

## Abstract

Cochlear implantation provides an opportunity to study the effects of variation in onset of auditory/linguistic experience on rates of language development. Twenty-seven children implanted between 13 and 40 months were followed. Language was measured using the *Minnesota Child Development Inventory* (MinnCDI). The average language quotient at the end of the follow-up was 73. The nonverbal developmental quotients were 112. A growth curve analysis showed that language growth rates were below average, but that children with earlier ages of implantation had more rapid rates of development. These data suggest that

## The Effect of Age of Cochlear Implantation on Language Growth in Infants and Toddlers

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## Background

Cochlear implants are a type of auditory prosthesis used to provide acoustic information to the auditory system by means of direct electrical stimulation of the auditory nerve. These devices are used to treat individuals with severe and profound bilateral hearing loss. The typical cochlear implant provides effective hearing thresholds at around 35 dB HL across the speech spectrum, however, the frequency and temporal resolution of these devices are considerably different from that of equivalent acoustic hearing. Children who have severe to profound hearing losses prior to the onset of language development typically have very poor patterns of spoken language development. As a result, these children have been receiving cochlear implants for over 15 years. Recently implantation of children as young as 12-months old has been approved by the U.S. Federal Drug Administration. Despite early concerns that the auditory information provided by the cochlear implant would not be sufficient for language development (Lane & Grodin, 1997), data from several studies show that there does appear to be sufficient information to support speech and language development. Several studies have compared the spoken language development of children who have received cochlear implants with children who were deaf but who were not implanted (Blamey & Sarant, 2000; Geers & Moog, 1994; Svirsky, et al., 2000; Tomblin et al., 1999). In each of these studies, it was shown that the language development of implant users was significantly better than that found in deaf children without implants.

### Growth Rates of Language Following Implantation

Studies have also shown that the rate of language development in children with cochlear implants typically approaches that of normally hearing children. Svirsky et al. (2000) have shown average post-implant-growth rates that match normal hearing children, whereas, others have reported rates that ranged from 45% to 67% of normal growth rates (Blamey et al, 2001; Connor et al., 2000).

### Age of Implantation and Language Development

The improvements in language growth associated with receipt of a cochlear implant suggest that language outcomes will be improved with earlier implantation. This benefit could come from earlier onset of improved growth and/or more rapid growth rates associated with earlier implantation. Children implanted during the preschool and school years have been shown to have better achievement levels and to have steeper rates of growth in speech sound development, vocabulary, and grammatical development than children implanted at older ages (Connor, et al., 2000, Svirsky, 2000; Tye-Murray, Spencer, & Woodworth, 1995). These studies provided support for the benefits of implantation prior to the age of 5. Recently, Moog and Geers (1999) reported that variation in age of implantation between 2 and 4 years of age was not associated with differential language outcomes at 8 years of age.

At this time there have been few studies reporting the benefits of children implanted before the age of 2 years despite the fact that implantation at 12 months of age is becoming common. Of particular interest is whether the benefits of very early implantation take advantage of an early sensitive period in language development that may result in more rapid language growth rates.

### Objectives of Current Study

This study was concerned with the following questions

- Are children implanted prior to 4 years of age approaching levels of language achievement found in children with normal hearing?
- Does earlier implantation result in improved rates of language development ?

## Methods

### Participants

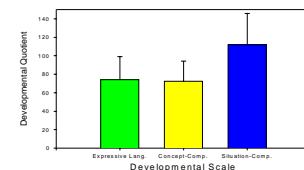
- 27 children with severe to profound hearing loss prior to 18 months of age, 12 girls and 15 boys.
- 6 children were users of the Nucleus 24M (straight electrode array) and 21 were fitted with the Nucleus 24R (contour electrode array) cochlear implants
- Age of receipt of cochlear implant: Mean = 23 months (range 13 - 40 months)

## Results

### Terminal Post-Implant Developmental Quotients

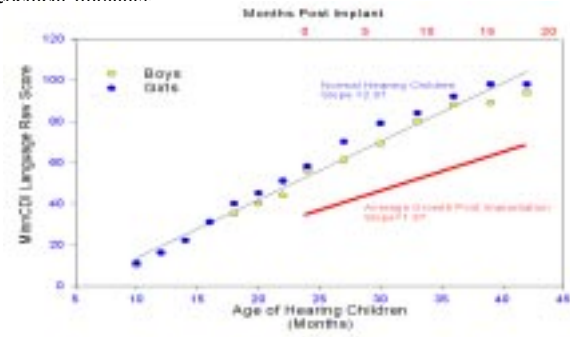
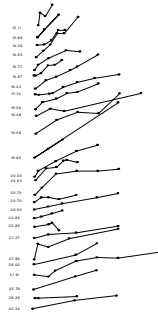
Developmental quotients from the *MinnCDI* for the children's last post-implant interval are shown in Figure 2. These data show that the average language quotient for the participants on each of the two language scales was below that of normally hearing age mates. This level of development contrasted with the developmental quotient obtained for "Situation Comprehension" where developmental levels were slightly above age expectations. The "Expressive Language Scale" was negatively correlated with the child's age at implantation ( $r = -.59, p = .001$ ). "The Comprehension-Conceptual Scale" was also weakly negatively correlated with implant age ( $r = -.27, p = .16$ ). Thus, short-term language outcomes, particularly expressive language are improved as the age of implantation is provided at an earlier age. The "Situation Comprehension Quotient" was not significantly correlated with age of implantation ( $r = .13, p = .51$ ).

Figure 1. Mean developmental quotients at last observation post-implant (Ave 17.25 mo.)

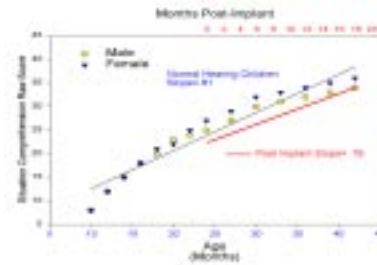


## Growth of Total Language and Situation Comprehension Post Implantation

The growth rates of composite language and situation comprehension are shown in Figures 2 and 3. Growth rates for hearing children are plotted along with the individual and average growth rates for children with cochlear implants.



Figures 2 (above) and 3 (below). Data in right panels show average composite language (above) and situation comprehension (below) growth rates for normally hearing children (blue and yellow circles). Average post-implant growth rate for children with cochlear implants are represented by the red lines. The panels on the left contain individual language (above) and situation comprehension (below) growth curves for each implanted child.



The individual growth rates for children with cochlear implants were analyzed using Proc Mixed of SAS. Results of these analyses are shown in Tables 1 and 2. Using an unconditional model, this analysis revealed that the growth rate for composite language in children with cochlear implants averaged 1.86 points per month of post-implant experience. As shown in Figure 2, this rate was 65% below the rate of normal hearing children (2.87 points per month). In contrast, these children with implants obtained an average unconditional growth rate of 0.62 points per month for the situation comprehension scales in comparison to 0.87 for hearing children or a difference of 71%. Thus, despite different terminal quotients, language and situation comprehension growth rates were similar. The difference in terminal quotients can be attributed to higher intercept levels at implantation for situation comprehension.

	Effect	Coefficient	Standard Error	t ratio
Unconditional Model	Intercept	36.81	3.42	10.75**
	Growth Rate Post Implant (Mo.)	1.86	.18	10.25**
Conditional Model	Intercept	35.1	2.29	15.29**
	Growth Rate Post Implant (Mo.)	1.87	0.14	13.25**
	Age of Implantation (Mo.)	1.64	0.28	5.81**
	Effect of Implant Age on Post Implant Growth Rate	-0.64	0.188	-3.41*

Tables 1 (left) and 2 (right). Parameter estimates and tests of significance for unconditional and condition models of language (Table 1) and situation comprehension (Table 2).

	Effect	Coefficient	Standard Error	t ratio
Unconditional Model	Intercept	23.12	1.34	17.24**
	Growth Rate Post Implant (Mo.)	0.62	0.06	10.30**
Conditional Model	Intercept	22.20	0.57	38.81**
	Growth Rate Post Implant (Mo.)	0.65	0.04	15.88**
	Age of Implantation (Mo.)	.76	0.07	10.57**
	Effect of Implant Age on Post Implant Growth Rate	-0.03	0.006	-4.71*

## Age of Implantation and Rate of Language and Conceptual Growth

The influence of early implantation on development was examined by including the effects of age of implantation and the interaction of age of implantation with growth rate post-implantation in the mixed model. Table 1 shows that language scores increased by 1.64 points for every month delay in implantation. Growth rates subsequent to implantation averaged 1.87 points per month. A significant negative interaction between growth rate post-implantation and age of implantation indicates that children implanted later had poorer growth rates than those who were implanted earlier. For each month of earlier implantation, growth slopes increased by .064 points per month. Thus, children implanted 10 months earlier than the average child (23 months) would be expected to have a growth rate of 2.28 or 79% of average. Age of implantation was also found to affect the rate of situation comprehension growth rate. Earlier implantation was associated with higher rates of growth as shown in Table 2. Thus, the effect of earlier implantation appeared to benefit a wide range of developmental abilities.

## Discussion

This study found that infants and toddlers with short-term experience with cochlear implants remain behind their hearing peers with respect to language development but are more similar to their hearing age mates with respect to nonverbal concept comprehension. The growth rate found for this group was quite similar to those reported for other preschool age children with cochlear implants.

The principal interest in this study was whether rates of language development would differ according to the age at which the child was implanted. Prior research using older children has shown that earlier implantation is associated with more rapid growth rates, suggesting that better learning conditions exist for younger children. The current data showed that this beneficial effect of earlier implantation extends below two years of age. The learning conditions that may account for this benefit may involve the presence of more optimal neural substrates for language learning either because of greater general neural plasticity and/or the prevention of neural loss due to auditory/linguistic deprivation. It is also possible, that more natural language learning environments are generated around infants who are able to respond appropriately to those around them. Thus, the language learning environments of children receiving cochlear implants at an early age may be more effective in providing them with needed language experience.

