms

CI-HS 112 CI students from the original sample of 184 elementary-aged children who returned for follow-up testing in high school.

CI-E	The 112 CI-HS students when they participated in the original study in elementary grades.
CI-E Sign Enhancement Ratio	The average ratio between language measures collected from CI-E students in an SC interview and those collected in an OC interview.
CI-HS Sign Enhancement	A difference score determined by subtracting the PPVT-A standard score obtained by teenagers in an OC administration from the PPVT-B standard score obtained in an SC administration.
MODEAVG	Parent ratings of their child's classroom communication mode immediately following receipt of a CI, averaged over 5-years, summarizing the amount of emphasis on speech and audition in each student's program.
NS-TD	Normative sample of typically-developing children on a standardized test
NHC-HS	Control group of 46 teenagers (screened for normal hearing) who were tested in this study to provide comparison data when NS-TD data were not available.
OC	Oral, or speech-only, communication mode
SC	Simultaneous, or speech plus sign, communication mode.
SES	Socioeconomic status, estimated using a value that combined the number of years of education completed by the most highly educated parent (e.g., 12 for high school graduate, 16 for college graduate) with a ranking of total family income (Table 4).
WISC-III –P	Wechsler Intelligence Scale for Children – Third Edition-Performance Scale (Wechsler, 1991). These subtests measure learning and reasoning ability without requiring verbal responses and therefore provide a relatively unbiased estimate of learning potential in deaf children.

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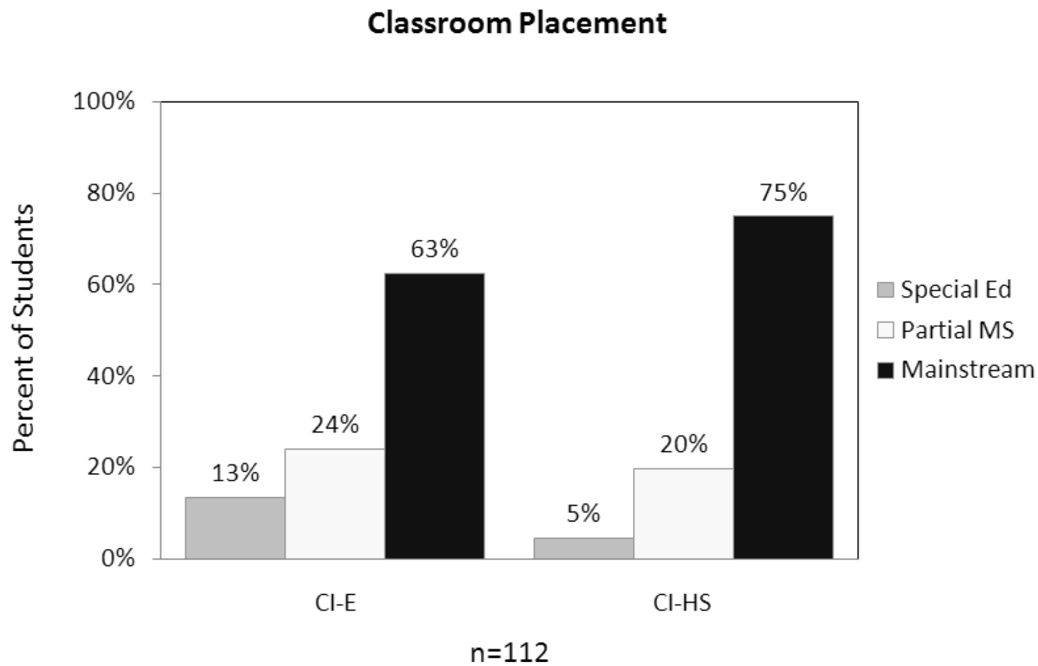

Figure 1.
Percentage of 112 participants in each classroom placement when they were in elementary and in high school are shown for three different placement categories: Special education (Special Ed) represents placement exclusively with students with hearing loss for all of the school day; partial mainstream (Partial MS) represents placement with typical hearing children for part of each school day and full mainstream represents full-day placement with typical hearing children.

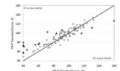

Figure 2.
Average classroom communication mode rating (1-sign emphasis to 6-speech emphasis) over 5 years following cochlear implantation is plotted against the average sign enhancement ratio obtained from SC and OC interviews conducted at age 8-9. Smaller ratio values indicate enhanced language performance in the SC over the OC interview.

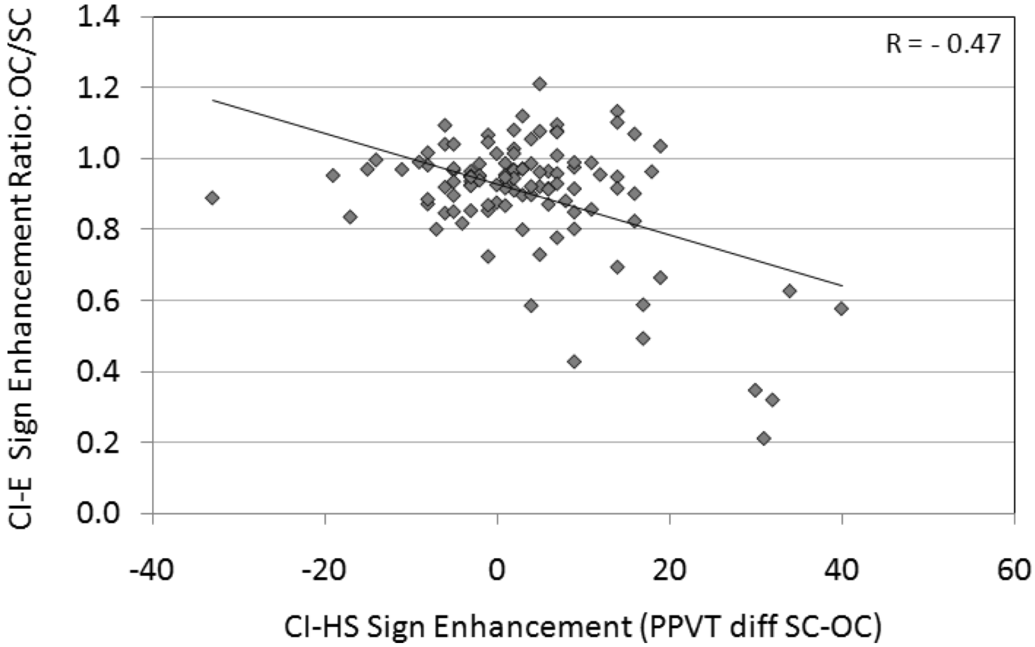

Figure 3.
PPVT standard scores obtained from CI-HS students in an OC administration (form A) are plotted against their scores in an SC administration (form B). Data points above the regression line indicate better performance in the SC mode, while those below this line indicate better performance in the OC mode. Bolded data points indicate greater than a 1SD (15 point) difference between scores in SC and OC modes.

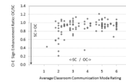

Figure 4.

Average sign enhancement ratio (OC/SC) at the CI-E session (age 8-9) is plotted against the sign enhancement score at CI-HS (PPVT standard score difference between SC and OC administration).

Table 1

Characteristics of the teenagers with cochlear implants (CI-HS) and the normal hearing control group (NHC-HS)

	CI-HS N=112			NHC-HS N=46		
	Mean	Std Dev	Range	Mean	Std Dev	Range
Age at test (yrs)	16.7	0.6	14.9 – 18.5	16.6	0.8	15.3-18.4
Highest parent education (yrs)	16.0	2.4	12 - 20	16.9	2.3	12 - 20
Percent minority	14%	-	-	13%	-	-
Percent female	53%	-	-	52%	-	-
Family size (members)	4.0	1.0	2 - 6	4.4	1.1	2 - 8
Vocabulary (PPVT[a])	90.0	22.6	40 - 160	109.6	9.2	88-128
Reading (TORC[b] General Vocabulary)	9.0	2.5	2 - 13	10.6	1.8	2 - 12
Reading (TORC[b] Paragraph Reading)	9.2	3.0	4 - 18	10.1	2.4	4 - 15

[a]Peabody Picture Vocabulary Test – Standard Score mean = 100; SD =15

[b]Test of Reading Comprehension – Scaled Score mean = 10; SD = 3

Table 2

Characteristics measured during the CI-E test session of participants returning and those unable to return for follow-up testing

	Returned (n= 112)	**Did not return (n = 72)**
Age first aided (months)	16.3	16.0
Age of implantation (years; months)	3;4	3;5
Percent minority	14.3	5.6
PIQ (WISC)	103	100
Early communication mode average (MODEAVG)	3.9	3.7
Speech intelligibility % correct*	69[a]	55
BKB % correct*	63[b]	47
PIAT reading standard score*	89[c]	81

*Significant mean differences at p<.01

[a] $F(1,181) = 9.39$, $p < .003$

[b] $F(1,182) = 8.54$, $p < .004$

[c] $F(1,182) = 10.12$, $p < .002$

Table 3

Distribution of WISC-PIQ scores in the CI-HS sample compared to test norms (NS-TD)

	PIQ	CI-HS	NS-TD
<-2 SD	≤70	3.6%	2%
-1 to -2 SD	71-85	10.8%	14%
-1 SD to 0	86-100	31.2%	34%
0 to +1 SD	101-115	31.2%	34%
+1 to +2 SD	116-130	19.6%	14%
>+3 SD	>130	3.6%	2%

Table 4

Special services received at school as reported by CI-HS participants for the past year

Service	Percent of Sample
Sign language interpreter	35
Oral interpreter	0
Teacher aide in the classroom	17
Resource room help	27
Media captioning (closed/real time)	32
Tutoring	16
Speech therapist	34
Note taker	33
FM-system	27
Other	13

Table 5

Means characteristics of the 112 follow-up participants measured in elementary grades (CI-E) and high school (CI-HS)

	CI-E			CI-HS		
Characteristic	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
Age at test (years)	8.9	0.5	7.9 - 9.9	16.7	0.6	15.0 - 18.5
Duration of CI use (yrs)	5.5	0.8	3.8 - 7.5	13.3	0.9	10.8 - 15.6
Duration of deafness	3.1	1.2	0.4 - 5.4			
Parent education (yrs)	15.8	2.5	12 - 20	16	2.4	12 - 20
Family size (#members)	4.2	1.0	2 - 6	4.0	1.0	2 - 6
WISC-PIQ	103.2	14.0	65 - 133	103.1	16.0	55 – 136
WISC Scaled Scores						
Picture completion	10.7	2.5	3 - 16	10.2	2.6	3 - 16
Picture arrangement	10.1	3.2	3 - 18	10.6	3.6	1 – 19
Block Design	11.5*	3.4	4 - 19	10.4	3.3	1 - 17

* Significant difference at $p<.05$

Table 6

Family income categories contributing to socioeconomic status ratings at CI-E and CI-HS

	Rank	$US Dollars
	1	Under $ 5,500
	2	$ 5,500 - $ 9,999
	3	$10,000 - $14,999
	4	$15,000 - $24,999
	5	$25,000 - $34,999
	6	$35,000 - $49,999
CI-E Median	7	$50,000 - $64,999
	8	$65,000 - $79,999
CI-HS Median	9	$80,000 - $94,999
	10	$95,000 and over

Table 7

Number of students in each classroom communication mode prior to the CI-E Test Session and rating of preferred communication mode at the CI-HS test session

Mode	Program	At Implant	Year 1	Year 2	Year 3	CI-E	CI-HS[a]
Simultaneous Communication	Sign emphasis	15	5	3	2	1	
	Equal emphasis	26	34	29	26	22	
	Speech emphasis	10	13	20	22	25	
	Sign and speech total	51	52	52	50	48	40
Oral Communication	Cued speech	5	6	5	4	5	
	Auditory oral	34	33	33	30	30	
	Auditory verbal	22	21	22	28	29	
	Speech Total	61	60	60	62	64	72
		112	*112*	*112*	*112*	*112*	*112*

[a]Number of individuals responding “sign and speech” to the student question: “How do you communicate when you go out by yourself?” or the Parent question: “How does your child typically communicate?”.

Table 8

Components of sign enhancement ratio for CI-E Group

	TC Interview		OC Interview		Ratio	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Different words per minute	13.2	3.3	12.2	4.2	0.92	0.23
Words per utterance	5.2	1.9	4.2	1.6	0.82	0.18
IPSYN Sentence Structure	23.3	4.8	21.8	6.1	0.93	0.20
IPSYN Noun phrases	19.2	2.1	18.4	3.8	0.95	0.17
Overall ratio					0.90	0.16