Research Report

LANGUAGE DEVELOPMENT IN PROFOUNDLY DEAF CHILDREN WITH COCHLEAR IMPLANTS

Mario A. Svirsky, Amy M. Robbins, Karen Iler Kirk, David B. Pisoni, and Richard T. Miyamoto

Department of Otolaryngology-Head and Neck Surgery, Indiana University School of Medicine

Abstract—*Although cochlear implants improve the ability of profoundly deaf children to understand speech, critics claim that the published literature does not document even a single case of a child who has developed a linguistic system based on input from an implant. Thus, it is of clinical and scientific importance to determine whether cochlear implants facilitate the development of English language skills. The English language skills of prelingually deaf children with cochlear implants were measured before and after implantation. We found that the rate of language development after implantation exceeded that expected from unimplanted deaf children (*p $< .001$*) and was similar to that of children with normal hearing. Despite a large amount of individual variability, the best performers in the implanted group seem to be developing an oral linguistic system based largely on auditory input obtained from a cochlear implant.*

Most children who are born profoundly deaf or who become deaf before the age of 3 fall significantly behind their normal-hearing peers in their mastery of the surrounding oral language in its written, read, spoken, and signed forms. Studies of English achievement in this population document significant delays in all language domains (Davis, 1974; Geers, Kuehn, & Moog, 1981; Levitt, McGarr, & Geffner, 1987; Moeller, Osberger, & Eccarius, 1986; Osberger, Moeller, Eccarius, Robbins, & Johnson, 1986). Lexical-semantic and syntactic-morphological abilities have been shown to be severely delayed regardless of whether the profoundly deaf children used oral communication (OC, which excludes the use of manual signs) or total communication (TC, the simultaneous use of oral and manual language). Numerous studies have found that profoundly prelingually deaf children lag in their English language abilities with respect to normal-hearing children. For example, a group of children was tested before and after a 3-year experimental instructional program designed to provide maximum academic achievement under ideal conditions (Moog & Geers, 1985). These children were deaf at birth or before their first birthday, received early amplification and instruction, and had at least average nonverbal intelligence. After training, despite a mean age of 9.92 years, their receptive and expressive language abilities (as tested with the Northwestern Syntax Screening Test, which samples a variety of syntactic English skills; Lee, 1971) were at the level of normal-hearing 4.5- to 6.3-year-olds. Delays in language development were also found in a large-scale study of Stanford Achievement Test Reading Comprehension scores in 8- to 18-year-old hearing-impaired students who received special services in schools throughout the United States. The study showed that by the time these students finished high school, their median reading comprehension levels were below those of average normal-hearing third graders (Allen, 1986).

Until the early 1980s, there was no treatment that would allow profoundly deaf persons to improve their hearing so they could understand speech again. With the advent of multichannel cochlear implants, many people who became deaf as adults were able to recover the ability to understand speech without the aid of lipreading (Eddington, 1980; Kiefer et al., 1997; Loeb & Kessler, 1995; Skinner et al., 1994; Wilson et al., 1991). A cochlear implant is a device that stimulates the auditory nerve electrically to produce hearing percepts. It has an external component that receives incoming sound, processes it according to a predefined strategy (Skinner et al., 1994; Wilson et al., 1991), and transfers the signal across the skin. A small, implanted electronic device receives and decodes the transmitted signal and stimulates electrodes in the cochlea. The electrodes stimulate the auditory nerve directly, bypassing the hair cells that implement the first stage of auditory neural processing in normal ears. The extended use of multichannel cochlear implants in adults brought about the first major success, both scientific and commercial, of a neural sensory prosthesis that replaced a human sense with an electronic device. Most postlingually deafened adult cochlear implant users (i.e., those who learned language before becoming deaf) can understand some speech without lipreading and can also conduct fluent conversations with the aid of lipreading (Skinner et al., 1994). The most successful can communicate fluently over the telephone (Gstoettner, Hamzavi, & Czerny, 1997), a difficult task because there are no visual cues to aid communication and because the acoustic signal is limited in frequency and possibly distorted by the telephone lines.

The use of cochlear implants has been clearly successful in postlingually deafened adults, but several studies demonstrate that multichannel cochlear implants also promote the development of speech perception and speech production in prelingually deafened children (Geers & Tobey, 1995; Osberger et al., 1991; Tyler et al., 1997; Waltzman et al., 1990). Recent studies of early-implanted children using state-of-the-art devices and stimulation strategies show that cochlear implants provide important sensory information to deaf children. For example, Waltzman et al. (1997), in a study of 38 consecutively implanted, prelingually deaf, orally educated children, showed that "all subjects had significant open-set speech recognition at the time of the last postoperative evaluation" (p. 342). Despite this and other studies, pediatric cochlear implantation continues to be criticized by members and advocates of the linguistic and cultural minority called the Deaf World. Members of this culture use a sign language as their primary language and do not see themselves as handicapped: They see their use of a sign language and their hearing

Address correspondence to Mario A. Svirsky, Indiana University School of Medicine, Department of Otolaryngology-Head and Neck Surgery, 702 Barnhill Dr., RR-044, Indianapolis, IN 46202-5200; e-mail: msvirsky@iupui.edu.

impairment as part of normal human variation. Although Deaf World advocates continue to make pessimistic claims about the speech perception skills of pediatric cochlear implant users (Lane & Bahan, 1998), these claims are largely based on studies that provided limited postimplant follow-up, or that employed devices that are now obsolete. Most authors agree that cochlear implants do not restore completely normal sensory information, but they do provide important cues for speech perception. Are the sensory information and the acoustic cues provided by a cochlear implant sufficient for the development of an oral language (English, in our case)? If it could be shown that cochlear implants enhance language development, in addition to just speech perception, this would be compelling evidence for the effectiveness of cochlear implants in the pediatric population. These goals are recognized, albeit implicitly, even by critics of pediatric cochlear implantation who claimed that "in the twelve years since the clinical trials began . . . , not a single case has been reported in the literature of a child acquiring language because of an implant" (Lane & Bahan, 1998, p. 299).

Members of the Deaf World (together with their hearing advocates, such as Harlan Lane in *The Mask of Benevolence*, 1992, and Oliver Sacks in *Seeing Voices*, 1989) object to pediatric cochlear implantation not only on the basis of the device's effectiveness or lack thereof, but also on the basis of an ethical argument. This argument has been articulated with particular sharpness by Lane and Bahan (1998), who have asserted that even if cochlear implants restored perfect hearing to congenitally deaf children, the technique would still be unethical because it might result in the "genocide" of Deaf culture due to the dwindling number of children who might otherwise become a part of the Deaf World and help maintain its viability.

Although we agree that parents of children seeking cochlear implants should seriously consider the perspective of the Deaf community (where "Deaf," so capitalized, makes reference to the Deaf World rather than to hearing impairment), we also think that parents have a right to make decisions on behalf of their children. If a child becomes profoundly deaf before the age of 3 and his or her parents decide to seek a cochlear implant, hoping to maximize the chances that the child will be able to interact in the hearing world, we find it mistaken to label that decision as unethical. Most important, we believe that public discussion must be informed by good science. In the present article, rather than discussing the ethical argument, we focus on the efficacy of the cochlear implant as an aid in the development of English language abilities, which has been recognized as the most important outcome measure by both proponents and opponents of cochlear implants.

However, it is not sufficient simply to document improvement in English language abilities by cochlear implant users, because even unimplanted deaf children do show a limited amount of improvement in English language abilities over time. In a previous study, we measured the English language abilities of 113 profoundly prelingually deaf children of various ages, who used conventional hearing aids instead of cochlear implants. Based on these data, we generated a linear model to predict language age in this population as a function of chronological age, residual hearing, and communication mode (see Svirsky, in press). In the present study, we compared the measured English language development of prelingually deaf children with cochlear implants and these children's predicted English language development had they not received the implants. Finally, the measured English language development of the sample of children with cochlear implants was compared with norms obtained from normal-hearing children.

METHOD

The language abilities of 70 children were assessed about 4 months before they received their cochlear implants, and then again 6, 12, 18, 24, and 30 months after implantation.[1] (Not all children were tested at all intervals because some were not available for testing and others had not yet reached the longer-term follow-up intervals.) Language development was assessed using the expressive section of the Reynell Developmental Language Scales (RDLS; Reynell & Huntley, 1985). This is a widely used standardized test that assesses a variety of language skills and is appropriate for hearing children between 1 and 7 years old. The test was administered in the child's preferred modality of English: either TC (simultaneous use of oral productions and manual signs) or OC (exclusive use of oral productions). This test has three components: structure, which assesses the complexity of expressive language; vocabulary, which assesses the child's ability to name objects and pictures as well as to describe internalized concepts; and content, which assesses the more creative uses of language. Raw scores are converted to a language age score, based on normative data from 1,319 children with normal hearing (Reynell & Huntley, 1985). In addition, spoken word recognition was tested in 18 children at the 2-year follow-up using the PBK word recognition test (Haskins, 1949).

Our first analysis concerned the language development of 23 of the children for whom we had complete data through the 18-month follow-up. To estimate the scores the same children would have obtained without a cochlear implant, we used the predictive model developed in our previous study (Svirsky, in press). As already noted, this model predicts language age as a function of chronological age, residual hearing, and the communication mode employed by the child. Briefly, the model predicts that every month the children with more residual hearing (those with pure-tone thresholds between 90 and 100 dB HL) increase their language age by 0.47 to 0.50 months, and those with less residual hearing (pure-tone thresholds greater than 100 dB HL) increase their language age by 0.38 to 0.41 months. To compare observed and predicted scores, we conducted a two-way repeated measures analysis of variance (ANOVA) in which the factors were testing interval (6 vs. 12 vs. 18 months postimplant) and measure (observed score vs. predicted score). To ensure that the linguistic skills of the cochlear implant users prior to implantation were similar to those of the unimplanted children whose data were used to generate the predictive model, we performed linear and nonlinear regressions to fit all the unimplanted language data (the group of children examined by Svirsky, in press, and the group of 23 children examined in

1. All the children were profoundly deaf before the age of 3. The mean pure-tone average (PTA) threshold was 113 dB HL (i.e., it was 113 dB higher than the mean PTA threshold for an average person with normal hearing), and the mean age at onset of profound deafness was 0.5 years. Only 2 children had a PTA threshold higher than 100 dB HL. Mean age at implantation was 4.5 years. Three children received the Clarion 1.2 device and used the CIS processing strategy. The other 67 children received the Nucleus-22 cochlear implant. At the end of the study, 50 of these Nucleus patients used the SPEAK strategy, 13 used the MPEAK strategy, 2 used the F0F1F2F5 strategy, and the other 2 used the F0F1F2 strategy.

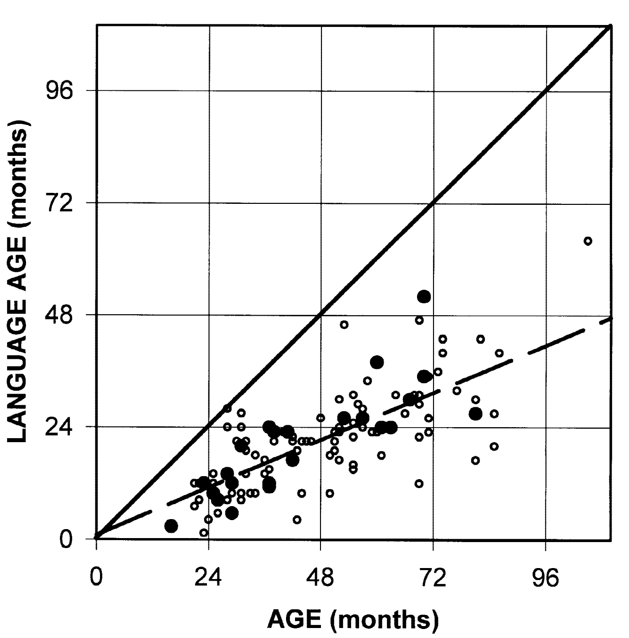

Fig. 1. Language age as a function of chronological age for the 23 cochlear implant users whose data are shown in Figure 2, prior to implantation (black circles), and for the 113 unimplanted deaf children (white circles) in a previous study (Svirsky, in press). The dashed line shows a linear regression of the expressive language scores by chronological age. The mean values for children with normal hearing fall on the solid diagonal line, where language age is equal to chronological age.

this study) as a function of chronological age and group.[2] We found that two separate regression lines, one for each group, did not result in a significantly better fit than using a single regression line. This suggests that the subjects in the present study did not differ from those in the earlier study with regard to their language skills before receiving a cochlear implant.

In the second analysis, we examined data obtained over the entire 2.5-year follow-up period to determine whether the increases in language abilities shown by implanted children were still significantly higher than those expected from unimplanted, profoundly deaf children over a period longer than 18 months. Expressive language gains between two consecutive testing intervals (obtained from all cochlear implant users tested at both intervals) were compared with the predicted gains for both unimplanted profoundly deaf children and normal-hearing children. Two paired-*t* tests were used to assess the significance of these comparisons.

Finally, to assess the relation between spoken word recognition and language development, we used the results from the PBK word recognition test (Haskins, 1949) administered 2 years after implantation. Of the 18 children who took this test, 7 used OC, and the remaining 11 used TC. To factor out the effect of age at testing, we used language quotient (LQ) as a measure of language development. LQ is defined as the ratio between a participant's language age and his or her chronological age. We hypothesized that the large intersubject differences in language development were at least partly due to differences in speech perception ability: In other words, the more children perceive and understand spoken words, the more readily they will develop oral language skills (Levitt, 1987; Levitt et al., 1987; Pisoni, Svirsky, Kirk, & Miyamoto, 1997). This relation was expected to be stronger for users of OC than for users of TC, because the former tend to rely more heavily on auditory information, whereas the latter receive linguistic input through the manual modality, even when speech perception is poor.

RESULTS

The black circles in Figure 1 show language age as a function of chronological age for the 23 children in the first analysis, prior to implantation. The white circles show the data set we used to generate the predictive model of language development in profoundly deaf children without implants (Svirsky, in press). As already indicated, the two groups showed substantial overlap, and there were no significant differences between the groups. Both groups showed substantial language delays, and all data points are below the diagonal. In other words, all of these deaf children showed a gap between their language age and their chronological age, and this gap was greater for older children.

The average language age for the 23 cochlear implant users prior to implantation and at the three postimplant intervals is shown by the black circles in Figure 2. The white circles show the average language age predicted for the same group of subjects at each interval if they had not received a cochlear implant. Note that implanted children lagged behind normal-hearing children (all filled circles fall under the diagonal), but also developed language faster than would be predicted from unimplanted deaf children (filled circles lie above the open circles). A significant interaction term ($p < .001$) in the ANOVA indicated that the difference between observed and predicted scores changed with testing interval. This difference occurred because the observed scores exceeded the predicted scores by a larger amount with each successive interval. Post hoc Newman-Keuls tests indicated that observed scores were significantly higher than predicted scores at the 12- and 18-month postimplant intervals.

Language gains for each 6-month interval during the first 2.5 years after implantation are shown in Figure 3. Cochlear implant users showed greater gains in expressive language than those predicted for unimplanted children, paired $t(170) = 6.602$, $p < .001$. The cumulated gains for cochlear implant users up to 2.5 years postimplant are about the same as those expected from children with normal hearing, paired $t(170) = 0.919$, $p = .36$. When cochlear implant users receive their

2. For example, the following model was employed: language age = slope × age + intercept + intdiff × group + slopediff × group × age, where group is a discrete variable (assuming a value of 0 or 1) indicating which study each data point came from, and slope, intercept, intdiff, and slopediff are the regression parameters. The first two parameters are the slope and intercept for the regression line including only those subjects belonging to the first group, and the second two parameters (intdiff and slopediff) are the numbers that must be added to slope and intercept to obtain a regression line that represents only the subjects in the second group. Slope was the only significant parameter ($p < .001$) when this model was used, indicating that two separate regression lines (one for the data from each study) do not represent the data set any better than a single regression line.

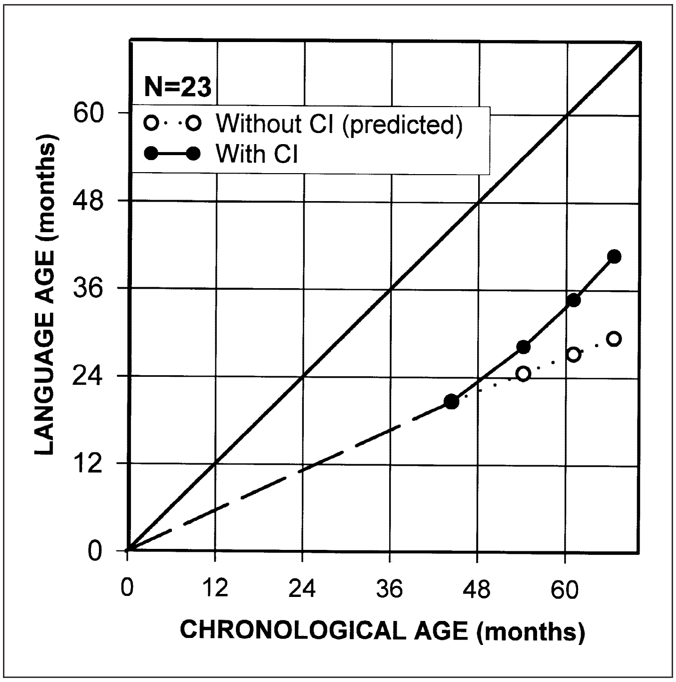

Fig. 2. Average language age as a function of chronological age for the 23 cochlear implant (CI) subjects before implantation and at three intervals after implantation (black circles). The white circles represent the expressive language growth predicted for these same children, had they not received cochlear implants. The solid diagonal line illustrates language growth expected of an average normal-hearing child.

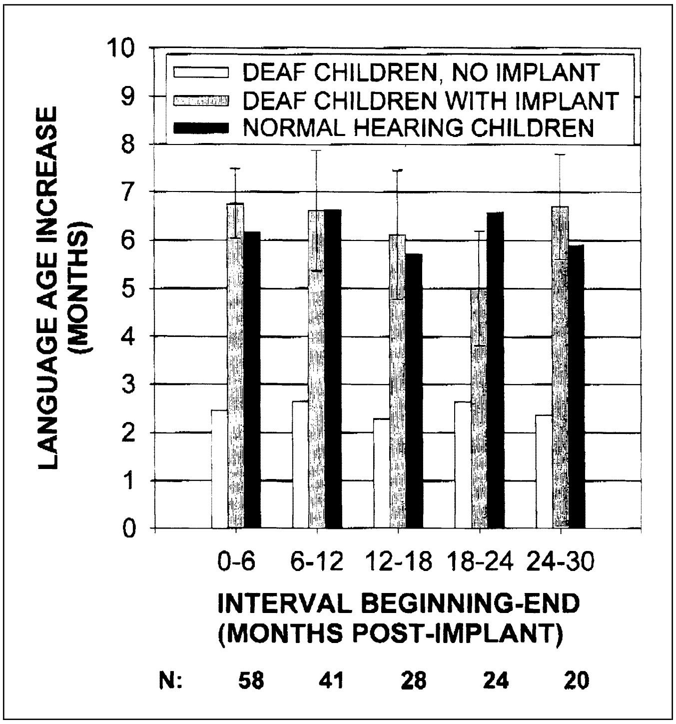

Fig. 3. Average gains in language age for each 6-month period during the first 2.5 years postimplant for the cochlear implant users. The number of children evaluated at each interval (*N*) is shown below the *x*-axis. Also shown are gains expected from normal-hearing children and from unimplanted, profoundly deaf subjects.

implant, they already have a language delay with respect to normal-hearing children. On average, the implant keeps this delay from increasing further. These findings suggest that earlier implantation in deaf children would result in smaller delays in language development.

However, these average results conceal a large amount of individual variability. Figure 4 shows individual data obtained at 2 and 2.5 years postimplant. Some children's language abilities remained severely delayed even after more than 2 years of experience with their cochlear implant, as illustrated in the data points that are well below the lines indicating −1 and −2 standard deviations in the normal-hearing population. However, some children displayed expressive language abilities that were very close to the average values shown by their normal-hearing peers (i.e., some points in Fig. 4 are close to the diagonal).

Figure 5 shows LQ as a function of phoneme recognition scores in the PBK test for users of OC (black circles) and TC (white circles), with the corresponding regression lines. As expected, the correlation between word recognition performance and LQ was very high for the OC group ($r = +.92$) and statistically significant ($p < .01$) despite the small number of subjects. The correlation was smaller for the TC group ($r = +.46$) and failed to reach significance. The difference in the strength of the correlation between word recognition and LQ for the two groups, together with the absolute levels of each parameter, suggest that users of TC may be able to develop their English language skills even when they show very low levels of speech perception (probably because they are developing these skills visually, not orally).

DISCUSSION

The present analyses demonstrate that cochlear implants have a significant beneficial effect on the development of English language in profoundly deaf children. The mean rate of language development in the deaf children after implantation was quite close to that of children with normal hearing, and it exceeded the development rate expected from unimplanted deaf children. Individual LQ scores from implanted children showed a large amount of variability, which may have been related to speech perception: Children who perceive spoken words better are much more likely to approximate normal development of oral language. This effect was much more pronounced in children who used OC, possibly because their language learning is more closely linked to speech perception than that of TC users, who can learn new vocabulary and language rules using manually encoded English even if their speech perception skills are nil. It should be pointed out that RDLS scores obtained from OC and TC users have qualitatively different implications for oral communication. Even when they have the same language skills as their peers who use TC, children who use OC typically have more intelligible speech and higher levels of speech perception (Osberger, Robbins, Todd, & Riley, 1994; Svirsky & Meyer, 1999; Svirsky, Sloan, Caldwell, & Miyamoto, in press). In other words, even though knowledge of the English language's rule systems may be similar in OC and TC users, OC users tend to be better oral communicators. Regardless of whether they used OC or TC, the best performers in the implanted group not only achieved very high levels of speech perception, but also seemed

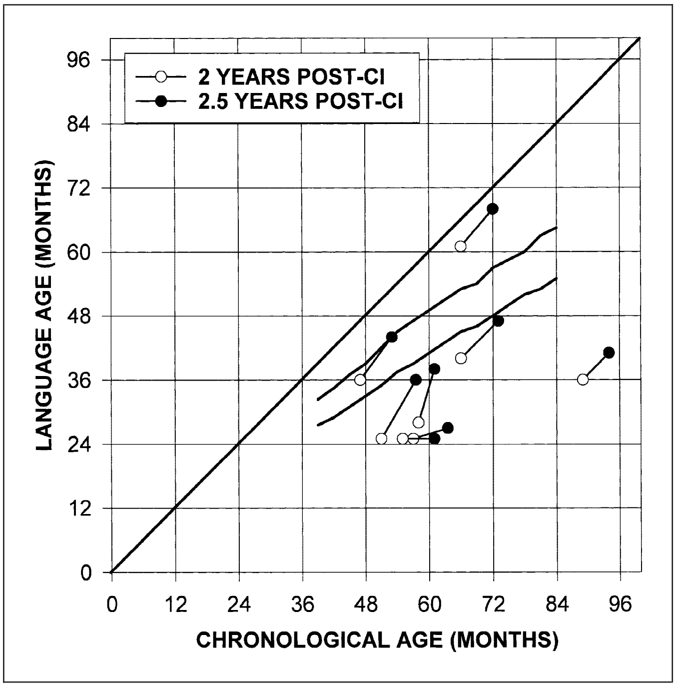

Fig. 4. Individual data measuring changes in language abilities for cochlear implant (CI) users between 2 and 2.5 years postimplant. The two black lines under the diagonal indicate −1 and −2 standard deviations below the mean for the normal-hearing population.

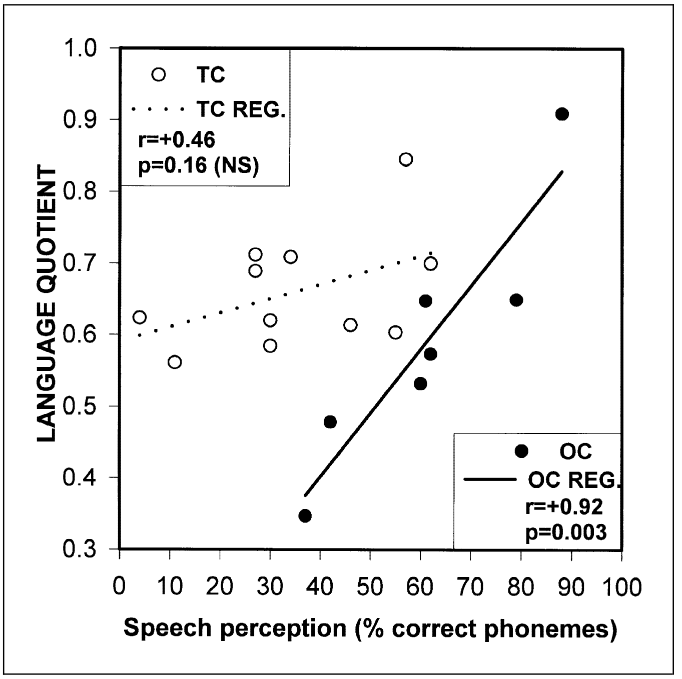

Fig. 5. Language quotient, or the ratio between language age and chronological age, as a function of speech perception performance for children who had used a cochlear implant for 2 years. White and black circles represent users of total communication (TC) and oral communication (OC), respectively. The lines in the graph show the best-fitting regression functions, and the insets show the correlations between speech perception and language quotient for the two groups.

to be developing an oral linguistic system based largely on auditory input from a cochlear implant.

Acknowledgments—This work was supported by National Institutes of Health Grants DC 00064 and DC00423. We appreciate Terri Kerr's assistance with data management and Susan Sehgal's help with data acquisition.

REFERENCES

Allen, T.E. (1986). Patterns of academic achievement among hearing impaired students: 1974 and 1983. In A.N. Schildroth & M.A. Karchmer (Eds.), *Deaf children in America* (pp. 161–206). San Diego: College Hill Press.

Davis, J. (1974). Performance of young hearing-impaired children on a test of basic concepts. *Journal of Speech & Hearing Research*, *17*, 342–351.

Eddington, D.K. (1980). Speech discrimination in deaf subjects with cochlear implants. *Journal of the Acoustical Society of America*, *68*, 885–891.

Geers, A.E., Kuehn, G., & Moog, J.S. (1981). EPIC: Experimental project in the instructional concentration: Evaluation and results. *American Annals of the Deaf*, *126*, 929–964.

Geers, A.E., & Tobey, E.A. (1995). Longitudinal comparison of the benefits of cochlear implants and tactile aids in a controlled educational setting. *Annals of Otology, Rhinology, & Laryngology*, *166*(Suppl.), 328–329.

Gstoettner, W., Hamzavi, J., & Czerny C. (1997). Rehabilitation of patients with hearing loss by cochlear implants. *Radiologe*, *37*, 991–994.

Haskins, H.L. (1949). *A phonetically balanced test of speech discrimination for children*. Unpublished master's thesis, Northwestern University, Evanston, IL.

Kiefer, J., Muller, J., Pfenningdorff, T., Schon, F., Helms, J., von Ilberg, C., Baumgartner, W., Gstoettner, W., Ehrenberger, K., Arnold, W., Stephan, K., Thumfart, W., & Baur, S. (1997). Speech understanding in quiet and in noise with the CIS speech-coding strategy (MED EL Combi-40) compared to the MPEAK and SPEAK strategies (Nucleus). *Advances in Oto-Rhino-Laryngology*, *52*, 286–290.

Lane, H., & Bahan, B. (1998). Ethics of cochlear implantation in young children: A review and reply from a DEAF-WORLD perspective. *Otolaryngology—Head and Neck Surgery*, *119*, 297–313.

Lane, H.L. (1992). *The mask of benevolence: Disabling the deaf community*. New York: Knopf.

Lee, L.L. (1971). *NSST manual*. Evanston, IL: Northwestern University Press.

Levitt, H. (1987). Interrelationships among the speech and language measures. *ASHA Monographs*, *26*, 123–139.

Levitt, H., McGarr, N., & Geffner, D. (1987). Development of language and communication skills in hearing-impaired children: Introduction. *ASHA Monographs*, *26*, 1–8.

Loeb, G.E., & Kessler, D.K. (1995). Speech recognition performance over time with the Clarion cochlear prosthesis. *Annals of Otology, Rhinology, & Laryngology*, *166*(Suppl.), 290–292.

Moeller, M.P., Osberger, M.J., & Eccarius, M. (1986). Language and learning skills of hearing-impaired students: Receptive language skills. *ASHA Monographs*, *23*, 41–53.

Moog, J., & Geers, A. (1985). EPIC: A program to accelerate academic progress in profoundly hearing-impaired children. *Volta Review*, *87*, 259–277.

Osberger, M.J., Miyamoto, R.T., Zimmerman-Phillips, S., Kemink, J.L., Stroer, B.S., Firszt, J.B., & Novak, M.A. (1991). Independent evaluation of the speech perception abilities of children with the Nucleus 22-channel cochlear implant system. *Ear & Hearing*, *12*(Suppl. 4), 66–80.

Osberger, M.J., Moeller, M.P., Eccarius, M., Robbins, A.M., & Johnson, D. (1986). Language and learning skills of hearing-impaired students: Expressive language skills. *ASHA Monographs*, *23*, 54–65.

Osberger, M.J., Robbins, A.M., Todd, S.L., & Riley, A.I. (1994). Speech-intelligibility of children with cochlear implants. *Volta Review*, *96*, 169–180.

Pisoni, D.B., Svirsky, M.A., Kirk, K.I., & Miyamoto, R.T. (1997, May). *Looking at the "Stars": A first report on the intercorrelations among measures of speech perception, intelligibility and language in pediatric cochlear implant users*. Paper presented at the Vth International Cochlear Implant Conference, New York.

Reynell, J.K., & Huntley, M. (1985). *Reynell Developmental Language Scales* (2nd ed.). Windsor, United Kingdom: NFER-Nelson.

Sacks, O.W. (1989). *Seeing voices: A journey into the world of the deaf*. Berkeley: University of California Press.

Skinner, M.W., Clark, G.M., Whitford, L.A., Seligman, P.M., Staller, S.J., Shipp, D.B., Shallop, J.K., Everingham, C., Menapace, C.M., Arndt, P.L., Antogenelli, T., Brimacombe, J.A., Pijl, S., Daniels, P., George, C.R., McDermott, H., & Beiter, A.L. (1994). Evaluation of a new spectral peak coding strategy for the Nucleus 22 channel cochlear implant system. *American Journal of Otology*, *15*(Suppl. 2), 15–27.

Svirsky, M.A. (in press). Language development in children with profound and prelingual hearing loss, without cochlear implants. *Annals of Otology, Rhinology, & Laryngology*.

Svirsky, M.A., & Meyer, T.A. (1999). Comparison of speech perception in pediatric CLARION cochlear implant and hearing aid users. *Annals of Otology, Rhinology, & Laryngology*, *177(*Suppl.), 104–109.

Svirsky, M.A., Sloan, R.B., Caldwell, M., & Miyamoto, R.T. (in press). Speech intelligibility of prelingually deaf children with multichannel cochlear implants. *Annals of Otology, Rhinology, & Laryngology*.

Tyler, R.S., Fryauf-Bertschy, H., Kelsay, D.M., Gantz, B.J., Woodworth, G.P., & Parkinson, A. (1997). Speech perception by prelingually deaf children using cochlear implants. *Otolaryngology—Head & Neck Surgery*, *117*, 180–187.

Waltzman, S., Cohen, N.L., Spivak, L., Ying, E., Brackett, D., Shapiro, W., & Hoffman, R. (1990). Improvement in speech perception and production abilities in children using a multichannel cochlear implant. *Laryngoscope*, *100*, 240–243.

Waltzman, S.B., Cohen, N.L., Gomolin, R.H., Green, J.E., Shapiro, W.H., Hoffman, R.A., & Roland, J.T., Jr. (1997). Open-set speech perception in congenitally deaf children using cochlear implants. *American Journal of Otology*, *18*, 342–349.

Wilson, B.S., Finley, C.C., Lawson, D.T., Wolford, R.D., Eddington, D.K., & Rabinowitz, W.M. (1991). Better speech recognition with cochlear implants. *Nature*, *352*, 236–238.

(RECEIVED 6/2/99; ACCEPTED 7/27/99)