Does Age Matter with Cochlear Implants? [STUDY]

Cochlear Implantation in Young Children: Effects of Age at Implantation and Communication Mode

Karen Iler Kirk, Richard T. Miyamoto, Elizabeth A. Ying, Amy E. Perdew, and Helen Zuganelis

Abstract

This study examined the effects of age at implantation on the development of communication abilities in early-implanted children. The 106 participants were prelingually deafened and used current cochlear implant technology. The children were administered a battery of speech and language outcome measures prior to implantation and again at successive six-month postimplant intervals. A mixed model analysis was used to examine the rate of growth in word recognition and language skills as a function of age at time of implantation. Results revealed significant improvements in communication skills over time. Spoken word recognition improved at a faster rate in the children implanted at five years of age or older, possibly because they were more likely to be familiar with the test vocabulary. In addition, the rate of spoken word development was significantly greater for children who used oral communication than for children who used total communication. Age effects on the development of receptive and expressive language differed from those on spoken word recognition. That is, the earliest implanted children showed more rapid rates of language development, or superior skills overall. Children implanted prior to 2 years had significantly faster rates of receptive vocabulary and language development than later-implanted children. Furthermore, children implanted prior to age 2 years had superior expressive language abilities compared to those who were implanted after that age. There were no significant differences in rates of language development between the oral and total communication groups.

Effects of Age at Implantation and Communication Mode

It has been more than 20 years since the first child received a cochlear implant in the United States. Since that time, there have been tremendous technological advances in the field. Cochlear implant recipients and their families now have several different cochlear implant manufacturers from which to select a cochlear implant system. Furthermore, each manufacturer offers an array of electrode and speech processing options that can provide substantial levels of open-set word recognition to the children who receive them (Cohen, Waltzman, Roland, Staller, & Hoffman, 1999; O’Donoghue, Nikolopolous, Archbold, & Tait, 1998; Osberger, Zimmerman-Phillips, Barker, & Geier, 1999; Young, Carrasco, Grohne, & Brown, 1999).

Cochlear implant candidacy criteria also have changed greatly in the last two decades. As scientists and clinicians learned more about the benefits of cochlear implantation, criteria were broadened to include ever-younger groups of children and those with more residual hearing. Current FDA candidacy guidelines permit the implantation of children with profound deafness as young as 12 months of age; implantation of patients with severe-to-profound hearing loss is permitted in children aged 2 years and above. This evolution in cochlear implant candidacy provides more children than ever before with the potential to develop spoken word recognition and language processing using auditory input from a cochlear implant. Furthermore, the rate of auditory skills development seems to be increasing as cochlear...
implant technology improves and as children are implanted at a younger age. Early studies reported significant increases in the discrimination of nonsegmental speech cues after only six months of implant use. However, significant increases in the discrimination of vowels and consonant features were not evident until 1.5 years of cochlear implant experience and auditory-only open-set skills continued to improve long after this time period. More recent studies have shown that many children achieve open-set speech recognition within the first year of device use (Miyamoto, Kirk, Svirsky, & Sehgal, 1999; Osberger, Fisher, Zimmerman-Phillips, Geier, & Barker, 1998) but these skills still continue to develop over time (Fryauf-Bertschy, Tyler, Kelsay, & Gantz, 1992; Fryauf-Bertschy, Tyler, Kelsay, Gantz, & Woodworth, 1997; Gantz, Tyler, Woodworth, Tye-Murray, & Fryauf-Bertschy, 1994; Miyamoto, Kirk, Robbins, Todd, & Riley, 1996; Miyamoto et al., 1994; Miyamoto et al., 1996; Osberger et al., 1996). Miyamoto et al. (1996) noted continued improvements in spoken word recognition even after five years of multichannel cochlear implant use. These findings highlight the need to conduct longitudinal studies in order to determine the ultimate benefits of implant use in children.

Despite the improvements in the field of cochlear implantation in children, large variability still exits in pediatric cochlear implant outcomes (Fryauf-Bertschy et al., 1997; Meyer, Svirsky, Kirk, & Miyamoto, 1998; Pyman, Blamey, Lacey, Clark, & Dowell, 2000). At present, it is not possible to predict the benefits of cochlear implant use in an individual child prior to implantation. At Indiana University, we have been conducting ongoing research for more than 15 years to document cochlear implant outcomes and to identify factors that contribute to individual differences in performance. Identifying such factors will have an important impact on determining candidacy and designing appropriate intervention strategies for this population.

One of the most important factors shown to influence the development of communication abilities in pediatric cochlear implant recipients is age at time of implantation (Gordon, Daya, Harrison, & Papsin, 2000; O'Donoghue et al., 1998). Previous work in our laboratory and others demonstrated that children implanted prior to 5 years of age achieve significantly better communication outcomes than children implanted after that age (Fryauf-Bertschy et al., 1997; Kirk, Pisoni, & Miyamoto, 2000; Miyamoto et al., 1997). Fryauf-Bertschy et al. (1997) found that closed-set word recognition performance did not differ between children implanted before and after 5 years of age. However, children implanted prior to age 5 had significantly better open-set word recognition than did the later-implanted. Similar results were reported by Miyamoto et al. (1997).

More recently, researchers have examined the effects of age at implantation on spoken word recognition in children who all were implanted prior to age 5 years (Kirk et al., in press; Waltzman & Cohen, 1998). Waltzman and her colleagues have conducted several studies to examine the speech perception abilities of children implanted between the ages of 2 and 5 years (Waltzman & Cohen, 1998). They found that the speech perception abilities of 11 children who were implanted prior to age 2 years increased significantly from preimplant to their latest postimplant interval.

Effects of age at implantation are not limited to the development of speech perception or spoken word recognition skills. A number of investigators have demonstrated that earlier implantation has a positive impact on the development of both receptive and expressive language skills. For example, Svirsky and his colleagues (Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000) found that prior to cochlear implantation, children with profound prelingual deafness developed language abilities at approximately half the rate of their peers with normal hearing. However, after cochlear implantation, the average rate of language development by the pediatric cochlear implant recipients was similar to that of their normally hearing peers. These results suggest that early implantation will reduce or prevent the language delays typically seen in young children with profound deafness.

Kirk et al. (in press) examined the rate of language development in 73 children with prelingual deafness who were implanted either before or after 3 years of age. Results revealed that children implanted prior to 3 years had significantly faster rates of language development than later-implanted children.

Two additional demographic factors that influence communication development in children with cochlear implants are communication mode and residual hearing. Children with prelingual deafness who use oral communication generally achieve significantly higher levels of speech perception, speech production, and/or language skills than their deaf peers who use total communication, that is, the combined use of signed and spoken English (Kirk et al., in press; Osberger & Fisher, 2000;
Tobey et al., 2000; Young, Grohne, Carrasco, & Brown, 2000).

The present study extends the work of Kirk et al. by examining whether there are sensitive periods for cochlear implantation prior to the age of three years in a large number of early-implanted children. Previous studies have determined that children with cochlear implants who use oral communication typically develop better speech perception and language skills than those who use total communication (Hodges, Ash, Balkany, Schloffman, & Butts, 1999; Osberger & Fisher, 2000). A secondary aim of this study was to examine the effects of communication mode on the development of speech perception and language skills in early-implanted children.

Methods

Participants

Participants in this investigation were a subset of children followed longitudinally at Indiana University School of Medicine in studies of pediatric cochlear implant outcomes. All children in our longitudinal study are prelingually deafened and have a severe to profound hearing loss with no additional handicapping conditions. In addition, the children in this investigation were those who were fit originally with the current generation of cochlear implant speech processors and speech processing strategies (i.e., SPEAK, ACE, or CIS). Children who used previous-generation speech processors, or those who previously used earlier versions and then upgraded to current cochlear implant speech processors/strategies were excluded from participation. The number of children who met all of these criteria was 106.

Participants were grouped according to their communication method (oral communication vs. total communication, or the combined use of signed and spoken English). Within each communication group, the children were further stratified into three groups by their age at time of implantation. The CI<2 groups received a cochlear implant prior to age 2;0 (years;months), the CI 2-4 groups received a cochlear implant between the ages of 2;0 and 4;11, and the CI > 5 groups received a cochlear implant at age 5 years or older. Table 1 presents the averaged demographic characteristics of children in the oral and total communication groups separately as a function of age at implantation. Their device characteristics are presented in Table 2.

Stimulus Materials and Procedures.

Children in our longitudinal studies are administered a battery of speech and language tests prior to implantation and every 6 months following implantation for at least 3 years. For the present study, data from two measures of spoken word recognition and from two measures of receptive and expressive language were analyzed.

Spoken Word Recognition Tests. The goal of spoken word recognition testing is to determine a child’s ability to understand and repeat speech presented through listening alone. Prior to actual testing, children are provided with test instructions in their preferred modality (using audition and speech reading for oral children, or simultaneous signed and spoken English for children who use total communication). During test administration, the examiner obscures her/his face with a mesh screen to eliminate the use of speechreading cues.

The Grammatical Analysis of Elicited Language-Presentence Level (GAEL-P) (Moog, Kozak, & Geers, 1983) has been adapted for use as a closed-set spoken word recognition task. Children are first familiarized with the 30 objects (toy clothing, food, animals, furniture, etc.) in the auditory-plus-visual modality. During test administration, the 30 stimulus items are presented in sets of four objects and the child must identify the target word through listening alone. Children respond by selecting one of the four items they believe matches the target word. The four-item set changes after each trial to prevent the child from using a process of elimination strategy. The item presentation has been reordered from that suggested by Moog et al. (1983) so that the 11 multisyllabic words are presented first, followed by the 19 monosyllabic words. This eliminates using syllable number as a cue and forces the child to rely primarily on segmental cues for word recognition.

The Mr. Potato Head task (Robbins, 1994) is a modified open-set measure of spoken word recognition consisting of a plastic potato “body” with approximately 30 body parts and accessories. The children are asked to assemble the Mr. Potato Head toy in response to 10 verbal commands presented in the auditory-only modality (e.g., “Give him some green shoes”). There are three alternative lists of 10 commands. This task is considered a modified open-set test because the number of items that can be
used is large but not unlimited. Although a child could choose the
correct object by chance, it is highly unlikely. The child’s responses
are scored as the percent of key words or sentences correctly
identified. For example, if the child responded to the above
command by touching the green shoes he or she would get credit
for a key word but not for a sentence.

Measures of Receptive and Expressive Language. In contrast
to the spoken word recognition tests above, language measures
in our test battery are administered in the child’s preferred
modality. Oral children are provided with access to auditory and
speechreading cues during both test instructions and testing.
Children who use total communication are instructed and tested
in simultaneous spoken and signed English. All language measures
in our battery yield raw scores that can be converted to an age
equivalency using normative data obtained from normal hearing
children. In our longitudinal study, these age equivalency scores
are then converted to language quotients by dividing the child’s
language age by his or her chronological age. This is done to
control for the differences in language performance as a function
of age. Language quotients less than 1.0 (where the language
age is less than the chronological age) indicate delayed language
development. Language quotients greater than one indicate
that the language age is greater than the chronological age. The
language measures used in the present study are described below.

The Peabody Picture Vocabulary Test-III (PPVT) (Dunn &
Dunn, 1997) is a measure of receptive vocabulary. During test
administration, the child is shown a series of picture plates, each
containing four pictures. They are presented with one word per
picture plate and asked to point to the picture that matches the
target word. The child’s raw score is converted to a receptive
vocabulary age using normative data provided.

The Reynell Developmental Language Scales (Reynell & Huntley,
1985) is a test of receptive and expressive language developed for
children with normal hearing. It has been used extensively with
children with hearing impairment. The Reynell requires children
to comprehend or express a hierarchy of language structures
ranging from object labeling to complex instructions. This test is
thought to reflect the kinds of communication demands children
might face in daily living. The Reynell yields raw scores that can
be converted to separate receptive and expressive age equivalency
scores using the normative data provided.

Data Analyses

Data analyses utilized analyses of variance with repeated
measurements. In the model, subject was considered a
random effect; length of device use, age at implantation,
and communication mode were the covariates. A compound
symmetry covariance structure was assumed for the observations
within subject. The dependent measures were the scores on the
GAEL-P, Mr. Potato Head task, PPVT, and the Reynell. For each
dependent measure, the model tests whether there is an effect of
age at implantation group, an effect of communication mode, and
whether the rate of improvement in scores is the same within each
age-at-implantation group.

The number of data points varied across tests and across children
for several reasons. First, children in the study had used their
cochlear implants for differing lengths of time and therefore, the
number of times they were tested at 6-month intervals varied
as well. Second, not every child was available for testing at every
interval. Finally, we were not always able to administer all of the
tests in our battery to every child due to time constraints on the
part of the family, the child’s attention span, etc. The number of
children from whom data were analyzed varied from 86 for the
GAEL-P to 103 for the Reynell.

Results

Spoken Word Recognition

Figure 1 illustrates the average rate of improvement in GAEL-P
scores as a function of age-at-implantation group for the two
communication groups. The rate of improvement in closed-set
spoken word recognition skills was similar between the oral and
total communication groups. However, the children who used
oral communication had significantly higher GAEL-P scores
overall than did the children who used total communication, after
adjusting for length of device use and age-at-implantation group
(\(p < .02\)).

Overall, the children demonstrated significant improvements in
their ability to recognize words from a closed-set with increased
device use (\(p < .0001\)). At the preimplant intervals, the average
GAEL-P scores were near chance levels of performance, 25%
words correct. Following 2 years of device use, the average
GAEL-P scores ranged from approximately 35% for the children implanted before the age of 2 years to approximately 60% words correct for the children implanted at 5 years or later. Although Figure 1 suggests that the children implanted at an older age (and thus tested at an older age) had higher GAEL-P scores, this trend was not significant. Finally, there was no interaction between age at time of implantation and length of device use. That is, the rate of improvement in closed-set word recognition skills was not significantly influenced by the age at time of implantation. This is evidenced by the similar slopes of the growth lines among the three age-at-implantation groups in Figure 1.

Performance on the open-set word recognition test, the Mr. Potato Head task, is shown in Figure 2 for both communication groups. For both the communication groups, spoken word recognition performance improved significantly with increased length of device use ($p < .0001$). The effect of age at implantation also was significant ($p < .02$). On average, children who were older at the time of implantation, and thus older at the time of testing, had higher open-set word recognition scores, both at the initial testing and over time. There was no interaction between age at implantation and length of device use, indicating that the rate of improvement in open-set word recognition abilities did not differ among the three age-at-implantation groups. Finally, there was a significant effect of communication mode on open-set spoken word recognition performance ($p < .01$). Oral children had significantly higher open-set word recognition scores than did children who used total communication.

Receptive and Expressive Language

Figure 3 plots the growth in receptive vocabulary knowledge over time as a function of age at time of implantation for the two communication groups. Specifically, the figure shows the rate of growth in the language quotients obtained on the PPVT over time. Recall that language quotients are derived by dividing the child’s language age equivalency score on the test measure by his or her chronological age. Children in all three age-at-implantation groups had average language quotient scores of less than 1.0, indicating delayed receptive vocabulary knowledge relative to their chronological age. There was no effect of communication mode on the rate of receptive vocabulary growth of the children. For both communication groups, language quotients derived from PPVT age equivalency scores increased significantly with increased length of device use ($p < .001$). This suggests that children were reducing the gap between their receptive vocabulary age and their chronological age with increased cochlear implant use. There was a significant effect of age at implantation on the rate of growth in receptive vocabulary. Post hoc analyses revealed that children who were implanted at 5 years of age or older had significantly higher language quotients (ranging from about 0.5 to 0.6) than children in the two younger age-at-implantation groups (ranging from about 0.1 to 0.3) ($p < .03$). However, there also was a significant interaction between age at time of implantation and length of device use ($p < .0001$). Pairwise comparisons revealed that children who were implanted prior to age 2 years had significantly faster rates of growth in PPVT language quotient scores than children implanted between 2 and 4 years of age ($p < .0001$), or those implanted at 5 years or older ($p < .0001$).
Figure 4 illustrates the growth in Reynell receptive language quotient scores over time as a function of age at implantation for the two communication groups. Overall, there was a significant increase in receptive language skills over time ($p < .0001$). There were no significant effects of age at implantation or communication mode on receptive language skills. However, there was a significant interaction between age at implantation and length of cochlear implant use ($p < .0001$). As shown in Figure 4, children implanted prior to age 2 years began the study with the lowest Reynell receptive language quotients, approximately 0.4, suggesting that their receptive vocabulary age was less than half that of their chronological age. Pairwise comparisons revealed that the rate of improvement in Reynell receptive language quotients over time increased significantly faster for children implanted prior to age 2 years than those implanted between 2 and 4 years ($p < .0001$) or at five years of age or older ($p < .0001$). The growth rate of Reynell receptive language quotients did not differ between children in the two older age-at-implantation groups. After two years of cochlear implant use, the average language quotients of the children implanted prior to age two years surpassed the language quotients of children implanted between 2 and 5 years of age.

Figure 5 illustrates the rate of improvement in Reynell expressive language quotients as a function of age at implantation for the two communication groups. Children in this study demonstrated significant improvements in expressive language abilities with increased cochlear implant use ($p < .0001$). Age at implantation had a significant effect on the development of expressive language abilities ($p < .01$). Children who were implanted prior to 2 years of age had the highest expressive language quotient scores at baseline and at subsequent test intervals. Pairwise comparisons revealed that children implanted before the age of 2 years had significantly higher Reynell expressive language quotients than children implanted between 2 and 4 years ($p < .01$) or children implanted at 5 years or later ($p < .04$). There was no significant difference between the Reynell expressive language quotients of children in the two older age-at-implantation groups. Overall, there was no significant effect of communication mode and no significant interaction between age at implantation and length of cochlear implant use on the development of expressive language abilities.
Discussion

One of the most consistent findings among studies examining the benefits of cochlear implant use in children is that performance improves significantly over time (Fryauf-Bertschy et al., 1997; Miyamoto et al., 1994). The prelingually deafened children in the present investigation obtained significant improvements in spoken word recognition and receptive and expressive language skills following cochlear implantation. Furthermore, communication skills improved significantly with increased cochlear implant use. The present study revealed significant age at implantation effects on spoken word recognition and language outcomes, but in opposite directions.

Spoken Word Recognition Outcomes

The open-set word recognition abilities of children in the oldest age at implantation group, those implanted at 5 years of age or older, were significantly higher than those of children who were implanted prior to that age. There are several possible reasons for this outcome. First, children who are implanted at a very young age may not be familiar with the vocabulary used on the tests. Older children may be more familiar with the vocabulary and thus better prepared for the tasks required. Second, very young children may not be developmentally ready to participate in a formal testing situation, even when it takes the form of a play activity. The difficulties in testing very young children were demonstrated by Robbins and Kirk (1996). They found that children with normal hearing could not perform with 100 percent accuracy on the Mr. Potato Head task until about 3.5 years of age. They suggested that this was due in part to the vocabulary demands of the task, such as identifying objects by color (e.g., “green shoes”). At present, many cochlear implant clinicians and researchers must rely on parent questionnaires to assess communication abilities in young cochlear implant candidates and recipients. Although parent insights can be extremely valuable, objective measures also are needed when determining cochlear implant benefit in deaf infants and toddlers. Such tasks are now under development in our laboratory.

Performance on both spoken word recognition measures, the closed-set GAEL-P, and the open-set Mr. Potato Head task, was significantly influenced by the method of communication employed by the children. Children who used oral communication had significantly higher word recognition scores at baseline and over time than did the children who used total communication. This finding is consistent with the results of previous studies (Kirk et al., in press; Osberger & Fisher, 2000; Tobey et al., 2000; Young, Grohne, Carrasco, & Brown, 2000).

Receptive and Expressive Language Outcomes

As mentioned above, children in the present study achieved significant postimplant gains in their receptive vocabulary knowledge, as measured by the PPVT, and in receptive and expressive language abilities, as measured by the Reynell. For all three language assessment areas, the average language quotient scores for each age at implantation group were less than 1.0 throughout the approximately two years of device use covered by the investigation. This indicates that on average, the children’s language age is below their chronological age. However, it is important to note that there was a significant gain in language quotient scores for receptive vocabulary, receptive language and expressive language skills over time. This finding suggests that the gap between the children’s language abilities and their chronological age narrows with increased cochlear implant use. There was a significant age at implantation effect on the receptive vocabulary skills of the children in this study. Children who received a cochlear implant at or after 5 years of age had higher language quotient scores on the PPVT than did the children implanted before 2 years or between 2 and 4 years of age. However, there was a significant interaction between age at implantation and length of device use. The children implanted under the age of 2 years may have had poorer vocabulary skills compared to their peers implanted at a later age, but they demonstrated a significantly more rapid gain in receptive vocabulary knowledge following cochlear implantation. It appears that vocabulary skills of the earliest implanted children may eventually catch up to or exceed those of their later-implanted peers with cochlear implants.

Compared to the PPVT, the Reynell assesses a much broader range of language abilities. At the initial levels of the test, children may be asked to perform relatively simple tasks such as selecting an object named by the clinician (e.g., “Show me the doll”) or labeling individual objects. The difficulty increases with each successive level. Thus, children may be asked to comprehend and follow complex instructions (e.g., “Which pencil has not been put
away?”) or to tell about an object’s attributes or produce a story. When growth in language skills was measured with the Reynell, the effects of age at implantation differed across the receptive and expressive components of the task.

Results from the receptive portion of the Reynell demonstrated a significant effect of length of device use and a significant interaction between age at implant and length of device use on the development of receptive language abilities. The rate of growth in the receptive language quotient scores was significantly faster for the children implanted prior to age 2 years than for the children implanted after that age. This suggests that children implanted prior to age 2 are closing the gap between receptive language age and chronological age at a faster rate than the other children in this study. In fact, children implanted at age 5 or after showed very little increase over time in their Reynell receptive language quotients. This does not mean that their receptive language abilities were not improving longitudinally. Rather, it suggests that the gap between their language age and their chronological age remained constant over time.

Expressive language quotient scores on the Reynell increased significantly over time, suggesting that children were narrowing the gap between their expressive language abilities and their chronological age. There was a significant effect of age at implantation on the development of expressive language skills. That is, children who were implanted prior to age 2 years had higher language quotients at both initial testing and over time than did children implanted after that age. This indicates that the gap between their language age and chronological age was smaller than for the children implanted at 2 years or later. Finally, there was no interaction between age at implantation and length of device, demonstrating that children in all three age groups were developing expressive language skills at a similar rate following implantation.

The results concerning age at implantation effects on the development of receptive and expressive language skills measured by the Reynell support and extend the earlier results of Svirsky et al (2000). They found that profoundly deaf children without implants typically had language ages that were similar to normal-hearing children who were about half their chronological age. That is, they made about 6 months gain in language skills over a 1-year time period. However, after implantation, the children with profound deafness began to develop language abilities at a similar rate to their peers with normal hearing; that is, 12 months gain in 12 months time. Svirsky et al. concluded that earlier implantation would help to minimize the gap between language abilities and chronological age in young deaf children. The present Reynell expressive language results in the present study are in agreement with this finding. Children implanted at the youngest age had the highest language quotients, or the smallest gap between language age and chronological age. Results for the receptive portion of the Reynell further suggest that early implantation (prior to age 2 years) may not only prevent increased language delays, but may in fact help to eliminate them. Many early-implanted children in our study demonstrate age appropriate speech and language skills.

For all three language measures, there was no significant effect of communication mode. This contrasts with the results obtained for spoken word recognition. One reason for this discrepancy is that the language measures were administered in the child’s preferred communication modality. It seems likely that children who use total communication rely on the visual input they receive to support the language development. Such visual cues were not available in the spoken word recognition task.

In summary, the present investigation demonstrated that young children with cochlear implants achieve significant gains in their communication abilities over time. The results suggest that very early implantation may not be crucial for the development of spoken word recognition abilities. Further study with more difficult spoken word recognition measures is warranted. In contrast, the present study revealed that very early implantation can have a significant impact on the rate of language development in children with profound deafness. Early implantation appears to minimize initial language delays and to promote the development of age-appropriate skills. With the goal of universal detection of hearing loss in infants by 3 months of age, and appropriate intervention (e.g., amplification) by 6 months of age (Pediatrics, 1994, 1999), we expect that ever-increasing numbers of very young children will be identified as potential implant candidates. We know that early intervention (i.e., by 6 months of age) and early intervention with hearing aids have a significant impact on language development in children with hearing loss (Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998). The present findings suggest that early intervention with cochlear implants is beneficial as well.

Source: The Volta Review, 2002