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Outcomes and Achievement of Students Who Grew Up with Access to Cochlear Implants

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Abstract

Objectives/Hypothesis—To provide long-term speech perception and production, educational, vocational, and achievement outcome data for pediatric cochlear implant recipients.

Study Design—This is a retrospective study using consecutive referrals of prelingually, profoundly deaf children at the University of Iowa Hospitals and Clinics.

Methods—Twenty-seven prelingually deaf young adults who received a cochlear implant between the ages of 2 and 12 years participated. Outcome measures included device-use information, perceptual information, reading results for all participants and educational achievement results for 17 of 27 participants, educational placement information/vocational information for all students, as well as a comparison of the child's educational/vocational outcome with that of the parent's educational/vocational outcome.

Results—Speech perception and production scores were highly correlated. Achievement test results indicated that scores were within 1 SD from normative data based on hearing individuals. Over 50% of the college-age eligible students enrolled in college. This initial group of implant users had a nonuse rate of 11% in the first 3 years. Eighty-nine percent of the users maintained full-time use for 7 years, and 71% of this group have maintained full-time use to date.

Conclusions—This cohort of cochlear implant users compared favorably with their hearing peers on academic achievement measures. Although there was a wide distribution of educational and vocational outcomes, the children tended to follow the educational/vocational patterns of their parents. As age of implantation decreases, it will be important to compare achievement outcomes of this first generation with those of subsequent generations of cochlear implant users.

Keywords

Pediatric; prelingual; cochlear implant; outcomes

INTRODUCTION

Child A was the first prelingually deaf child to receive a multichannel cochlear implant (CI) in at The University of Iowa Hospitals and Clinics in 1987. Fifteen years later, this individual, now a young adult, is a biomedical engineering student and a member of a university marching band. Not all pediatric CI users have attained this level of achievement.

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Indeed, one would not expect to see a uniform level of outcome in any cross-sectional study of achievement in a heterogeneous group of hearing children. Yet it is important to examine outcome data for children who receive CIs to identify trends in development and to target remedial programming for areas of weakness.

Criticism of pediatric cochlear implantation was high throughout the 1990s. In 1991, the National Association for the Deaf (NAD) referred to the Food and Drug Administration's approval of the device for children as "unsound scientifically, procedurally and ethically."[1] The NAD has made substantial alterations in their position papers after positive reports regarding improved speech perception skills, improved speech production skills, and finally improved language and literacy skills.[2–7] In the 2000 position paper of the NAD, the initial harsh criticisms have been blunted and replaced with the view that "Cochlear implantation is a technology that represents a tool to be used in some forms of communication. Cochlear implants…do not by themselves impart the ability to understand spoken language through listening alone. In addition they do not guarantee the development of cognition." Francis et al.[8] reported that cochlear implantation accompanied by aural rehabilitation leads to higher rates of mainstream school placement, with a resulting cost savings. Thus, converging evidence indicates that CIs provide beneficial input for increasing speech perception, speech production, language, and literacy. This study will examine long-term outcomes of the first cohort of pediatric implant users who received CIs at the University of Iowa Hospitals and Clinics. Outcome measures will include data with regard to auditory perception skills, average speech production proficiency, educational, vocational and achievement outcomes, and information regarding consistency of device use.

MATERIALS AND METHODS

Participants

Twenty-seven participants met the criteria for participation in this study, which included the first consecutive group of prelingually deaf children receiving implants at the University of Iowa Hospitals and Clinics who were either in 10th grade or 16 years or older and who presented with no concomitant identified disability such as blindness or cerebral palsy. CI surgery occurred between the years 1987 and 1995. Average age at surgery was 6.4 ± 3.1 (mean ± SD; range 2.4 –12.7) years. The mean length of use was 9.9 ± 3.4 (mean ± SD; range 3–14) years. All children received the Nucleus 22 devices. Nineteen participants used the spectral peak (SPEAK) speech-coding strategy, and eight used the multi-peak (MPEAK) speech-coding strategy (Cochlear Corp, Englewood, CO). All participants received their education in a mainstream, public school setting, using a sign-language interpreter, whereas their classroom teachers spoke English. One child transferred to a private, oral school for the middle school years and returned to a public high school with a sign-language interpreter. Table I provides biographic information.

Outcome Measures

All data collection was in accordance with the ethical standards for the responsible committee on human experimentation at the University of Iowa and with the Helsinki Declaration of 1975, as revised in 1983.

Speech Perception

Speech perception tests administered included the Word Intelligibility by Picture Identification test (WIPI) and the phonemes correct score of the Phonetically Balanced Kindergarten Word List (PBK)[9,10] The stimuli from the Hearing In Noise Test (HINT)[11] was presented in quiet by way of sound field to assess open set sentence perception.

Speech Production

Speech production skills were assessed by administering the short-long sentence repetition task. This task consisted of 14 sentences (e.g., How are you going to get there? Please stop making so much noise). The speech-language pathologist presented each item with both speech and sign, and the participant imitated the model. The productions were transcribed and subsequently scored using a target transcription to compare this with the actual production. The phonetic transcriptions yielded a percent phonemes produced correct score.

Reading Achievement

The Passage Comprehension subtest score from the Woodcock Reading Mastery Tests–Revised[12] was used to measure reading comprehension ability. This test used a modified close procedure that assessed the ability to comprehend short passages. The task required that the readers comprehend the entire passage to supply the correct missing word from the passage. Participants were allowed to provide their answers using sign, voice and sign, or voice only.

Academic Achievement

In 1999, academic achievement testing was initiated. All participants who had completed 10th grade were tested. Several participants had completed their annual follow-up visits by this point in time and were enrolled in postsecondary school or vocational programs and were not followed after they had turned 18; thus, a total of 15 participants completed this testing. To assess scholastic achievement, the following subtests from the Woodcock-Johnson Tests of Achievement[13] were administered: Letter-Word Identification; Passage Comprehension; Dictation; Writing Samples, Science, Social Studies, Humanities.

Vocational Achievement

Vocational information for all students who had reached their senior year of high school or later was collected. Sixteen participants completed this portion of the study. In addition, the educational/vocational outcome information of these participant's mothers was collected.

Consistency of Device Use

Consistency of device use was ascertained by way of questionnaire. Each participant supplied this information at each annual visit.

RESULTS

Speech Perception and Speech Production

Average percent of words identified correctly on the WIPI test was 70% ± 27% (mean ± SD; range 16–100%), and average percent of phonemes identified on the PBK test was 49% ± 27% (mean ± SD; range 0–88%). HINT sentence test accuracy was available for 14 of the users, who achieved an average score of 68% ± 27% (mean ± SD; range 15–94%). Regarding speech production, the average number of phonemes produced accurately in the short-long sentence repetition task was 79% ± 20% (mean ± SD; range 33–100%). The data in Figure 1 display the association between the composite speech perception scores for PBK and WIPI word scores and the speech production scores. The correlation between speech perception and speech production was strong and significant (Pearson $r = 0.78$, $P < .0001$).

Reading Achievement

The results of the paragraph comprehension task are presented in Figure 2 using standard scores. The standard score scale is based on a mean of 100 and a SD of 15. Thus, we would

expect that the mean score for normal hearing individuals would be 100. The first box plot (light gray) reveals that the median standard score for the CI cohort was 89 ± 17, as depicted by the heavy black line, whereas the dotted line depicts the mean score of 92 ± 17 (mean ± SD; range 65–138). The whiskers describe the 5th and the 95th percentile. The second box (white) represents the performance of the students who remained as full-time users. Their median and mean standard scores were 99 ± 15 (mean ± SD; range 71–138). The final box (dark gray) represents the scores of the inconsistent users, who achieved a median score of 80 ± 7 and a mean score of 77 ± 7 (mean ± SD; range 65–84).

Academic Achievement

The standard score was derived by transforming the raw scores obtained on the seven subtests into the standard score scale provided by the test developers, which is based on a mean of 100 and a SD of 15. Again, we would expect the mean score achieved by hearing individuals to be 100. The mean composite standard score for the CI participants on the achievement test was 103.88 ± 19.93 (mean ± SD; range 79–186). This mean is slightly higher than the mean provided by the standardization sample used in the developing the achievement test, where the participants had normal hearing and were randomly selected within a stratified sampling design to control for variables such as region of origin, sex, race, and age. A summary of the scores for each subtest is provided in Table II.

Vocational Achievement

Sixteen participants have reached the age of 18 years or older. Seventy-five percent of these young adults (n = 12) are attending posthigh school institutions, including seven different universities and five community colleges. Two of the remaining participants are homemakers, and two failed to report their current educational or vocational status.

Figure 3 depicts the relationship between the child's and parent's educational status. The reader should note that the children tracked very closely to the achievement level of their parents; however, at the time of this study, none of the CI participants had begun a graduate-school program.

Device Use

Average length per day of device use was 10.56 hours. Twenty-four (89%) of the participants reported 7 years of consistent device use (8 waking hours or more). Of these 24 individuals, 71% remain as consistent users to date, and 7 (29%) reported they had become inconsistent users and tended to wear their devices only during school or work or for specific classes, with less than 6 hours of device use per day. Three (11%) participants became non-users within the first 3 years after implantation. These three participants were 9.3, 12.6, and 11.8 years of age at time of implant surgery, and two of the three had mitigating family situations that arose in the first years after implantation, which included intervention by way of social service agencies.

Contributing Factors to Variability in Use

Inconsistent users were older at age of implant, 8.2 ± 3.5 (mean ± SD; range 4.8–12.9) years, compared with consistent users, 5.4 ± 2.6 (mean ± SD; range 3.4–10.9) years. This difference was significant by a two-tailed test of paired samples (t_{25} = 2.33, P = .05). Perceptual skills in the two groups were examined. On the WIPI test, consistent users achieved higher scores than inconsistent users, 84.1 ± 14.08 (mean ± SD; range 10.5–91.4), compared with 37.14 ± 22.1 (mean ± SD; range 14.3–57.5), and on the PBK test, consistent users achieved a mean score of 60.3 ± 23.1 (mean ± SD; range 17.3–72.2), and the inconsistent users score was 22.2 ± 16 (mean ± SD; range 10.3–37.0). The differences were

significant by a two-tailed test for paired samples, t_{22} = 6.27, P < .0001 (for the WIPI) and t_{22} = 3.95, P < .001 (for PBK). Similarly, the consistent users scored higher on speech production measures than did inconsistent users. Mean percent phoneme correct production for the consistent users was 85.2 ± 15.2 (mean ± SD; range 11.3–92.9) and 65.4 ± 23 (mean ± SD; range 14.9–86.7) for the inconsistent users. Again, the difference was significant by a two-tailed test for paired samples, t_{22} = 2.48 P < .05.

Reasons provided for less than full-time use in the preteen/teen years included the fact that the individuals reported they did not feel they were gaining much listening advantage and chose to move to a residential school (case XC18, 19, 21, 22); some individuals reported that the long cords were too cumbersome and interfered with sports participation, and they were successful communicators by way of lipreading and in a supported sign environment (cases XC 20, 23). Finally, in the case of XC 24, who had meningitis, the individual had a gradual device failure after 4 years of use and total failure by 7 years of use. Subsequently, the child underwent reimplantation surgery yet was not satisfied with auditory signal thereafter.

DISCUSSION

The present study is one of the first to offer long-term achievement, educational, and vocational outcome data from a cohort of prelingually deaf children who grew up with access to the information provided by a CI. speech perception and speech production skills were highly correlated. The group produced almost 80% of their speech sounds accurately, and the individuals who scored higher on perceptual tasks also achieved higher accuracy levels for speech production. In addition, children who received implants at younger ages tended to wear their devices consistently and subsequently developed better speech production skills. There are some outliers with regard to this pattern of performance, however (e.g., a child receiving an implant at 10.7 years produced 93% of phonemes correctly after 7 years of CI experience, and a child receiving an implant at 3.6 years of age produced 59% of phonemes correctly after 11 years of experience).

The cohort was successfully educated within a mainstream environment in public schools that provided total communication programs. Achievement test results indicated these participants obtained mean scores on standardized tests of academic achievement that were equal to or above their normal-hearing peers. Over 50% of the college-age eligible students have enrolled in college. In addition, the educational level of the children in this study followed the path of their parents. Thus, the parental influence on scholastic attainment is preserved in this population and is in concert with intergenerational effects seen in hearing children.[14]

CONCLUSIONS

This first generation of CI users performed at levels that were similar to their hearing peers with regard to academic achievement testing and educational and vocational outcomes. Eleven percent of this cohort became nonusers within the first 3 years after implantation, whereas 88% remained consistent users up until their teen years. Knutson et al.[15] reported that identified unreliable use within the first years after implantation was not attributable to limited audiologic benefit. In the current study, however, the group of individuals who became inconsistent users after 7 years of consistent use demonstrated significantly lower perceptual testing results. It is unclear whether the lower performance on speech perception testing in the current study was a cause of the reduced use or a by-product of inconsistent use in these older children. The Knutson study also reported that behavioral difficulties between mothers and children might limit the audiologic benefit of young users during the

initial years after implantation. This pattern may have been repeated in the adolescent years in the present study. The current study found that inconsistent users established a prolonged pattern of inconsistent use in the teen years that eventually led to decreased listening performance and a reduction in wearing consistency. Additional research is indicated to investigate the link between parent/child interactions, age at implantation, and consistency of device use in the teen years. As age of implantation decreases and CI technology advances, it will be important to compare achievement outcomes of this first generation with those of subsequent generations of CI users.

In addition, it was found that, in general, younger age at implantation was associated with higher rates of speech intelligibility and better performance on speech perception skills. There were instances of high-achieving individuals who received implants at age 8 or older and, conversely, low achievers who received implants before 4 years of age. This heterogeneity of effect illustrates that we do not yet completely understand all the variables that contribute to outcome and calls for continued investigation into mechanisms contributing to ultimate achievement levels within this population.

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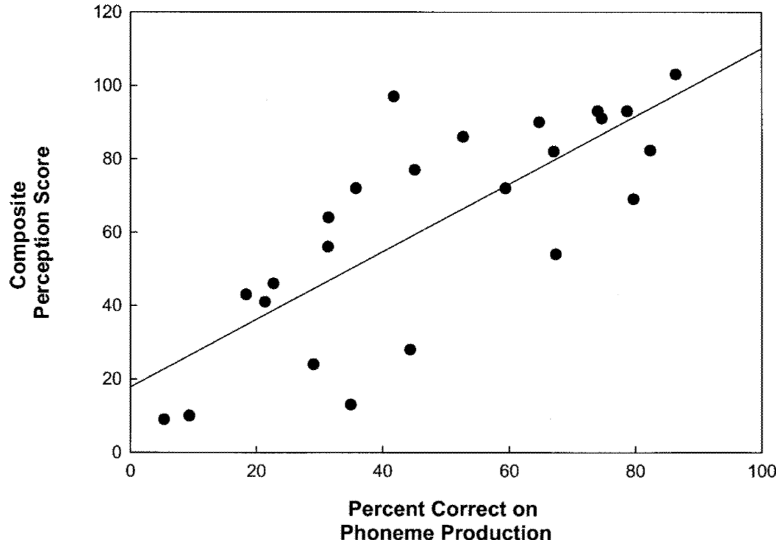

Fig. 1.

The strong relationship between speech perception and speech production as assessed by percent correct for composite speech perception scores on the PBK phonemes and WIPI and percent phonemes produced correctly on the short-long sentence repetition task. The regression line is represented by the solid line ($r = 0.78$, $P < .0001$).

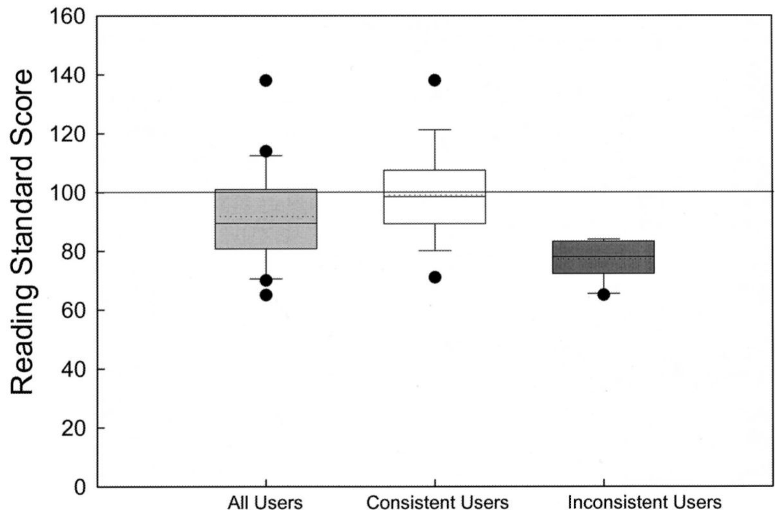

Fig. 2.

The relationship between reading standard scores for the cochlear-implant and normal-hearing groups. Mean standard score of 100 (solid black line), which is based on the normative population with normal hearing. Scores for the entire cohort (light gray box); scores for the subset of consistent users (white box); scores for the subset of inconsistent users(dark gray box).

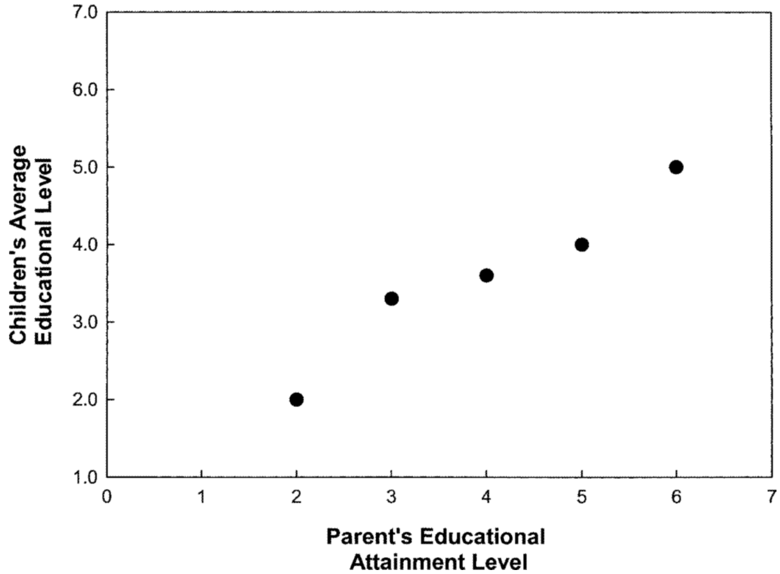

Fig. 3.

The relationship between average parental educational attainment and children's average educational attainment level. The x-axis corresponds to parent educational level, where 2 represents the high school attendance, yet no diploma was received; 3 represents attainment of a high school diploma; 4 represents college attendance, without completion of a degree; 5 represents completion of a college degree; and 6 signifies a postbaccalaureate degree. The y-axis is the child's average educational level achieved by the children whose parents are at the corresponding x-level. The scaling numbers for the x-axis mirror the same attainment levels as the y-axis.

TABLE I

Demographic Information for Participants and Audiometric Results.

Participant	Etiology	Age at Surgery (yrs)	Length of Experience (yrs)	Processing Strategy	HINT Sentences	WIPI	PBK Phonemes	Phonemes Produced
C-1	Unknown	3.8	14	Speak	94	100	88	96
C-2	Unknown	3.6	11	Speak	19	54	28	59
C-3	Heredity	10.7	7	Speak	45	82	64	93
C-4	Unknown	5.2	13	Speak	15	72	49	68
C-5	CMV	3.6	11	Speak	93	100	89	73
C-6	Waardenberg	4.4	11	Speak	80	86	70	100
C-7	Unknown	4.7	12	Speak	89	88	80	96
C-8	Unknown	9.7	10	Speak	87	76	48	87
C-9	Unknown	4.2	11	Speak	76	92	72	97
C-10	Meningitis	3.4	13	Speak	65	100	78	96
C-11	Unknown	3.7	12	Speak	39	66	31	86
C-12	Unknown	5.6	12	Speak	82	100	79	88
C-13	Meningitis	5.	10	Speak	84	80	52	94
C-14	Meningitis	2.7	13	Speak	80	100	87	95
C-15	Meningitis	4.0	9	Speak	NA	88	63	96
C-16	CX26	10.9	9	Speak	NA	80	23	47
C-17	Ototoxicity at birth	7.2	12	Speak	NA	66	24	79
XC-18	Viral infection	4.8	11	Speak	NA	38	24	76
XC-19	Unknown	4.7	6	Mpeak	NA	40	40	77
XC-20	Malformed cochlea	12.9	6	Mpeak	NA	84	33	96
XC-21	Unknown	4.6	8	Mpeak	NA	28	0	33
XC-22	Meningitis	10.6	6	Mpeak	NA	16	0	42
XC-23	CX26	5.4	10	Speak	NA	28	32	81
XC-24	Meningitis	5.8	6	Mpeak	NA	26	27	53
NC-25	Meningitis	9.3	3	Mpeak	NA	NA	NA	NA
NC-26	Unknown	12.7	3	Mpeak	NA	NA	NA	NA
NC-27	CMV	10.8	3	Mpeak	NA	NA	NA	NA
Mean		6.4	9.9		67.74	70.42	49.20	79.5
SD		3.1	3.4		27.04	27.23	27.4	19.6

C = continuous user; XC = continuous user for 7 years; NC = nonuser within first 3 years postimplant; CMV = cytomegalovirus; WIPI = Word Intelligibility by Picture Identification Test; PBK = Phonetically Balanced Kindergarten Word List; Mpeak = multi-peak; Speak = spectral peak; HINT = Hearing in Noise Test.

TABLE II

Achievement Testing Standard Scores: Mean Standard Score (Standard Deviation) for Each Subtest.

Subtest Group	Mean Standard Score CI Group	Mean for Norm
Word identification	97 (15)	100 (15)
Passage comprehension	99 (12)	100 (15)
Dictation (spelling, punctuation)	109 (20)	100 (15)
Writing sample	125 (29)	100 (15)
Social studies	99 (15)	100 (15)
Science	102 (12)	100 (15)
Humanities	98 (9)	100 (15)

CI = Cochlear implant.