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Early Implantation and the Development of Communication Abilities in Children[1]

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Abstract. Early cochlear implantation of children with prelingual, profound deafness promotes the acquisition of communication abilities. Previously, we found that children implanted prior to age six years had superior communication abilities than children implanted after that time. This study examined the effects of age at implantation and communication mode on the development of listening skills in age-matched children with prelingual deafness who were implanted during the preschool years. Participants were deafened before age three years, implanted between the ages of two and five years, and used the Nucleus cochlear implant with the SPEAK speech processing strategy. The 28 participants were approximately five and a half years old at the time of testing. Closed- and open-set spoken word recognition and receptive and expressive language abilities were compared as a function of age at implantation and communication method. We also consider the case of a child implanted at 16 months of age and compare his performance with that of the other 28 age-matched participants. The results show that children implanted prior to age three years had higher spoken word recognition than those implanted later. Also, children who used oral communication had significantly better open-set speech understanding than children who used total communication (i.e., the combined use of spoken and signed English). This suggests that early implantation yields significant advantages in children's ability to encode, process and produce spoken language.

Introduction

The purpose of this investigation was to examine the benefits of early cochlear implantation on the development of communication skills in children with congenital or prelingual, profound deafness. Detailed longitudinal studies of speech perception, speech production and language acquisition have justified a trend toward cochlear implantation at young ages (Frauf-Bertschy, Tyler, Kelsay, Gantz & Woodworth, 1997; Meyer, Svirsky, Kirk & Miyamoto, 1998; Robbins, Svirsky, Kirk, Miyamoto, Bollard & Green, in press). We have previously shown that children with congenital deafness have the potential to derive similar speech perception benefit from a multichannel cochlear implant as do children who had some limited exposure to spoken language before the onset of their deafness (Miyamoto, Osberger, Robbins, Myres & Kessler, 1993). In addition, previous studies have shown that some children with profound hearing loss who have received a cochlear implant can attain speech perception abilities similar to other profoundly deaf children who have some residual hearing and use conventional amplification (Cowan et al., 1997; Miyamoto, Osberger, Robbins et al., 1991; Staller, Dowell, Beiter & Brimacombe, 1991; Miyamoto, Kirk, Robbins, Todd, Riley & Pisoni, 1997; Snik, Vermuelen, Brokx & van den Broek, 1997). However, the speech production (Geers & Tobey, 1992; Waltzman et al., 1997; Miyamoto, Svirsky, Kirk, Robbins, Todd & Riley, 1997) and language skills (Miyamoto, Svirsky & Robbins, 1997; Hasenstab & Tobey, 1991) of most profoundly deaf children, even with a cochlear implant, are significantly below those of their age peers with normal hearing. Early implantation offers children access to spoken language during the preschool years that are so important to language acquisition. This, in turn, may have important consequences for the development of spoken language and ultimately, academic success.

In this report, we will consider the case of the youngest child implanted to date at Indiana University School of Medicine. (We will refer to this child by his participant code, SHJ.) SHJ was implanted at 16 months of age and has used his cochlear implant for approximately four years. He is now approximately 5.5 years of age and is approaching the age at which formal schooling will begin. We will compare his communication abilities with those of age-matched peers who were implanted between the ages of two to five years.

Case Study Participant

SHJ, a male child with congenital, profound hearing loss, was the product of a normal pregnancy and delivery. Brainstem Evoked Response Audiometry conducted when SHJ was 11 months of age suggested a bilateral, profound hearing loss. SHJ was first seen in the Department of Otolaryngology at Indiana University School of Medicine for follow-up testing when he was 12 months old, and he was fit with bilateral conventional amplification at the age of 13 months. SHJ and his parents quickly began a family-centered habilitation training program with a speech-language pathologist to help SHJ acquire oral-aural communication. After a three-month trial of amplification and appropriate intervention, audiologists concluded that SHJ derived little or no benefit from his hearing aids. SHJ was implanted with the Nucleus 22-channel cochlear implant at the age of 16 months. His Spectra speech processor was programmed with the SPEAK processing strategy one month after surgery.

SHJ's parents agreed to have him participate in the longitudinal study at Indiana University School of Medicine to assess the benefits of pediatric cochlear implantation. As part of this study, children are administered a battery of speech perception, speech production and language measures prior to implantation, again at six month-intervals during the first three years of implant use, and then annually thereafter. The test battery administered to all young children is described below.

Communication Assessments and Procedures

Speech Perception Tasks

All speech perception testing for very young children is carried out in the auditory-only modality with stimuli presented via live voice at approximately 70 dB SPL. Performance on both a closed-set and open-set speech perception measure is assessed. The Grammatical Analysis of Elicited Language—Presentence Level (GAEL-P) (Moog, Kozak & Geers, 1983) has been adapted for use as a closed-set speech perception measure. Children are first familiarized with the 30 objects in the auditory-plus-visual modality. During testing, the children must identify the target word from a set of four objects at a time, through listening alone. The test is scored as the percent of words correctly identified; chance performance is 25%.

The Mr. Potato Head Task (Robbins, 1994) is a modified open-set speech perception task. Mr. Potato Head is a toy for children consisting of a plastic "potato" body with approximately 30 body parts and accessories that can be attached. Children are asked to carry out 10 commands presented auditorily only to assemble the Mr. Potato Head toy (e.g., "Give him some green shoes"). A sentence score is generated for the number of commands correctly carried out, and a word score is generated for the number of key words (out of 20) correctly identified even if the command was not followed correctly (e.g., if the child picked up the green shoes but did not put them on the toy).

Speech Intelligibility Task

The intelligibility of the children's speech production is evaluated using a procedure developed in our laboratory (Miyamoto et al., 1997). Each child is asked to repeat 10 simple sentences from the Beginner's Intelligibility Test (Osberger, Robbins, Todd & Riley, 1994) and these productions are recorded on audiocassette. Each child's sentences are then digitized and randomized for presentation to separate panels of three listeners with normal hearing who have no experience in listening to the speech of deaf talkers. The listeners are asked to write down each sentence as they hear it; intelligibility is measured as the mean percent of words correctly identified across the panel of three listeners.

Table 1.

Speech perception, intelligibility and language scores obtained by SHJ over time.

Testing Interval	GAEL-P (Closed-set)	Potato Head Task (Open-Set)		Speech Intelli-gibility	Reynell Language Quotients	
	Words	Words	Sentences		Receptive	Expressive
Preimplant	CNT*	CNT*	CNT*	0%	0.0	0.18
Postimplant						
6 months	CNT*	CNT*	CNT*	0%	0.3	0.65
12 months	67%	0%	20%	0%	0.59	0.72
18 months	93%	50%	60%	11%	0.83	0.89
24 months	87%	70%	70%	40%	0.76	0.95
30 months	93%	40%	55%	31%	0.77	0.83
36 months	100%	100%	100%	70%	0.72	1.26
48 months	100%	100%	100%	NA^	0.82	0.92

* Could not test due to vocabulary constraints
^ Intelligibility sentences collected at this interval have not yet been played to panels of listeners

Language Task

The Reynell Developmental Language Scales (Reynell & Huntley, 1985) are administered to assess independently receptive and expressive language abilities. The test is administered in the child's preferred communication mode (oral or total communication). Normative data have been obtained for this measure from more than 1,300 children with normal hearing. The Reynell Developmental Language Scales are appropriate for a broad age range (between 1-7 years) and have been used extensively with deaf children. The test requires the children to comprehend or express a hierarchy of language structures ranging from object labeling to complex instructions. This test has high face validity and reflects real-world communication demands similar to those that children might encounter in daily living situations. The Reynell Language Development Scales yield separate receptive and expressive vocabulary ages. The vocabulary age scores are then converted into separate language quotients (vocabulary age divided by chronological age). A language quotient of 1.0 indicates that the child's language age and chronological age are equal. Language quotients <1.0 indicate that the child's vocabulary age lags behind his or her chronological age; >1.0 indicate that the vocabulary age exceeds the chronological age.

Longitudinal Results for SHJ

Table 1 presents SHJ's speech perception and speech intelligibility scores and his Reynell receptive and expressive language quotients obtained prior to implantation and then over four years of implant use. Before receiving his implant, SHJ had minimal communication abilities. Vocalizations were inconsistent and primarily consisted of undifferentiated vowel sounds. He was unable to identify or label any objects on either the speech perception tasks or the Reynell Developmental Language Scales.

After 12 months of cochlear implant use, SHJ identified words from a closed-set at significantly greater than chance levels and demonstrated some limited open-set sentence recognition. By 36 months postimplant, SHJ had reached ceiling levels of performance on both closed- and open-set word recognition tasks. Similar improvements were noted in speech intelligibility. Although none of SHJ's speech attempts were intelligible preimplant, by 36 months postimplant, 70% of the sentences he produced could be understood by naive listeners. This represents a very high level of speech intelligibility, as there were no contextual or visual cues to aid naive listeners in understanding SHJ's speech. Finally, SHJ has also shown a marked increase in his ability to comprehend and produce spoken language. Large gains in his expressive language skills were evident as early as six months postimplant with corresponding increases in receptive language noted at 12 to 18 months postimplant. Now, after three to four years of cochlear implant experience, SHJ's language skills are nearly age-appropriate. Most importantly, SHJ is able to communicate effectively in daily communication situations with both familiar and unfamiliar persons. This fall, SHJ will be fully mainstreamed in a public school kindergarten classroom. He continues to see a speech-language pathologist on a weekly basis.

A Comparison of SHJ and his Age-Matched Peers

In order to examine more carefully the effects of early implantation, SHJ's speech perception and language scores obtained at his most recent testing interval (four years postimplant) were compared with those of his age-matched peers who received a cochlear implant prior to age six years. In addition, the communication abilities of these age-matched peers were examined as a function of age at time of implantation. Separate analyses were carried out for children in the comparison group who used oral and total communication (the combined use of signed and spoken English).

Comparison Participants

The children in the comparison group were selected from the population of children with prelingual deafness who were implanted at Indiana University School of Medicine. Selection criteria included: 1) implantation prior to age 6 years; 2) use of the most recent speech processing strategies (SPEAK or CIS); and 3) chronological age similar to that of SHJ at his most recent test interval (i.e, 5.5 years) Twenty-eight children met these criteria; all children were implanted with the Nucleus cochlear implant and used the SPEAK speech processing strategy. The participants were divided into three groups based on age at implantation. The groupings consisted of children implanted before the age of 3 years (*n*=10), those implanted between 3 years and 3 years, 11 months (*n*=8), and those implanted between 4 years and 5 years, 4 months (*n*=10). In each age group, some of the children used oral communication and some used total communication. Tables 2 and 3 present demographic information for these oral and total communication participants, respectively.

Comparison Study Procedures

The children selected for the comparison group had been administered the same test battery at the same intervals as SHJ. For each comparison participant, we analyzed data from the test interval at which his or her chronological age was closest to 5 years, 5 months (range = 5.0-5.9 years). This was done because we wished to compare performance across groups as a function of age at implantation while controlling for chronological age at the time of testing; we also wished to compare SHJ's performance with that of his age-matched peers. Thus, the mean length of device use differed across the three age-at-implantation groups. For children within the comparison group, scores on each of the measures described below were subjected to a two-way analysis of variance with age-at-implantation group and communication mode as the independent variables.

Table 2.

Oral participant characteristics as a function of age at time of implant.

	Age at Time of Implant					
	< 3 yrs (n=7)		3.0 - 3 yrs, 11 mos (n=5)		4.0 - 5 yrs, 4 mos (n=5)	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
Age at Onset (yrs)	0.3	(0.7)	0.4	(0.8)	0.7	(0.5)
Length of CI Use (yrs)	2.9	(0.3)	1.98	(0.2)	0.9	(0.5)
Age at Testing (yrs)	5.4	(0.2)	5.5	(0.3)	5.7	(0.2)
Pure Tone Average (dB HL)	111	(8.2)	110	(1.6)	112	(5.9)

Table 3.

Total communication participant characteristics as a function of age at time of implant.

	Age at Time of Implant					
	< 3 yrs (n=3)		3.0 - 3 yrs, 11 mos (n=3)		4.0 - 5 yrs, 4 mos (n=5)	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
Age at Onset (yrs)	0.0	(0.0)	0.2	(0.4)	0.0	(0.0)

Length of CI Use (yrs)	3.0	(0.1)	1.9	(0.2)	0.8	(0.3)
Age at Testing (yrs)	5.7	(0.2)	5.3	(0.1)	5.3	(0.1)
Pure Tone Average (dB HL)	116	(3.6)	110	(1.6)	113	(7.3)

Comparison Study Results

Figures 1-5 illustrate the communication abilities of SHJ compared with the mean scores for children in the three age-at-implantation comparison groups. In each of these figures, the score for SHJ is plotted to the left of the mean score for children who were implanted prior to age 3 years.

Speech Perception Results

Figure 1 illustrates the percent of words correctly identified on the closed-set measure, the GAEL-P. For the comparison group, age at time of implantation significantly influenced closed-set word identification ($F(2,20) = 4.25$; $p = .03$). Mean GAEL-P scores were 96%, 86%, and 62%, respectively, for children in the <3 years, 3-4 years, and 4-5 years age-at-implant groups. Children implanted before the age of three years had significantly better closed-set word recognition than the children in the two remaining groups. Finally, there was a trend for the oral children to have higher GAEL-P scores than the children who used total communication (88% vs. 76% words correct, respectively) but this difference was not significant. SHJ's score of 100% was similar to the mean performance of the oral children in the <3 years age at implantation group.

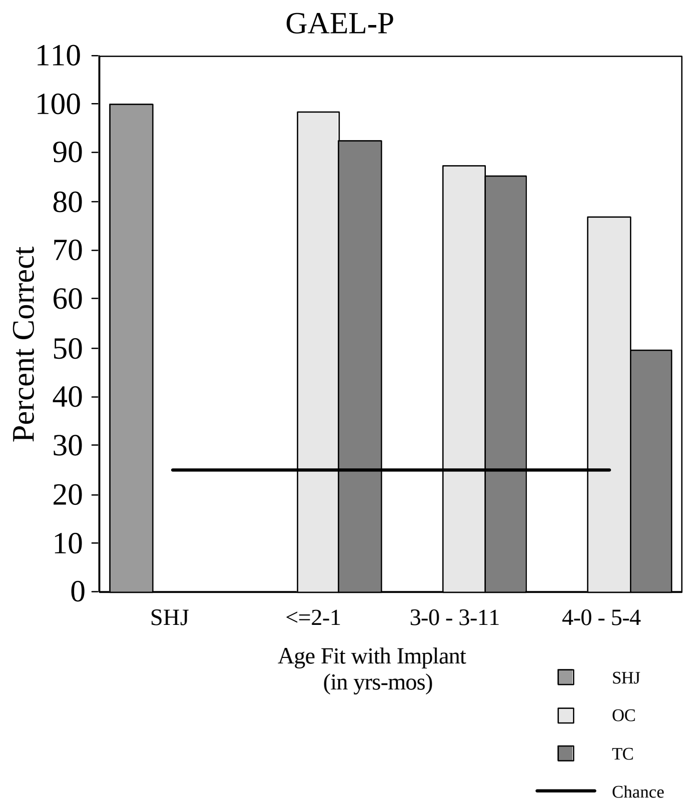

Figure 1. Percentage of words correctly identified on the GAEL-P, a closed-set measure of speech perception, as a function of age fit with an implant.

Figures 2 and 3 present the percent of words and sentences correctly identified, respectively, on the open-set Mr. Potato Head Task. Differences in both open-set word and sentence recognition performance among the three age-at-implantation groups were marginally significant. Mean word recognition scores were 84%, 63%, and 49%, respectively, for children in the <3 years, 3-4 years, and 4-5 years age-at-implantation groups ($F(2,22) = 3.25$; $p = .058$). For the same three groups, mean open-set sentence recognition scores were 80%, 60%, and 44% ($F(2,22) = 2.71$; $p = .089$). Finally, the oral children had significantly higher open-set word recognition ($F(2,22) = 6.42$; $p = .02$) and sentence recognition ($F(2,22) = 5.60$; $p = .03$) than did children who used total communication. SHJ's score of 100% for both word and sentence recognition exceeded the mean score of the oral children in the earliest age-at-implantation group. In fact, only one of the 28 children in the three comparison groups also achieved a perfect score on both of these open-set measures.

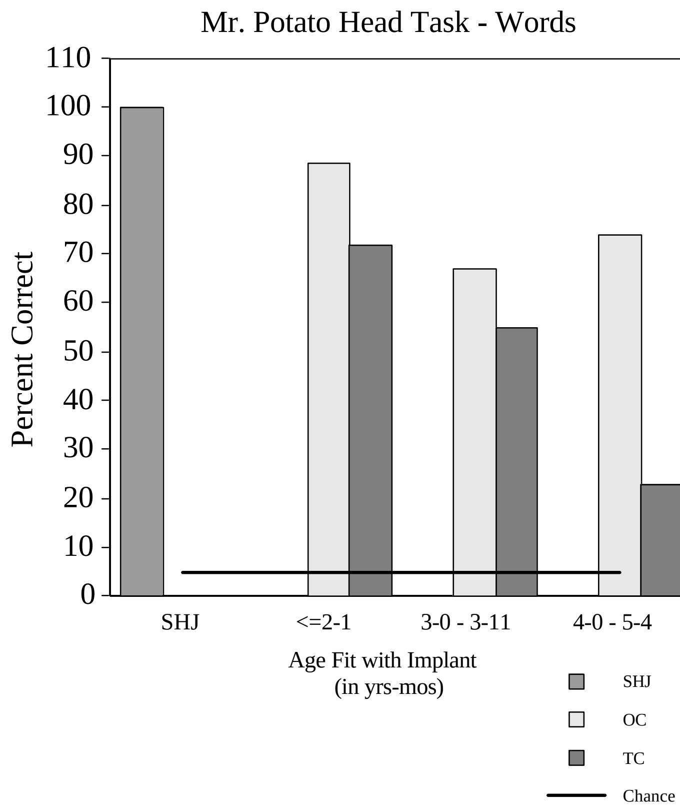

Figure 2. Percentage of words correctly identified on the Mr. Potato Head Task, an open-set measure of speech perception, as a function of age fit with an implant.

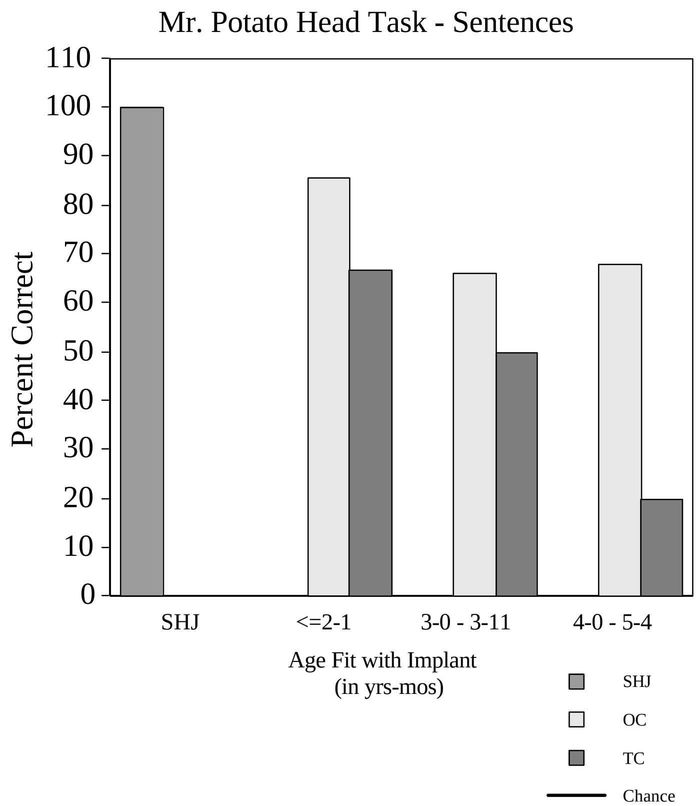

Figure 3. Percentage of sentences correctly identified on the Mr. Potato Head Task, an open-set measure of speech perception, as a function of age fit with an implant.

Receptive and Expressive Language Results

Figure 4 illustrates the receptive language quotients obtained on the Reynell Developmental Language Scales. Recall that a language quotient of 1.0 indicates that the child's receptive language age was equal to his or her chronological age. On this measure, children in the three comparison groups did not differ significantly as a function of age at time of implantation. Mean receptive language quotients for children in the comparison groups ranged from 0.57-0.60, indicating a mean vocabulary age that is somewhere near half of the mean chronological age. In addition, there were no significant differences in receptive language abilities as a function of communication method. Individual variability within the three comparison groups was noted, however. Across the 28 age-matched children, receptive language quotients ranged from 0.25 to 1.23. There was a trend for children who were implanted by around four years of age and used oral communication to demonstrate the highest language quotients. SHJ's receptive language quotient of 0.82 was higher than all but two of the children across the three comparison groups.

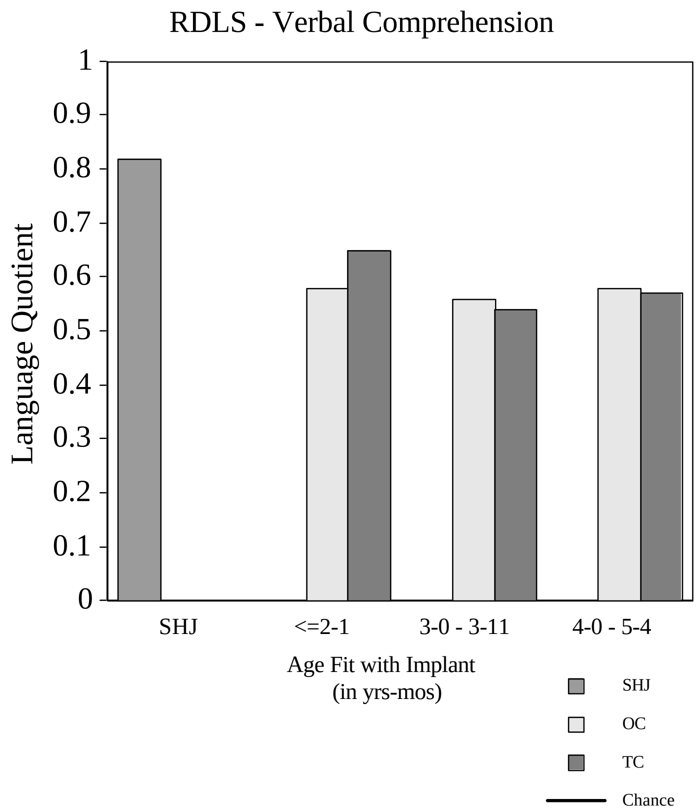

Figure 4. Receptive language quotient on the Reynell Developmental Language Scales as a function of age fit with an implant.

Figure 5 presents the expressive language quotients from the Reynell. Across age-at-implant groups, expressive language quotients ranged from 0.52-0.63. For all of the children in the comparison group, individual expressive language quotients ranged from 0.23-1.27. There were no significant effects of age at implantation or communication mode. Once again, there was a trend for children implanted prior to age 4 years to have higher language quotients, but these differences were not significant. SHJ's expressive language quotient of 0.92 was higher than that obtained by the majority of children in the comparison groups. Four children in the comparison groups achieved expressive language quotients that were similar to SHJ's (range = 0.91-1.27). Of these four, three received their cochlear implant before the age of four years.

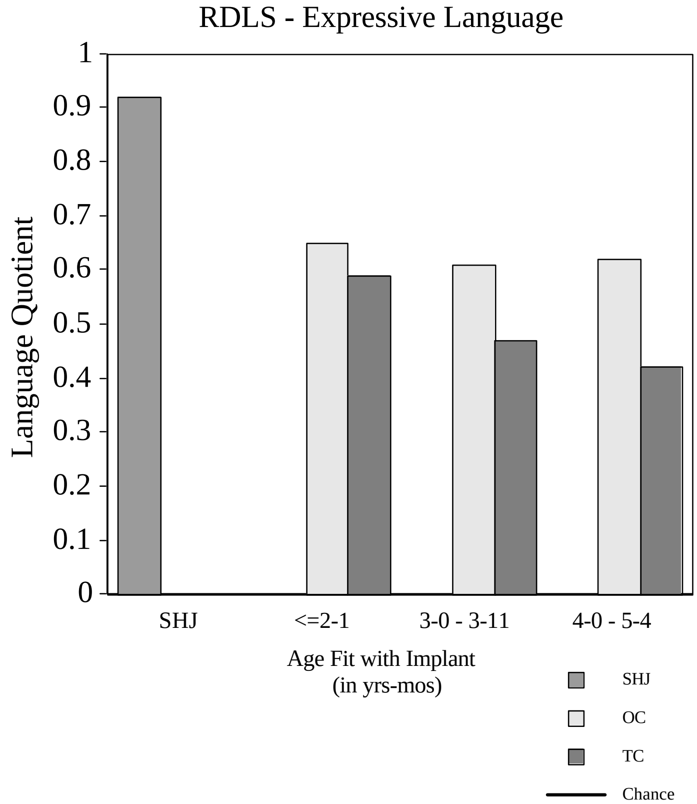

Figure 5. Expressive language quotient on the Reynell Developmental Language Scales as a function of age fit with an implant.

General Discussion

The current results demonstrated that both age at implantation and communication mode have significant effects on the development of a number of communication skills in profoundly deaf children. Our comparisons of communication abilities among age-matched peers who differed in the age at implantation revealed that children implanted by around three years of age generally had higher spoken word recognition than children who were implanted after that time. In contrast, there were minimal differences among the average language quotients of the three age-at-implantation groups on the receptive or expressive language measures. The effects of early implantation on receptive and expressive language abilities may emerge over a longer time period than that examined here.

Children in this study who used oral communication had significantly better spoken word recognition abilities compared to children who used total communication. This finding should be interpreted with some caution as children in the two communication groups were not matched on any variables other than chronological age. However, our results support earlier findings from our laboratory and suggest that a strong emphasis on the development of speaking and listening abilities promotes the acquisition of these skills.

The importance of cochlear implantation for children with profound hearing loss is exemplified by the superior communication abilities demonstrated by our youngest implant recipient, SHJ. His communication abilities were superior to the majority of his age-matched peers in this study. All of these children are approaching the age at which formal education begins; their communication abilities will impact greatly on their academic placement and success.

In summary, the present study demonstrates that early implantation for children with profound deafness promotes the acquisition of speaking and listening skills during critical periods of development. Children implanted prior to age three years showed significant advantages in their ability to encode, process and produce speech compared to age-matched peers who were implanted at later ages. It should be noted that the children in this study had used their cochlear implant for differing lengths of time; it is not clear yet whether their skills will ultimately plateau at the same level. Nonetheless, the increased early auditory experience provided by implanting children as young as possible should have important consequences for the development of reading and other academic skills. We plan to continue following these children over time to evaluate the ultimate benefits of early implantation.

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