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Children with a cochlear implant: Characteristics and determinants of speech recognition, speech-recognition growth rate, and speech production

Niños con Implante Coclear: Características y determinantes del reconocimiento, de la tasa de crecimiento del reconocimiento y de la producción de lenguaje

Key Words
Cochlear implant
Prelingually deaf children
Implantation outcome factors
Speech perception
Speech production
Speech perception growth rate

Abstract

The objectives of the study were to describe the characteristics of the first 79 prelingually deaf cochlear implant users in Norway and to investigate to what degree the variation in speech recognition, speech-recognition growth rate, and speech production could be explained by the characteristics of the child, the cochlear implant, the family, and the educational setting. Data gathered longitudinally were analysed using descriptive statistics, multiple regression, and growth-curve analysis. The results show that more than 50% of the variation could be explained by these characteristics. Daily user-time, non-verbal intelligence, mode of communication, length of CI experience, and educational placement had the highest effect on the outcome. The results also indicate that children educated in a bilingual approach to education have better speech perception and faster speech perception growth rate with increased focus on spoken language.

Sumario

Los objetivos de este estudio fueron describir las características de los primeros 79 usuarios de implante coclear sordos prelingüísticos en Noruega e investigar hasta qué grado la variación del reconocimiento de lenguaje, de la tasa de crecimiento de este reconocimiento y de la producción de lenguaje puede ser explicada por las características del niño, el implante coclear, la familia y el ambiente educacional. Los datos obtenidos longitudinalmente fueron analizados usando estadística descriptiva, regresión múltiple y análisis de la curva de crecimiento. Los resultados muestran que más del 50% de la variación puede ser explicado por estas características. El mayor efecto en los resultados es producto del tiempo de uso cotidiano, la inteligencia no verbal, el modo de comunicación, el tiempo de experiencia con el IC y el ambiente educacional. Los resultados también indican que los niños educados con un enfoque bilingüe tienen mejor percepción del lenguaje y una más rápida tasa de crecimiento en éste, si se incrementa el énfasis en el lenguaje hablado.

Many studies have demonstrated improved auditory speech recognition and speech production ability in prelingually deaf children after cochlear implantation (e.g. O'Donoghue et al, 1998; Geers et al, 2003b; Waltzman et al, 2003). The results, however, show large variation in speech recognition, and a number of studies have investigated several factors that might explain this variation (e.g. Archbold et al, 2000; Geers et al, 2003a; Tomblin et al, 2005). Essential factors seem to be found in the characteristics of the cochlear implant (CI) user, the implant, the family, the mode of communication in education, and the educational setting. Results from Geers et al (2003a) indicated that children with the highest non-verbal intelligence, the newest technology, those with oral communication, and those situated in ordinary educational settings had the best speech recognition skills. Connor et al (2000) however, found that the effect of total communication versus the effect of oral communication on speech recognition was minimal. These results suggested that new technology, early implantation, and having all the electrodes functioning were more important than mode of communication. A number of studies find that characteristics of the CI user account for a large part of the variability, and age at implantation seems to be the most important factor (Kirk et al, 2002; Sharma et al, 2005; Lesinski-Schiedat et al, 2006).

The purpose of the present study was: (1) to determine the following characteristics of the CI users: speech recognition and speech production skills, type of implant, family, educational setting, and mode of communication, and (2) to examine the degree to which the variation in speech recognition, speech-recognition growth rate, and speech production can be explained by any of these characteristics.

Materials and Methods

Participants

All of the first 100 children with CI in Norway, implanted before the age of 16, were examined and asked to participate in a

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further study. Ninety-five percent of the children agreed to participate. The children received their CI during the years 1992 to 2001, with 65 of the implantations performed from 1998 to 2001. All the children were included in the CI program at Rikshospitalet, Radiumhospitalet Medical Centre (RR MC) and were tested in an ordinary clinical routine setting, without any organized intervention. The present paper reports data from the children who were prelingually deaf ($N = 79$, 43 boys and 36 girls), while data from the 16 children who were postlingually deaf will be reported elsewhere. The CI users' parents and teachers were regarded as additional informants.

Questionnaires

A composite questionnaire was constructed and included questions from the meaningful auditory integration scale (MAIS), meaningful use of speech scale (MUSS) (Robbins at al, 1991), categories of auditory performance (CAP), and listening progress (LIP) (Archbold et al, 1995). In addition, The parent participation in therapy questionnaire (St. Louis Institute for The Deaf) was translated into Norwegian and used. The questionnaires were designed to evaluate the following characteristics pertaining to the users: (1) preoperative demographics, (2) cochlear implant device characteristics, (3) family characteristics, and (4) educational characteristics.

Variables regarding preoperative demographics were: preoperative hearing aid use, age at diagnosis of deafness, age at deafness, length of deafness, (non-verbal) intelligence, and age at implant.

Variables concerning the cochlear implant device were: length of CI use, the implant type, stimulation rate, and number of active electrodes.

Variables describing the family were: family size, the educational level of the parents, the family's hearing status, parent participation in the CI user's spoken language development, and the CI user's daily CI use time.

Variables regarding the educational setting were: degree of involvement in special versus mainstream educational setting, time spent on speech therapy, number of children in the educational setting, the teachers' number of years of experience working with hearing impaired children, and the choice of communication mode in the educational setting.

Questionnaires were administered to the CI users, to their parents, and to their current main teacher. Generally, they answered the same questions and one of the three answers was used in the statistical analyses, depending upon the theme of the question (e.g. the teacher's answer was chosen for questions regarding education, the parent's answer for family matters, and the user's answer for personal issues). Data gathered from the questionnaires were intended to give information about the CI user's situation one year before cochlear implantation, the first five years after implantation, and the situation at the time of the study. We used a five-point Likert-type scale and a yes/no format as a response scale in the questionnaire. The scale was actually ordinal, but as the variables represented a quantitative attribute, we treated them as continuous variables in the statistical analysis (Tabachnick & Fidell, 2001). Variables like mode of communication and educational placement were reported both as an index on a one-to-five point Likert-type scale reflecting an average of the situation during the CI user's time with CI, and also as a cross-sectional score of the situation at the time for the study. The five-point graded scale for mode of communication was categorized by: (1) Norwegian sign language only (+ written Norwegian) (NSL), (2) NSL as the first language and spoken language as the 2nd language, (3) spoken language as the first language and NSL as the 2nd language, (4) spoken language with sign support, and (5) spoken language only.

Speech recognition and speech production tests

A Norwegian equivalent of the closed set early speech perception test (ESP-N) (Moog & Geers, 1990) and the phonetically balanced kindergarten test (Haskins, 1949) (PBK-N) were used to evaluate speech recognition. The PBK-N consists of phonetically balanced single syllable words (lists of 25 and 50 words). Note that Cronbach's alpha was used to assess the internal consistency of the Norwegian equivalent of the ESP and the PBK test. Results for the ESP-N were .72, and .93 for the PBK-N words. Test-retest reliability on ESP-N part 4 was estimated on the basis of responses from 20 randomly chosen children, age 4–11. Test-retest was done within three days and showed a correlation of .94.

Speech production was evaluated using a shortened version of the Norwegian phoneme test (Tingleff 1996). The children were tested once every year. Live stimuli were used for all the children when their open speech recognition was tested for the first time. However, children tested with live voice might produce a lower test score when they are mature enough to perform the test using recorded stimuli. In order to compensate for possible increased maturity and test-leader effect we compared results from 20 randomly chosen children tested with both live and recorded stimuli. We found the CI users scored an average of 14% better on live versus recorded test-words, using lists of 25 and 50 words. To compensate for possible increased maturity and test-leader effect, we reduced the scores on live voice testing by 14%. When live mode was used, the CI user and the pedagogue sat opposite each other 1 metre apart with the test book on a table between them. For the recorded mode the CI user sat 2 metres from the loudspeaker. A Sony 57ES DAT recorder was connected to a Madsen OB 822 audiometer and a 14″ specially constructed speaker. The measured word value varies between 60–70 dBA fast.

The number of test results gathered for each CI user depended on the length of CI experience, the consistency of attending the yearly CI check, and the user's ability to perform in the test situation. At least one data point for speech recognition results was available for all 79 CI users. Longitudinal speech recognition data over a period of three years or more were obtained for 49 users (62%), and speech production results after two years or more of CI experience were obtained for 50 CI users (63%). The main analyses in this study were performed on speech recognition and speech-recognition growth rate.

Speech recognition categories

The test battery allows a characterization of the degree of hearing into 10 speech recognition categories, plus category 0 for non-users. Even though the category scale was actually ordinal, we treated the scale as continuous as it contains a large number of categories measuring a continuous degree of speech recognition skills (Tabachnick & Fidell 2001). Table 1 shows the categories and the speech recognition criteria for each category.

Table 1. Speech perception categories

Category	*Speech perception criteria*
10	>95% word recognition (+ Hint scores)
9	>90% word recognition
8	70–89 % word recognition
7	50–69 % word recognition
6	30–49 % word recognition
5	Beginning open-set word recognition
4	Vowel identification in monosyllable words
3	Vowel identification in two-syllable words
2	Pattern perception
1	Speech detection
0	Non-user

Test results based on recorded stimuli were used as the basis for the CI users' category placement. For children too young or too immature to respond to recorded stimuli, live voice test results were used. As a third choice, results from the closed-set test were used. The results from the ESP-N test were used as criteria for category placement 1 to 5. The criteria for category placement are similar to those presented by Cheng et al (1999), based on Moog & Geers (1990). A placement in categories 6 to10 implies open-set speech recognition. We based the criteria for placement in categories 6 to10 on information from Stach (1998) and Dubno et al (1995). Stach (1998) shows a general guideline for describing degree of hearing loss. Dubno et al (1995) found the expected word recognition score based on the degree of hearing loss.

Intelligence test

Raven Progressive Matrices (Raven et al, 2000) and the Leiter International Performance Scale (Leiter 1980) were used to measure the CI users' non-verbal intelligence. Both the Raven test and the Leiter test were completed without auditory verbal language.

Statistical analyses

Descriptive statistics were used to report the results concerning the study's first objective: to determine the characteristics of the CI user, the implantation, the family, the educational setting, and the mode of communication. The Pearson's product moment correlation was used for simple correlations. An independent *t*-test was used to compare the mean speech recognition between groups. Two-tailed tests of significance were used and the level of significance was set to $\leq$05, (without any correction for multiple testing). For the second objective in this study multiple linear simultaneous and hierarchical regression analyses, as well as growth curve analyses were used to explore the variation in speech recognition, speech-recognition growth, and speech production. Variables that did not contribute significantly to increased explanation of the variation were removed. In the hierarchical analysis, the factors were entered into the analysis in separate stages. Sets of variables were entered into the analysis in the following order: (1) characteristics of the CI user, (2) characteristics of the CI, (3) family characteristics, and (4) characteristics of the educational setting, assuming that the relative influence of the variables on the outcome was in this order. Geers et al (2003a) used a similar order.

For speech-recognition growth curve analyses the Hierarchical Linear Modelling (HLM) 5.0 statistical analyses program was used (Raudenbush et al, 2000). The data consisted of repeated measures of speech recognition derived from the ESP-N-test and the PBK-N-test. The CI users were tested once every year after the initial stimulation with the cochlear implant. According to these test results the CI users were placed in speech recognition categories ranging from categories 0 to 10. By the end of the study, 49 CI users had $\geq$3 years of CI experience, and had accomplished the speech recognition tests $\geq$3 times. The primary reason for using growth curve analysis was to determine the CI user's individual speech recognition growth rate and to study to what degree the variation in growth-rate could be explained by the variables investigated. The level-one model (within-subjects model), in the HLM was used. The individual growth was estimated by the Empirical Bays residuals (EB-residuals) for the independent model in the HLM analysis. The EB-residuals express the individual CI user's divergence from the average growth in the group. The individual growth score reflects a time dependent change in speech recognition. Instead of modelling a level-2 model containing predictors of speech growth, results from the unconditional model (level-1) were used as dependent variables in a simultaneous multiple regression analysis. This enabled entering several independent variables into the analysis and to investigate if the variation in speech recognition growth rate could be explained by any of these variables. A problem with this approach is that the estimated growth does not take errors into account.

Results

Results from the questionnaires

THE CI USER

Sixty-six children were born deaf, and 13 lost their hearing before the 25th month of life. All the children had a bilateral hearing loss of 90 dB HL PTA or higher before implantation. The average age at diagnosis was 15.6 months (SD = 10, min = 0, max = 46). The children were born from 1987–1999. The children were on average 9.3 months at the first suspicion of hearing loss (SD = 8.7, min = 0, max = 42), and in 79% of the cases the parents were the first to suspect such a loss. The CI users' average age at investigation/testing was 6.8 years (SD = 2.9, min = 2.4, max = 17.3). The average age at implantation was 50 months, (SD = 29.7, min = 17, max = 181). Thirty-eight children (48%) had been wearing hearing aids on a regular basis before implantation. Twenty-three children (29%) did not wear their fitted hearing aids on a regular basis. Two users (2.5%) were re-implanted because of trauma against the head and the implant. As shown in Table 2, the etiology of hearing loss was unknown for 57%.

According to the teachers and the parents, five children (6.5%) had additional impairment (specific language problems, ADHD) that was assumed to have moderate to strong effect (two children, 2.5%) on the CI user's ability to learn spoken language. The CI user's non-verbal intelligence showed average or above average intelligence for 81%, below average intelligence for 13%,

Table 2. Etiology

Etiology	*Number*	*Percent*
Unknown	45	57.0
Heredity	11	13.9
Meningitis	10	12.7
Mondini	4	5.1
Rubella in pregnancy	1	1.3
Usher syndrome	6	7.6
Birth damage	1	1.3
Ototoxic drugs	1	1.3
Total	79	100

and 6% showed intelligence extensively below average, or did not want to fulfil the test.

CHARACTERISTICS OF IMPLANT USE

The average length of CI experience was 3.2 years (SD = 1.8, min = 1, max = 11). The implant was used all day by 87% of the CI users, but 12% of these all-day users took the implant off during short periods during the day. In addition 11% used the implant approximately half the day, 1% used the CI only a few hours a week, and another 1% became non-users during the study. Among the 87% all-day CI users were children who did not take the implant off even when sleeping. Among the 12% who had short breaks during the day were children who argued that they needed an intermission from the sound, or found the sound too loud in noisy settings. Within the 11% group of CI users who used the CI half the day were children in special educational settings who used sign language. Some of these children argued that they did not need auditory skills in the educational setting and therefore found no point in using the implant during school time. Some of the children also argued that they did not want to be different from the rest of the children, who did not use any hearing aids. These CI users mainly used the implant after school, when they watched television or interacted with people who used spoken language. We also found children who only used CI when at pre-school/school, and not at home. The parents had given up trying to make the child wear the CI at home and during the weekends. Nucleus 24 implants were used by 85%, Nucleus 20 + 2 by 13%, 1% had Nucleus 22M, and another 1% had Medel 40 +. ACE stimulation method was used in 80% of the implants. For 91% of the CI users, all the active electrodes were working, 8% had up to two electrode failures, and 1% had five electrodes not connected because of cochlear anomaly.

THE FAMILY

Ninety-six percent of the CI users had parents with normal hearing. Eighteen percent had a sibling with a cochlear implant. Ninety-three percent had parents whose first language was Norwegian, four percent had parents using both Norwegian and another spoken language, and three percent had parents not familiar with the Norwegian language. Thirty-nine percent of the parents had a higher educational degree. Forty-two percent of the parents had been hesitant about giving their child an implant, mainly due to worries about the operation and about the ethical aspect of 'a deaf identity'. The average score for parent participation in the child's spoken language development was 3.9 on a five-grade scale, indicating a high parent involvement in the child's spoken language development.

EDUCATIONAL SETTINGS

Most of the CI users (96%) had attended a pre-school/kindergarten program. At the time of investigation 40% of the CI users were in special educational settings for the deaf, 20% were in classes for hard of hearing, and 40% attended ordinary educational settings. The average class size was between six and eleven children. Typical for the CI users in this study was the consistency of their educational setting regardless of how many years of CI experience they had. Even the CI users in educational settings for the deaf remained in this setting in spite of increased benefit from the cochlear implant. The correlation between the type of educational setting the first year with CI, and after 2–5 years of CI experience was .95. The educational placement index indicating the CI users' degree of mainstreaming during the CI users' time with CI, showed a mode value of 1, a median value of 2.4 and an average of 2.7 (SD = 1.53, min = 1, max = 5) on a 1 to 5 point graded scale.

MODE OF COMMUNICATION

Figure 1 shows that 9% of the participants at the time of investigation were in educational settings where only sign language was used. Seventy-one percent were in a setting with a bilingual approach using sign language and spoken language. Twenty percent were in a setting where spoken language was used alone or with single signs as support.

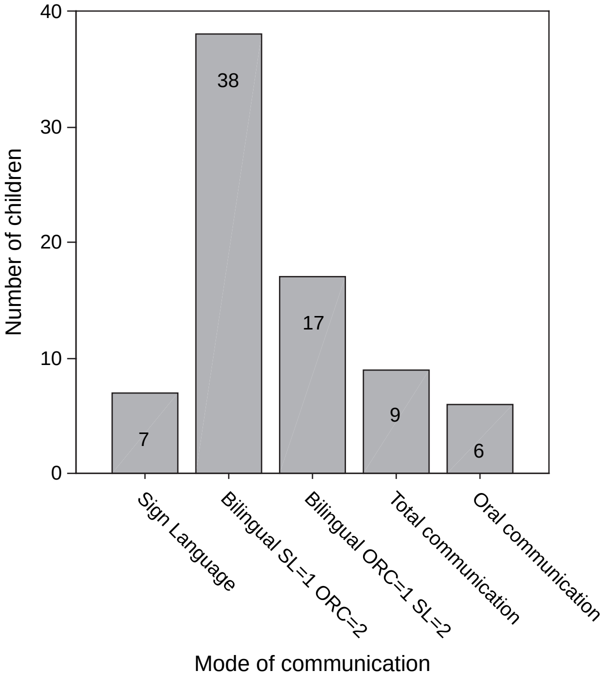

Figure 1. Mode of communication in educational setting by the time of questionnaire. The term "SL = 1 and ORC = 2" indicate that Norwegian sign language (NSL) is learned as a first language, and a spoken language, using oral communication is learned as a second language. The term "ORC = 1, SL = 2" means that a spoken language, using oral communication is learned as a first language, and NSL is learned as a second language (n = 77).

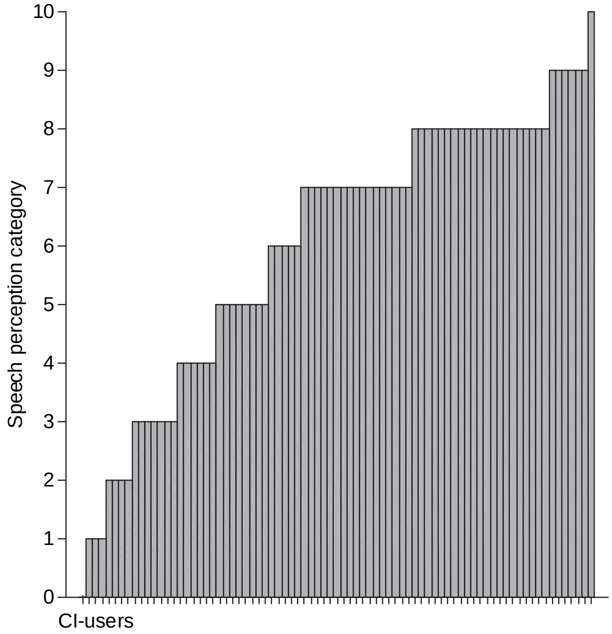

Figure 2. Individual speech recognition category placement at final test point ($N = 79$).

The mode of communication index indicating the CI users' use of spoken language versus use of sign language during the time with CI, showed a median and a mode of 2, and an average of 2.5 ($SD = 1.0$, $\min = 1$, $\max = 5$) on a 1 to 5 point graded scale. The results indicate that most of the CI users have used both sign language and spoken language (with and without sign support).

Results from speech recognition and production tests

At the final test point 71% of the CI users had achieved open-set speech recognition. The average score on PBK-N words was 63% ($SD = 22.54$, $\min = 2\%$ $\max = 96\%$). Average category placement was 6.04 ($SD = 2.34$, $\min = 0$, $\max = 10$) (Figure 2).

At the final test point, speech production results were gathered from 50 children (63%) within the age range of 3.3 years to 15.6 years, and an average CI-experience of 3.56 years. The average score on a 1 to 5 point graded scale was 2.75 ($SD = 1.09$, $\min = 1$, $\max = 4.9$). Forty-eight percent achieved a score between 1 and 2.5, indicating that their speech mainly consisted of non-understandable sound production. Twenty-two percent of the participants achieved a score between 2.6 to 3.7, indicating correct placement of the vowel in the words, and that the speech is understandable for family members and close friends. Thirty percent of the CI users achieved a score between 3.8 to 4.9, indicating that they produced childlike speech that is understandable for most people. Among the latter group, five CI users achieved a score ranging from 4.5 to 4.9, indicating they have nearly normal speech production.

Variables associated with the best performance in speech recognition: simple correlations

Table 3 shows the simple correlations between the CI users' speech recognition, speech-recognition growth rate, speech production and a variety of predictors.

The highest correlation with speech recognition is daily CI use ($r = .500$, $p < .001$). The CI users with the longest daily user-time had the highest speech recognition scores. The correlations between age at implant and speech recognition ($r = -.375$, $p < .001$), and speech recognition growth rate ($r = -.438$, $p = .002$) indicate that children implanted early in life had the best speech recognition and the fastest speech recognition growth rate. After three years of CI experience the mean speech recognition score for the deaf born children implanted before the age of three ($n = 15$) was 6.8 ($SD = 2.04$, $\min = 1$, $\max = 9$). The mean score for the deaf born children implanted at three years or older ($n = 16$) was 4.8 ($SD = 2.8$, $\min = 0$, $\min = 7$). An independent t-test demonstrated that these means were significantly different [$t\ (28) = -2.24$, $p = .033$]. Table 3 shows a significant correlation between age at implant and speech recognition, no correlations between age at testing and speech recognition, but a medium correlation between speech recognition and individual speech recognition growth rate, and a strong correlation between age at implant and age at testing (.807). In order to avoid collinearity in the multiple regression analysis we decided to use the variable age at implant. (Table 3)

Variables associated with the best performance in speech recognition: regression analyses

Table 4 shows the result of a simultaneous multiple regression analysis of the variation in speech recognition in the CI users in this study.

Variables not contributing to increased explanation of the variation in speech recognition were dropped from the analysis. The overall model accounted for 50.1% of the variance. Daily CI use (.368, $p > .001$) was the strongest predictor of variations in speech recognition, followed by non-verbal intelligence (.331, $p > .001$), mode of communication (.257, $p > .008$), time of CI experience (.251, $p > .005$), and finally the educational setting (.156, $p > .097$ ns). The regression analysis indicated best speech recognition among children who had the longest daily CI-use time, had the best non-verbal intelligence, predominant orally orientated mode of communication, the longest experience with CI, and had spent the most time in ordinary educational settings.

We also used a hierarchical regression analysis (Table 5) to assess the amount of variance in speech recognition predicted by educational factors after variance due to the CI user, the implant, and the family characteristics had been removed.

Variables concerning the CI user, the implant, the family, and the educational situation were entered into the analysis in four successive steps. We included all the variables that within each step contributed significantly to increased explanation of the variation. The results demonstrated that all factors included could explain a total of 54.6% of the variation in speech recognition. The variables age at implantation, pre-operative hearing aid experience, mother's education, family hearing status, and educational placement were significant contributors within each set. However, when these variables were considered in combination with the rest of the variables, the effects were no longer significant. The results are consistent with the results in the simultaneous regression analyses. (Table 4, Table 5)

Table 3. Correlation matrix for essential variables and the CI users' speech recognition, speech-recognition growth rate, and speech production.

	Speech reco.1	*Speech reco.2*	*Individ. s.r.growth*	*Speech prod.*	*CI-exp time*	*Age at impl.*	*Preopha-use*	*Nonverb. intellig.*	*Edu. setting*	*Mode of com.*	*Daily CI-use*	*Mothers Edu.*
Speech perception 2												
r	.866**											
p	.000											
N	79											
Individual speech perception growth rate												
r	.288*	.542**										
p	.045	.000										
N	49	46										
Speech production												
r	.682**	.569**	−.258									
p	.000	.000	.083									
N	50	50	46									
CI-experience time												
r	.314**	.261*	−.386**	.520**								
p	.005	.020	.006	.000								
N	79	79	46	50								
Age at implant												
r	−.249*	−.375**	−.438**	−.067	−.023							
p	.027	.001	.002	.643	.841							
N	79	79	49	50	79							
Preoperative hearing aid use												
r	.343**	.255*	−.145	.284*	.042	−.002						
p	.002	.024	.319	.045	.716	.984						
N	78	78	49	50	78	78						
Nonverbal intelligence												
r	.183	.288*	.190	.034	−.024	−.057	.028					
p	.108	.011	.192	.817	.837	.621	.808					
N	78	78	49	50	78	78	77					
Educational setting												
r	.249*	.305**	.353*	.035	−.138	−.137	.161	.055				
p	.028	.077	.013	.812	.229	.231	.161	.637				
N	78	78	49	49	78	78	77	77				

Table 3 (*Continued*)

	Speech reco.1	*Speech reco.2*	*Individ. s.r.growth*	*Speech prod.*	*CI-exp time*	*Age at impl.*	*Preopha-use*	*Nonverb. intellig.*	*Edu. setting*	*Mode of com.*	*Daily CI-use*	*Mothers Edu.*
Mode of com. in education												
r	.360**	.391*’	.149	.208	−.061	−.168	.274*	.000	.348**			
p	.001	.000	.307	.151	.595	.142	.016	.997	.002			
N	78	78	49	49	78	78	77	77	78			
Daily CI-use												
r	.437**	.500**	.330*	.133	.087	−.367**	.190	−.043	.246*	.326**		
p	.000	.000	.022	.367	.454	.001	.100	.717	.032	.004		
N	76	76	48	48	76	76	76	75	76	76		
Mothers education												
r	.293*	.325**	−.065	.150	.071	−.103	.040	.308**	.053	.125	.203	
p	.010	.004	.661	.309	.534	.378	.734	.007	.647	.282	.078	
N	76	76	48	48	76	76	76	75	76	76	76	
Age at testing												
r	−.043	−.185	−.611**	.215	.557**	.807**	.007	−.075	−.199	−.188	−.236**	−.065
p	.706	.102	.000	.133	.000	.000	.951	.514	.081	.099	.040	.578
N	79	79	49	50	79	79	78	78	78	78	76	76

*p <.05, ** p <.01, N = number of cases.

Speech perception 1 is the results from tests done at the time of the questionnaires, and *speech perception 2* two is the results form the study’s last testing point.

Table 4. Summary of Simultaneous Regression Analysis for variables predicting Speech Perception (N = 75).

	Simple Correlations					*Beta values*	
	Dependent variable	*Independent variables*					
Independent variables	*Speech recognition*	*Daily CI-use*	*Intelligence*	*Mode of com.*	*Length of CI-experience*	*Standardized regressions coefficient*	*Multiple Correlations*
Daily CI-use	.499**	1				.368 **	
Intelligence	.312**	−.043	1			.331 **	
Mode of communication	.401**	.324**	−.040	1		.257 **	**$R^2 = .501$****
Length of CI-experience	.251*	.092	−.016	−.061	1	.251 **	
Educational placement	.305**	.249*	.022	−.341**	−.150	.156	

Adjusted $R^2 = .465$**, *$p < .05$, ** $p < .01$.

VARIABLES ASSOCIATED WITH THE BEST PERFORMANCE IN SPEECH-RECOGNITION GROWTH RATE

The result from the hierarchical linear model (HLM) analysis is done in two steps. First, the intercept of the curve and the change rate were estimated through an independent model. Then the variations between the individual CI users were modelled, and the predictors for change were estimated. Results reveal an average level of change of 1.17-speech recognition categories per year (SD = .54, max = 2.24, min = .20) for the 49 CI users included. Figure 3 shows the individual speech perception growth rate for the CI users.

The simultaneous multiple regression analysis reveals that the factors included in the study could explain 55.6% of the variation in speech recognition growth rate (see Table 6).

The standardized beta coefficients for the independent variables showed that age at implant and time of CI experience explained most of the variation (−.460, p = .000), (−.459, p = .000). The CI users with the youngest age at implant and with the shortest CI experience had the fastest growth rate. The third important variable was age at deafness (−.340, p = .002), and finally educational setting (.320, p = .004). The analysis indicated fastest speech-recognition growth rate in the CI users who were youngest at implantation, had the shortest experience with CI, were born deaf, and had spent most of the educational time in mainstream settings. (Table 6)

VARIABLES ASSOCIATED WITH THE BEST PERFORMANCE IN SPEECH PRODUCTION

Results of a simultaneous multiple regression analysis of the variation in speech production illustrate that 35.2% of the variation in speech production could be explained by the characteristics of the CI user and the implant characteristics. Better speech production was found in children who had the longer time of CI experience (.522, p < .01) and had preoperative hearing aid experience (.253, p = .05) with time of CI experience explaining most of the variance. Results from a hierarchical regression analysis were consistent with this result.

Results summary

The most essential results are as follows: Average age of diagnosis was 15.6 months, and average age at implantation was 50.4 months. Eighty percent had a Nucleus 24 implant, with ACE as the chosen method of stimulation. Average CI experience was 3.2 years, with one year as the shortest, and 11 years as the longest time of experience. Seventy-eight percent of the participants used their CI all day, 12% used it most of the day 11% used it several hours of the day, and 3% used it rarely or not at all. Ninety-six percent of the children attended or had attended kindergarten. The average score of monosyllabic word recognition was 63%. Most of the CI users were in speech recognition categories 7–10, which means open speech recognition of 50–96%. Twenty-eight of these children have scores above 70%, which can be equivalent to hearing through a well-fitted hearing aid for a hearing loss of 60–40 dB HL.

In relation to the study's second objective, the following variables were shown to be of importance for speech recognition: daily user-time, non-verbal intelligence, mode of communication, length of CI experience, and educational setting. The variables age at implantation, length of CI experience, age at deafness, and educational placement were significant predicators of speech recognition growth-rate.

Discussion

The results from the first extensive study of prelingually deaf children with CI in Norway, confirms earlier demonstrations of improved auditory speech recognition and speech production ability. The results, however, show considerable variations among the CI users.

Factors associated with the development of speech recognition

Daily CI use was the most important predictor of speech recognition (Table 4). The CI user with the longest everyday use-time had the best speech recognition. The results demonstrate that parents' attitude to the use of the CI can be of significant importance for speech recognition results after cochlear implantation. We found a small significant correlation between the family's hesitation to giving the child a cochlear implant and the child's every-day use-time (r = .273, p = .017), and a moderate-to-strong correlation between everyday use-time and speech recognition (r = .500, p < .001). The daily use-time was shorter if the parents were uncertain that a CI was the right choice for their child, and the speech recognition was poorer if the daily use-time was short. These results indicate that good parent support and emphasis on the importance of wearing the device all day may be beneficial.

Our finding that non-verbal intelligence is the second most important variable predicting speech recognition corresponds to the findings of Geers et al (2003a). In our hierarchical analysis (Table 5), non-verbal intelligence was the only significant

Table 5. Summary of Hierarchical Multiple Regression Analysis for Variables predicting Speech Recognition (N =75).

Independent variables	*B*	*β*	*% Explained variance*		*Multiple Correlations*
Step 1.			Unique contributions	Total contribution	
Age at implant	−.026	−.315**	9.9 %		
Intelligence	.666	.293**	8.5 %		
Hearing aid. pre.op	1.249	265*	7.0 %	26.5%	
Step 2.			Unique additional contributions	Total additional contribution	
Age at implant	−.026	−.313**			
Intelligence	.658	.289**			
Hearing aid. pre.op	1.217	.258*			
Length of CI-experience	1.018	.236*	5.6%	5.6%	
Step 3.			Unique additional contributions	Total additional contribution	
Age at implant	−.014	−.165			
Intelligence	.576	.253**			**R^2 =.546****
Hearing aid. pre.op	.870	.185*			
Length of CI-use	.755	.175			
Daily CI-use	1.021	.363**	10.2 %		
Mother education	.258	.146	1.8 %		
Family hearing status	.602	.111	1.2 %	15.5%	
Step 4.			Unique additional contributions	Total additional contribution	
Age at implant	−.011	−.138			
Intelligence	.600	.264**			
Hearing aid. pre.op	.559	.119			
Length of CI-use	.953	.221*			
Daily CI-use	.792	.281**			
Mother education	.223	.126			
Family hearing status	.557	.103			
Mode of communication	.518	.223*	3.8 %		
Educational placement	.204	.133	1.4 %	7 %	

Adjusted R^2 =.483**, *p <.05, ** p <.01.

The Unique contributions and the unique additional contributions are quadrates of semi partial correlations (sr2).

variable within CI user characteristics that independently predicted speech recognition, when considered in combination with implant, family, and educational characteristics.

Mode of communication was the third most important variable predicting speech recognition (Table 4), and more important than the choice of educational setting. This seems reasonable, as the degree of spoken language use differs largely within the educational settings for the deaf. Our findings indicated better speech recognition with increased involvement in the spoken language, demonstrating that we need to target increasing speech recognition skills, and focus on the possibility of CI users participating in ordinary educational situations. The present study differs somewhat from studies investigating total versus oral communication, as the focus was on a sign language approach (no voice) versus a spoken language approach (voice with single sign support). Still, our results may be considered consistent with a number of studies demonstrating better speech recognition outcome with increased focus on oral communication (Archbold et al 2000; Geers et al, 2003a). Length of CI experience was the fourth and the last variable contributing significantly to explaining the variation in speech recognition (Table 4). The result supports previous studies (e.g. Fryauf-Bertschy et al, 1997) indicating improved speech production with longer CI experience.

The finding that age at implantation and preoperative hearing aid use did not predict speech recognition ability was unexpected, particularly given the number of studies showing advantages for early auditory stimulation and early implantation. However, both these variables were predictors when considered alone, but their effect was no longer significant when they were considered together with implant, family, and educational characteristics. These findings demonstrate that the effect of early implantation depends on implant, family, and educational factors. There is less advantage in early implantation if, for example, the CI use is limited, or if the child receives limited stimulation on spoken language. Possibly, the relatively high age at implantation in our study may explain why age at implantation failed to be of significant importance for speech

Table 6. Summary of Simultaneous Multiple Regression Analysis for Variables Predicting Speech Recognition Growth Rate (N = 49).

Simple Correlations					*Beta values*	
	Dependent variable	*Independent variables*				
Independent variables	*Speech recognition growth rate*	*Age at implantation*	*Length of CI-experience*	*Age at deafness*	*Standardized regression coefficient*	*Multiple Correlations*
Age at implantation	−.438**	1			−.460**	$R^2 = .556$**
Length of CI-experience	−.386**	−.118	1		−.459**	
Age at deafness	−.188	−.105	−.075	1	−.340**	
Educational placement	.353**	−.211	−.021	−.217	320**	

Adjusted $R^2 = .515$**, * $p < .05$, ** $p < .01$.

recognition. The first two years of life are most essential for auditory development and only one child in the present study was implanted before 24 months of age. Our findings are in line with Geers et al (2003a) who did not find age of implant to be of significant importance.

When evaluating the effect of the variable age at implant, it is necessary to acknowledge that the influence of this variable on speech recognition seems to depend on age at diagnosis, age at deafness, duration of deafness, and preoperative hearing aid use. Yoshinaga-Itano et al (1998) report results demonstrating the importance of identification and intervention before six months of age to language development in the hearing impaired, regardless of the degree of hearing loss. The high average age at diagnosis could have had an influence on the results, as only 17% in the present study were diagnosed within the critical six months of age. However, we did not find any significant correlation between speech recognition and age of diagnosis. Neither did we find age at implantation to be important when including only individuals with hearing aid experience before implantation. This might be due to other factors like the CI user's preoperative auditory experience. Only 48% had hearing aid experience before implantation, and only three of these children were aided by the age of six months. The hearing aid users and the non-users had a difference of 33 months for the first introduction to sound. A significant effect of age at implantation when only CI characteristics were evaluated (Table 5) indicated that early use of hearing aid, even on very large hearing losses, can be of importance for speech recognition after cochlear implantation. The reason for lack of hearing aid use for children in the present study is uncertain. It is possible that the importance of auditory stimulation was not emphasized or known among the educators working with the CI user at that time, as sign language was considered as the CI user's future mode of communication. The lack of emphasis on auditory stimulation is apparent through the fact that 85% of the CI users one year before implantation were involved in a rehabilitation program focusing on sign language. Considering the findings of Yoshinaga-Itano at al (1998), and Mehl & Thomson (2002), we seem to have a substantial opportunity for improving speech recognition in children with cochlear implants by starting with newborn hearing-screening, early hearing aid use, and early cochlear implantation.

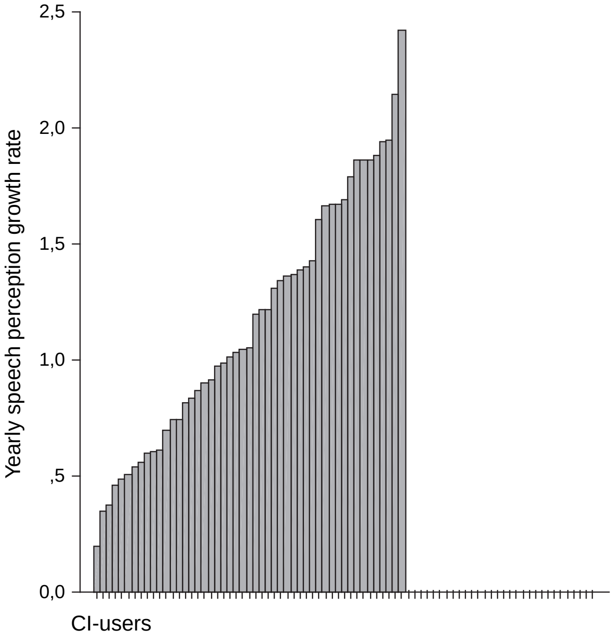

Figure 3. Individual speech recognition growth rate in prelingually deaf CI-users. The results are presented as change in speech perception categories. (N = 49).

Factors associated with speech-recognition growth rate

Two of the variables predicting speech recognition growth-rate were nearly equally important: age at implant, and length of CI experience. Children who were youngest at implantation, and who had the shortest time of CI experience had the fastest speech-recognition growth rate. Our results are consistent with the findings by Connor et al (2000), and Kirk et al (2002). Length of CI experience was the second most important variable. It is reasonable to find the most rapid change during the first years of CI use. The fact that we found age at implant to be a significant predictor of speech-recognition growth rate, but not of speech recognition when measured cross-sectionally, might indicate that the effect of age at implant is not apparent on test scores after several years with implant use when the children are implanted after the age of two. Age of deafness was the third most important predictor of speech-recognition growth rate, indicating that children born deaf had the fastest speech-recognition growth rate. However, in the present study, one should also consider the influence of etiology, as most of the children (10 of 13) deafened after birth had meningitis, which is often associated with co-morbidity. The average speech recognition score after three years of CI experience was significantly lower among meningitis patients compared to the CI users with an unknown etiology.

In our study, the educational setting was a predictor of speech-recognition growth rate, supporting results from Kirk et al (2002), who found more rapid gains in communication abilities in children who used oral communication only, than in children who used total communication. Even though there is great variation in the degree of sign language use (no voice) in the different schools for the deaf, the results indicate that the dominating language environment influences how fast the CI user attains speech recognition. Our results demonstrate better speech recognition for children with cochlear implant in mainstream educational settings. The challenge within the mainstream setting, however, is to offer appropriate educational support, considering the needs of the individual hearing-impaired child.

Factors associated with development of speech production

Our results demonstrate that prelingually deaf CI users can attain understandable spoken language. Even if the CI user did not have optimal benefit of the CI with regard to hearing, the opportunity to learn to speak must be considered as a substantial benefit. Preoperative hearing aid use was important in this group, indicating that early auditory stimulation is important for developing speech production skills. The results support focus on speech habilitation among prelingually deaf CI users. In the present study, however, we only used one speech production test, and the majority of the CI users had short CI experience time. For further studies in this field, a more extensive speech production test battery is recommended. More valid results can be expected by studying CI users with longer CI experience time.

Study limitations

The results in the present study must be interpreted cautiously and considered as indications, as the study has an observational and not an experimental design. However, high correlation between very different ways of collecting data indicates good validity, which means that the data gathered gave a reasonably good picture of the CI user's speech recognition. The results from both simultaneous and hierarchical regression analyses, as well as growth curve analyses indicated similar factors to be of importance to speech recognition and production, and to speech-recognition growth rate. This consistency in the results may strengthen a causal interpretation of the observed predictors.

Categorization implies transforming exact results into less accurate results, possibly obscuring significant relations. However, the use of speech recognition categories allows us to use one speech recognition scale for the entire group of the first 79 prelingually deaf cochlear-implanted children, and without any floor or ceiling effect. The need for our analysis to include all these CI users is of special interest because of the strong focus on Norwegian sign language in education. We considered it important to include the entire group of children from the clinic's CI program, in order to achieve trustworthy results and a better understanding of the situation for the first prelingually deaf children with cochlear implants in Norway.

Conclusions

In our study of 79 prelingually deaf children with cochlear implants, we observed high levels of speech recognition skills one to three years after cochlear implantation. The most important variables predicting speech recognition were daily use-time, nonverbal intelligence, mode of communication, time of CI experience, and educational setting. As regards speech-recognition growth rate, the variables age at implantation, length of CI experience, age at deafness, and educational placement were significant predictors. For children educated with a bilingual approach to education (NSL and spoken language) the results demonstrate better speech recognition and speech-recognition growth rate with increased focus on, and use of, spoken language. This shows the need for increased focus on speech recognition and production skills, and suggests a change in the educational approach in Scandinavia from sign language (NSL) towards spoken language, when educating prelingually deaf children with cochlear implants.

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