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**Improvements in Speech Perception in Prelingually-Deafened Children:
Effects of Device, Communication Mode, and Chronological Age¹**

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Improvements in Speech Perception in Prelingually-Deafened Children: Effects of Device, Communication Mode, and Chronological Age

Abstract. Miyamoto, Osberger, Todd, Robbins, Karasek et al. (1994) compared the speech perception skills of children with profound prelingual deafness who had received the Nucleus multichannel cochlear implant (CI) to those who were not implanted and used conventional hearing aids (HA). The CI users were tested over time and the HA users were tested at a single point in time. They found that the CI users improved their scores on speech perception tasks a great deal over time. After about 2.5 years of device use, the CI users were performing better than the average performance from a group of Silver (PTA=104 dB HL) HA users on all tests, and their scores were approaching the average scores from a group of Gold (PTA=94 dB HL) HA users except on tests of open-set sentence recognition.

The present investigation expanded on the earlier study of Miyamoto et al. by examining speech perception scores over time for both groups of children as a function of communication mode of the child. Separate linear regressions of speech perception scores as a function of age were computed to estimate the rate of improvement in speech perception abilities that might be expected due to maturation for the HA users (n=58) within each communication mode. The resulting lines were used to compare the estimated rate of speech perception growth for each HA group to the observed gains in speech perception made by the children with multichannel CIs. A large number of children using CIs (n=74) were tested over a long period of implant use (mean, 3.5 years; max, 8.5 years). In general, speech perception scores for the children using CIs were higher than those predicted for the Silver HA users, and they approached the scores predicted for the Gold HA users.

Introduction

Numerous research groups have examined speech perception performance in prelingually-deafened children with multichannel cochlear implants (Carney et al., 1991; Cowan et al., 1994; Fryauf-Bertschy, Tyler, Kelsay, & Gantz, 1992; Fryauf-Bertschy, Tyler, Kelsay, Gantz, & Woodworth, 1997; Gantz, Tyler, Tye-Murray, & Fryauf-Bertschy, 1994; Gantz, Tyler, Woodworth, Tye-Murray, & Fryauf-Bertschy 1994; Geers & Brenner, 1994; Kirk, Osberger, & Pisoni, 1995; Miyamoto, Osberger, Robbins, Myres, Kessler et al., 1991; Miyamoto, Osberger, Robbins, Myres, & Kessler 1993; Miyamoto, Osberger, Todd, Robbins, Karasek et al., 1994; Miyamoto, Osberger, Todd, Robbins, Stroer et al., 1994; Miyamoto, Kirk, Todd, Robbins, & Osberger, 1995; Miyamoto, Kirk, Robbins, Todd, & Riley, 1996; Osberger, Miyamoto et al., 1991; Osberger, Robbins et al., 1991; Somers, 1991; Staller, Beiter, Brimacombe, Mecklenburg, & Arndt, 1991; Staller, Dowell, Beiter, & Brimacombe, 1991; Waltzman, Cohen, & Shapiro, 1992; Waltzman et al., 1994; Waltzman et al., 1995). Early research in this field utilized descriptive analyses of the speech recognition scores of cochlear implant (CI) users. This method of reporting data provided an understanding of some of the benefits in speech perception the CI users received from their implants, but it did not provide any insight as to any gains these children might have made had they not been implanted. Some of the more recent studies have used a treatment/control group paradigm, where speech recognition scores of CI users have been compared to scores from unimplanted children who use hearing aids (HAs) or tactile devices to

enhance their communication. Such studies have shown that the average scores of children with CIs exceed the average score of HA users who have unaided thresholds poorer than 100 dB HL (Osberger, Miyamoto et al., 1991; Somers, 1991). In general, one of two methods was used to make comparisons between groups: (a) the longitudinal performance of pediatric CI users measured over time was compared to the performance of a cross-section of children using HAs assessed at a single point in time (Miyamoto, Osberger, Todd, Robbins, Karasek et al., 1994); or (b) the scores from small groups of CI users were compared to scores from age-matched HA or tactile aid users who served as controls (Geers & Brenner, 1994; Kirk et al., 1995).

These methods are an improvement over simply describing and reporting the changes seen over time with device use, but generalizations from these types of studies are difficult to make. In the first method described (longitudinal vs. cross-sectional), the scores from the group of CI users assessed longitudinally appear to improve over time whereas the data from the control group (HA users) sampled cross-sectionally cannot. The use of single-point measures of hearing aid users' speech perception as controls for children with cochlear implants makes it difficult to interpret the speech perception increases found for cochlear implant users. That is, improvements in speech perception over time might also occur in children who use hearing aids simply as a result of maturation or additional aural rehabilitation.

In the second method described above (age-matched controls) the groups are often very small and there is a great deal of variability in speech perception scores for prelingually-deafened children. In the past, we have attempted to control for the effects of maturation by comparing the performance of children with CIs at one postimplant interval (e.g., 2 years postimplant) to that of hearing aid control subjects who were matched to CI users by age at onset of hearing loss and age at the time of testing (Kirk et al., 1995). However, because of the difficulty in finding matched-pairs of CI and HA users, this type of analysis can be applied to only limited numbers of subjects, and generalizations are difficult to make.

In the present study, we examined the speech perception measures collected from cochlear implant and hearing aid users over time in our laboratory. We used linear regression analyses of the speech perception scores from the HA users as a function of their age at testing. These linear regressions were used to generate predictions about the improvement in speech perception expected from HA users over time. Actual performance over time from CI users was then compared to the predicted improvements in performance for the unimplanted profoundly deaf HA users.

Because we have relatively large numbers of both Oral and Total Communication (TC, or the simultaneous use of signed and spoken English) HA users in our database, the linear regression analyses were performed on the data separately within each communication mode. The predictions of improvements in speech perception for the children using HAs for both modes of communication were compared to observed benefits children receive with cochlear implants. Such comparisons, as well as similar comparisons for improvements in speech production intelligibility and language between children with CIs and HAs (Svirsky, 1996), impact directly on the issue of cochlear implant candidacy. When a prelingually-deafened child is being considered for cochlear implantation, it is important that the clinicians working with the child have valid information about the expected gains in communication for that child based on that child's age, residual hearing, communication mode, and communication device.

The goals of the present study were: (1) to estimate the amount of improvement in speech perception scores that can be expected with maturation as a function of degree of hearing loss and mode of communication for the HA users; and (2) to compare the observed changes over time in speech perception by pediatric CI users to the improvements predicted for profoundly deaf HA users. Because the estimated

improvements for the HA users may vary as a function of degree of hearing loss or communication mode, comparisons for the two modes of communication will be made independently (Oral-CI to Oral-HA; TC-CI to TC-HA). In carrying out these analyses, we assessed whether the observed speech perception skills of CI users met or exceeded the estimated skills of profoundly hearing-impaired children using HAs.

Methods

Participants

Participant characteristics for the 58 hearing aid users and the 74 cochlear implant users are presented in Tables 1, 2, and 3.

A. Hearing Aid Users

Fifty-eight (58) children with prelingual (congenital or onset at less than 3 years of age) profound hearing losses who used HAs participated in the study. The HA users were grouped in terms of their better ear unaided thresholds at 500, 1000, and 2000 Hz. Participants were identified as "Gold" HA users if two of the three thresholds were between 90 and 100 dB HL with none greater than 105 dB HL, and "Silver" HA users if two of the three thresholds were between 101 and 110 dB HL. Of the 24 children with the most residual hearing (i.e., Gold HA users), 15 used Oral Communication, and 9 used Total Communication. Of the 34 Silver HA users, 16 used Oral Communication and 18 used Total Communication (see Table 1). Thirteen of the Silver HA were subsequently implanted; thus the two participant groups (HA and CI) are not mutually exclusive. The cause of deafness for the majority of the children in the present study was unknown (66%). Meningitis was the cause of deafness for the highest percentage of children in which the cause of hearing loss was actually known (17%) (see Table 2). The average age at the onset of deafness and the mean age a hearing aid was fit were similar for the two groups of HA users, as well as for the two modes of communication (see Table 3).

Table 1.

Number of Participants by Communication Mode.

	Oral	TC	Total
CI	37	37	74
Gold HA	15	9	24
Silver HA	16	18	34

Table 2.**Number of Participants by Etiology of Hearing Loss.**

Etiology	CI		HA			
	Oral	TC	Gold		Silver	
	Oral	TC	Oral	TC	Oral	TC
Unknown	22	21	9	5	13	11
Meningitis	14	10	3	2	2	3
Mondini	0	1	0	0	0	0
Genetic	1	3	1	2	1	1
CMV	0	1	0	0	0	1
Viral Infection	0	0	1	0	0	0
Rubella	0	0	1	0	0	0
Febrile Seizures	0	0	0	0	0	2
Total	37	37	15	9	16	18

Table 3.**Age at Onset of Hearing Loss and Fitting with Device.**

Devise		Onset (yrs)		Fit (yrs)	
		Oral	TC	Oral	TC
CI	Mean	0.35	0.64	5.72	4.78
	St. Dev.	0.73	0.82	1.58	1.72
	Range	0.0-3.0	0.0-2.8	2.7-8.9	2.2-8.7
Gold HA	Mean	0.71	0.41	2.29	1.29
	St. Dev.	0.90	0.88	1.26	0.75
	Range	0.0-3.0	0.0-2.5	0.8-5.0	0.3-2.8
Silver HA	Mean	0.05	0.31	1.56	1.23
	St. Dev.	0.14	0.62	0.88	0.83
	Range	0.0-0.4	0.0-2.0	0.3-4.1	0.1-3.0

B. Cochlear Implant Users

Seventy four (74) children with prelingual profound hearing loss who received the Nucleus 22-channel CI participated in the study. Of the 74 children with cochlear implants, 37 used Oral Communication and 37 used Total Communication (see Table 1). The cause of hearing loss for most of the CI users was unknown (61%). Just like the children wearing HAs, meningitis was the most common cause of hearing losses in which the etiology was known (32%) (see Table 2). The age at onset of deafness was quite similar for the CI users as compared to the HA users. The average age at implantation was similar for the children using Oral or Total Communication (see Table 3). Of the 47 children implanted for whom we have preoperative records, 32 were Bronze HA users (hearing loss > 110 dB HL at two of three frequencies, 500 Hz, 1000 Hz, or 2000 Hz), 14 were Silver HA users, and one was a Gold HA user.

CI Speech Processing Strategy

Children using CIs were tested with their current speech processor and coding strategy. In terms of the latest processing strategy used by the participants, five subjects used the F0F1F2 (Blamey, Dowell, Clark, & Seligman, 1987) strategy, 31 subjects used MPEAK (Skinner et al., 1991), and 38 subjects used SPEAK (Skinner et al., 1994). Five subjects had partial insertions. The number of active electrodes ranged from 8-22. As the technology of the CI speech processor and strategy improved during the course of the study, five subjects changed from the F0F1F2 to the MPEAK, and 18 subjects changed from the MPEAK to the SPEAK speech processing strategy. The number of subjects using each processor was similar for the Oral and TC groups. The new processors and processing strategies (SPEAK) should provide the user with more information and improved speech perception scores. However, if a CI user switches processors, it often takes a period of time for the user to become accustomed to the device, and scores on speech recognition tests can decrease during this period (Sehgal, Kirk, Svirska, & Miyamoto, submitted). If all of the CI users had been using the most advanced speech processing strategy available at the present time for the Nucleus-22 device (SPEAK), the CI users may have achieved even higher speech perception scores than those seen in the present study.

Testing Intervals

Speech perception scores have been collected longitudinally from children with CIs for many years. Miyamoto, Osberger, Todd, Robbins, Karasek et al. (1994) compared longitudinal data from CI users to cross-sectional data from HA users. In the present study, we expanded on the Miyamoto et al. study in that we have attempted to collect and examine longitudinal data for both experimental (CI) and control (HA) groups. The data from neither the CI group nor the HA groups are strictly longitudinal. The vast majority of both the HA users and the CI users were tested more than once, but a few of the children were tested only once. In general, the CI users were tested at 6-month intervals if they were tested at Indiana University and yearly if they were implanted and tested elsewhere. Not every child was tested at each and every testing interval. Thus, the number of children tested at each time interval varied and was dependent on many factors including, but not limited to, distance from testing center and continued willingness to participate in the research study. Time is another factor in a longitudinal study; for the more recently-implanted children there are fewer data points. Thus, the data in the present study are not strictly longitudinal, nor can they be described simply as cross-sectional.

A. Hearing Aid Users

The Gold HA users were tested between one and six times at 6-month or yearly intervals. The Silver HA users were tested between one and four times at 6-month or yearly intervals. Thirteen of the Silver HA users were subsequently implanted.

B. Cochlear Implant Users

Participants were tested preoperatively as a baseline and then at 6-month or yearly intervals thereafter. Participants were tested for as long as 8.5 years postoperatively. Although rare, a few participants were tested only once postoperatively. Many of the children with cochlear implants were implanted at facilities other than Indiana University. These children are tested yearly for at least three years postoperatively as part of our longitudinal project.

Speech Materials

Participants were tested on a variety of speech perception materials in the Indiana University cochlear implant test battery. Two measures obtained from our test battery were selected for the present analysis (again, as an extension of Miyamoto, Osberger, Todd, Robbins, Karasek et al., 1994): the Minimal Pairs Test (Robbins, Renshaw, Miyamoto, Osberger, & Pope, 1988) and the Common Phrases Test (Osberger, Miyamoto et al., 1991). The Minimal Pairs test is an 80-item test designed to assess closed-set speech perception based on vowel and consonant feature recognition. One word (e.g., "bear") is presented to the child with two possible responses that differ by a single phoneme (e.g., "bear" and "pear"). Each pair of words appears twice, and each word from the pair acts as the stimulus once. Thus, if "bear" was the stimulus for the first presentation, "pear" would be the stimulus for the second presentation. Chance performance is 50%. Vowel height and place of articulation recognition are assessed with 32 of the 80 items, and consonant voicing, manner, and place of articulation are assessed with the remaining 48 items. The test is administered in an auditory-only mode. The children respond by identifying (or pointing to) a picture of the perceived stimulus.

The Common Phrases Test (Osberger, Miyamoto et al., 1991) assesses open-set sentence comprehension using three cue-presentation modalities: Auditory only (A), Visual only (V), and Auditory + Visual (A+V). The test items consist of six lists of ten two- to six-word phrases (simple commands or questions). The phrases are spoken to the child and the child responds by repeating the entire phrase or by correctly answering questions either orally or with the use of signed English. Scoring ranges from 0 - 100% in increments of 10% because only the number of completely correct responses is computed. The Visual-only modality is presented with the child's CI or HA turned off. We examined data from all three test conditions (A, V, A+V) in the present study. Both tests are administered via live-voice at approximately 70 dB SPL by an experienced audiologist or speech pathologist. When testing in the auditory modality, the experimenters covered their faces with an opaque mesh screen to eliminate visual cues.

Statistical Analysis

The data from the HA users were analyzed using linear regression analysis of speech perception scores as a function of age at testing to assess the effects of maturation (aging) on speech perception scores. First, linear regressions were carried out separately for the Oral and TC children in each of the hearing aid groups (Gold and Silver) for speech perception scores as a function of the age of the child at testing. This provides an estimate of the expected improvement in speech perception scores due to maturation in the absence of cochlear implantation. Second, the measures of speech perception by pediatric CI users collected over time were compared to the obtained regression lines, that is, to the estimates of performance for the hearing aid groups as a function of the age of the child at the time of testing. Again, comparisons were made separately within each communication modality.

Results

Minimal Pairs Test

Linear regressions (score vs. age at testing for the HA users) were performed for only the consonant subtest as the mean scores for the Vowel subtest approached the ceiling (100% correct) rapidly for all groups of children using either HAs or CIs and either Oral or Total Communication.

Insert Figure 1 about here.

The linear regression functions are shown in Figure 1. The top panel is for the Oral children and the bottom panel is for the TC children. Correlations are placed next to the corresponding line. Significant correlations are highlighted by asterisks (* $p < .05$, ** $p < .01$). Improvements in scores as a function of age at testing are predicted for both Gold and Silver HA users for both communication modes (positive slopes of the linear regression functions). Based on this analysis, consonant perception scores for the HA users would be expected to improve between 1 - 2% per year for a HA user irrespective of the mode of communication (Oral or TC) or the amount of residual hearing (Gold or Silver). As is shown in the top panel of Figure 1, for the children who use Oral communication, predicted performance for the Gold HA users is higher than predicted performance for the Silver HA users. The predicted scores for the Oral Gold HA users are approximately 20-30% higher at all points in time than the predicted scores for the Oral Silver HA users. This is to be expected because the Gold HA users have more residual hearing than the Silver HA users. As shown in the bottom panel of Figure 1, for the children who use Total communication, predicted performance is only slightly less than predicted performance of the children using Oral communication (top panel). There is a great deal of overlap in the predicted performance for the TC Gold and TC Silver HA users. Performance is predicted to improve over time for both groups at a rate of 1-2% per year.

When the data from the children using CIs are examined, the results follow the same general trend as the findings from Miyamoto, Osberger, Todd, Robbins, Karasek et al. (1994) in that the performance on the Minimal Pairs Test increases with the length of implant use. The data for the Oral children are shown in Figure 2 and the data from the children using TC are shown in Figure 3. The data derived from the linear regressions shown in Figure 1 for the HA users are plotted as points connected by lines and the data from the CI users are plotted as bars. The points represent the predicted scores for the HA users at the mean age of the CI users at that particular testing interval.

As illustrated in Figures 2 and 3, the number of children with CIs being tested at the different postoperative intervals varied. Therefore, the corresponding average age of the children tested at each postimplant interval does not increase linearly because (a) the number of children tested at each interval is different, and (b) the actual testing interval is somewhat variable. For example, a child could be tested between 10-14 months postimplant for the "1-year" testing interval. The average ages of the CI users at the preoperative testing interval were 6.1 years for the Oral subjects and 5.8 years for the TC subjects. At the 1-year postoperative testing interval, the average ages for the CI users were 6.8 years for the Oral subjects and 6.9 years for the TC subjects (instead of 7.1 years and 6.8 years, respectively). Therefore, the predicted scores for the children using HAs do not follow straight lines. Rather, they are the predicted scores for the HA users (from Figure 1) at the average age of the CI users at that particular testing interval.

Predicted P(C) vs. Age - HA users

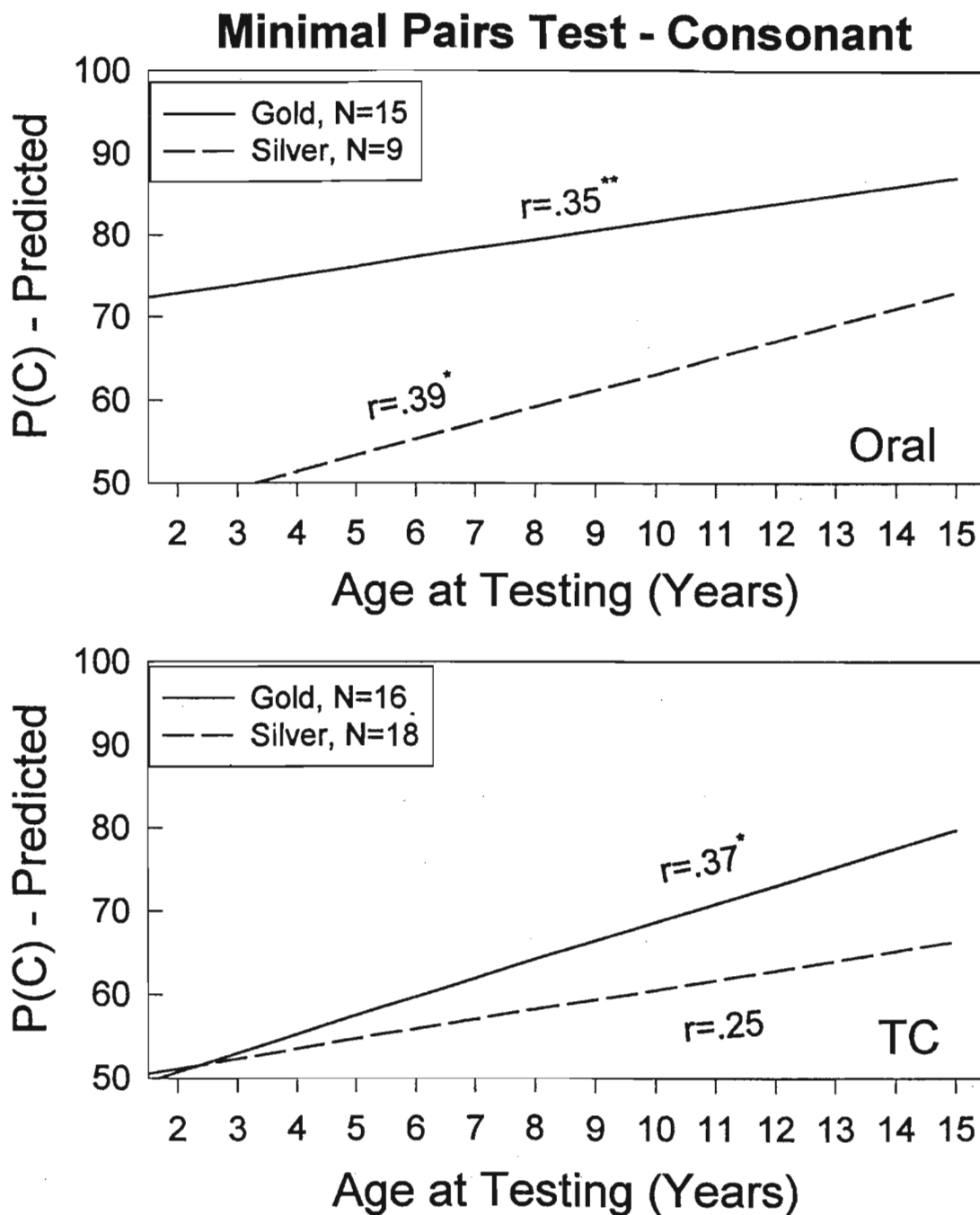


Figure 1. Linear regressions of test score vs. chronological age for the Minimal Pairs Test - consonant. Regression lines for the Oral children are in the top panel, and lines for the TC children are in the bottom panel. * $p < .05$, ** $p < .01$.

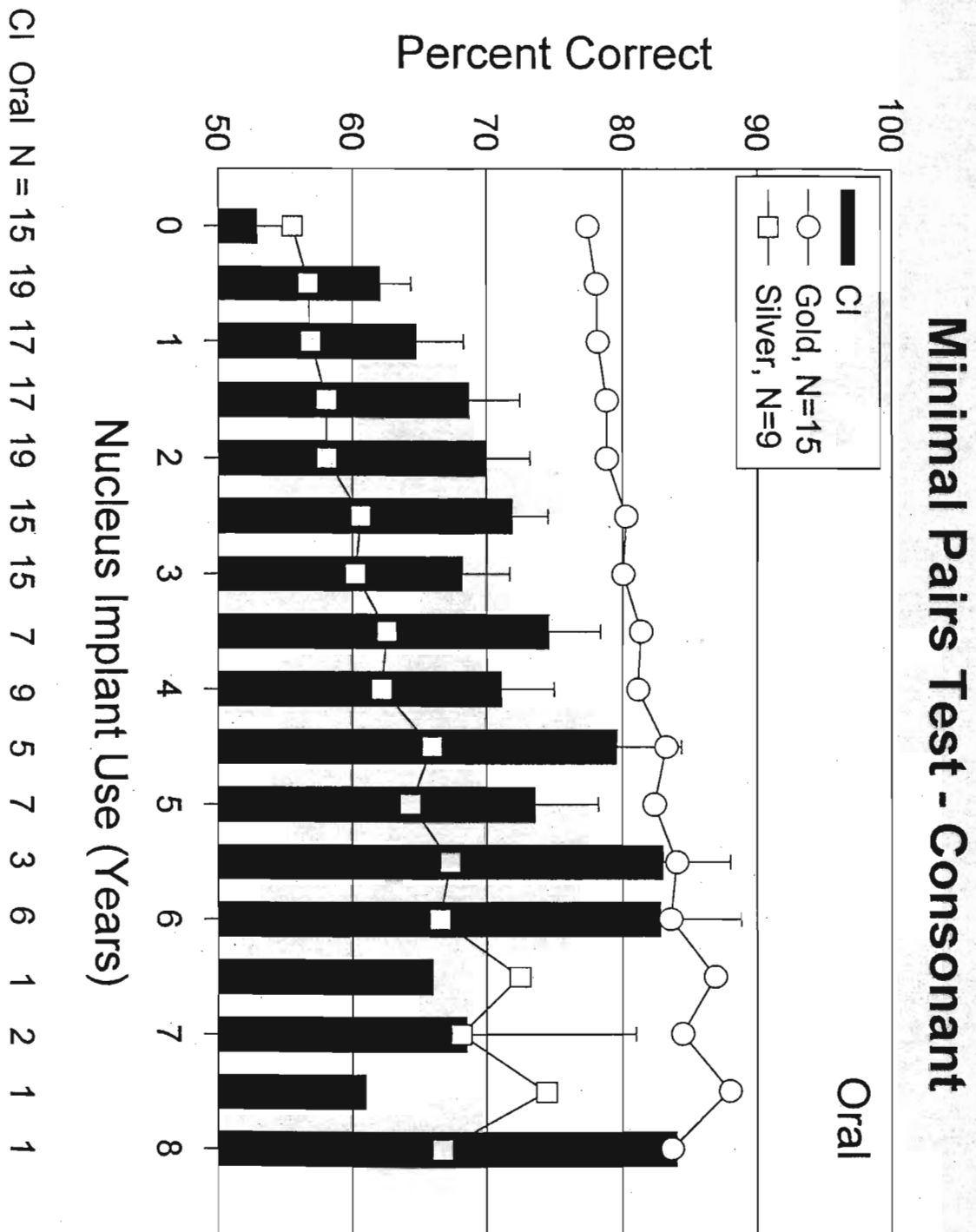
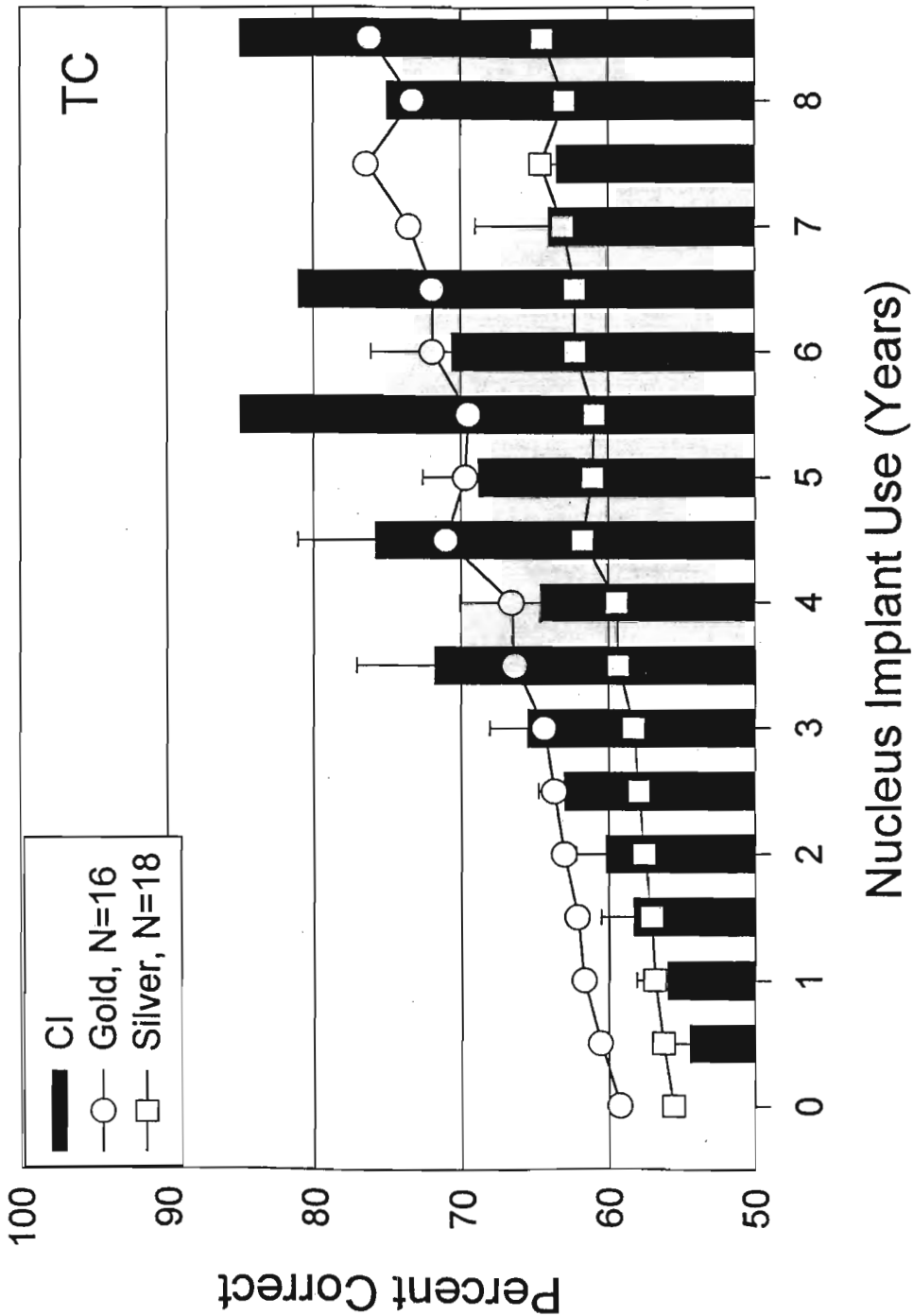


Figure 2. P(C) vs. implant use for the Minimal Pairs Test - consonant for Oral children. Data for the Gold and Silver HA users are predictions from the linear regressions in Figure 1 based on the average age of the CI users at a particular testing interval. Chance performance (50%) is shown by the dashed line. Error bars represent standard errors of the mean.

Minimal Pairs Test - Consonant



TC N = 25 27 22 23 18 6 8 4 4 6 1 5 1 2 2 1 1 1 1

Figure 3. P(C) vs. implant use for the Minimal Pairs Test - consonant for the TC children. Data for the Gold and Silver HA users are predictions from the linear regressions in Figure 1 based on the average age of the CI users at a particular testing interval. Chance performance (50%) is shown by the dashed line. Error bars represent standard errors of the mean.

Insert Figures 2 and 3 about here.

Again, we are comparing speech perception scores for children using the same mode of communication. Chance performance on the Minimal Pairs Test is 50%, and a score of 65% on the 48-item consonant perception subtest is considered significantly greater than chance ($p=.03$). Scores for both Oral and TC CI users were at chance levels (50%) just prior to implant. For the Oral children, the mean consonant perception score reached a level statistically greater than chance (65%) by approximately one year postimplantation, and the mean score of the TC users reached this level (65%) by approximately 3 years after implantation. For the Oral children, the average score for the CI users approached the predicted score for the Gold HA users after approximately 5 years of implant use. For the children using TC, the mean scores for the CI users were approximately equal to the predicted scores for the Gold HA users after approximately 3 years of implant use. The average scores for the Oral children using CIs were slightly higher on the Minimal Pairs Test than the average scores for the children using TC. The number of participants tested with long (> 5 years) implant use is quite small, and the associated data should be interpreted with some caution.

Common Phrases Test

A. Hearing Aid Users

Separate linear regressions were performed (score vs. age at testing for the HA users) for the A, V, and A+V test conditions for the TC and Oral children. The linear regression functions are shown in Figure 4.

Insert Figure 4 about here.

The data for the Oral children are shown in the left two panels (Gold - top, Silver - bottom), and the data for the children using TC are shown in the right two panels (Gold - top, Silver - bottom). Correlations are placed next to the corresponding line. Significant correlations are highlighted with asterisks (* $p < .05$, ** $p < .01$). Improvements in scores as the age at testing increases (positive slopes of approximately 3% increase in score per year) are predicted for the Oral Gold and Oral Silver HA users for the A (audition alone) condition. As with the Minimal Pairs Test, the predicted scores for the Oral Gold HA users (left panels) were substantially higher (they obtained 25-40% higher scores under the A condition) than scores for the Oral Silver HA users.

For the participants using TC (right panels), no improvement in speech perception as a function of age is predicted for the A condition (slope of approximately 0% increase in score per year). The average score for the TC Gold HA (35%) users is substantially higher than the average score for the TC Silver HA users (6%).

The results from the Common Phrases Test carried out in the V condition demonstrate that the rate of improvement over time was much greater for the Oral HA users (5.7 to 7.7 % improvement per year) than for the TC HA users (-1.0 to 2.0 % improvement per year). The predicted scores for the TC Gold HA users were higher than the predicted scores for the TC Silver HA users. This difference is related to the negative slope (although not significantly different from 0.0) of the regression line for the Silver HA users.

Predicted P(C) vs. Age - HA users

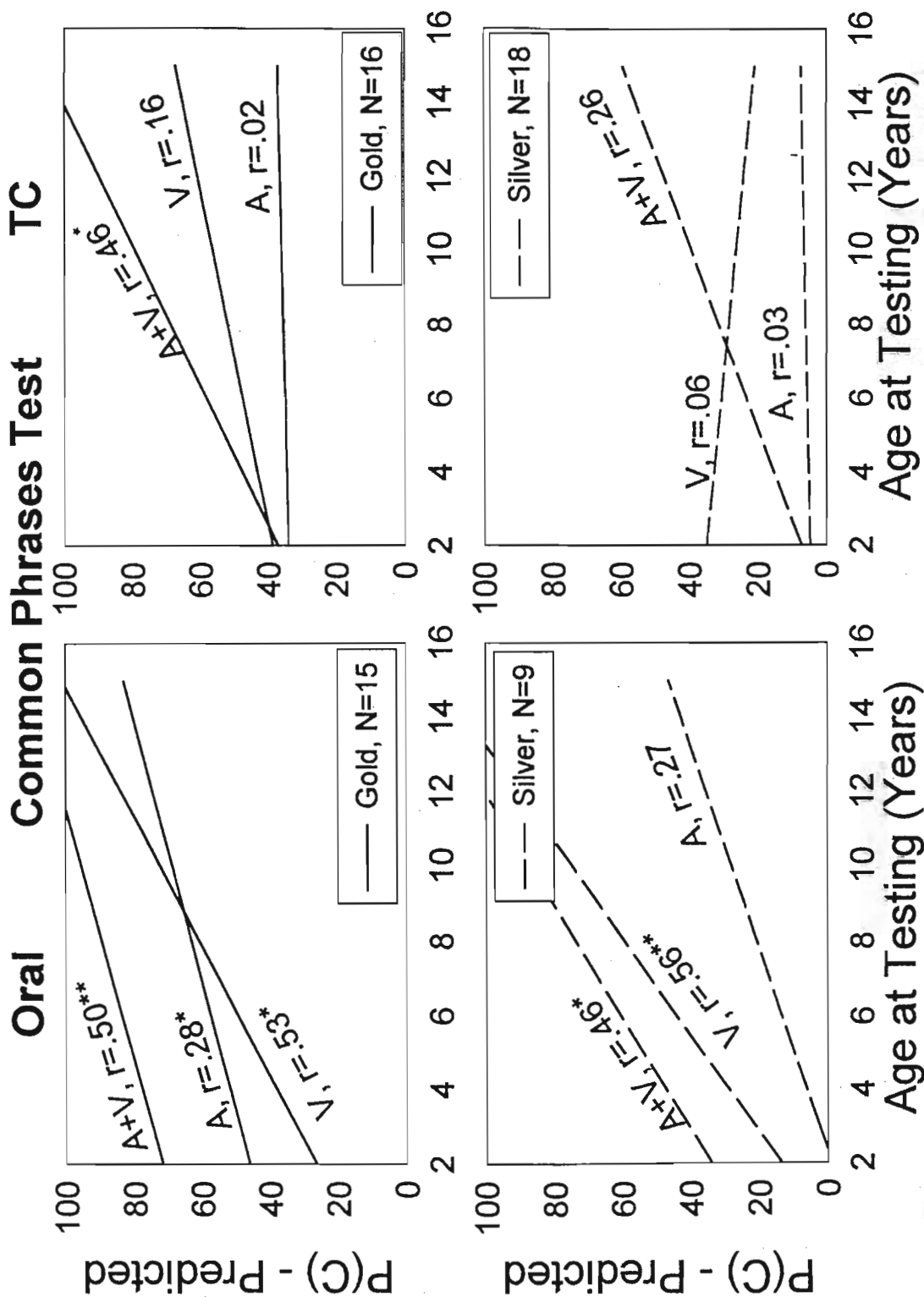


Figure 4. Linear regressions of test score vs. chronological age for the Common Phrases Test. Regression lines for the Oral children are in the left two panels (Gold - top, Silver - bottom), and lines for the TC children are in the right two panels. Regression lines were generated for the Audition alone (A), Vision alone (V), and audition plus vision (A+V) conditions. * $p < .05$, ** $p < .01$.

For the Oral children, the regression lines for both the Gold and Silver HA users overlap, and differences between the two groups are small ($\pm 10\%$).

When visual cues were added to the auditory condition, large rates of improvement with age at testing were predicted (3-6% improvement per year) for both Silver and Gold HA users and both Oral and Total Communication modes. Predicted performance for the Gold HA users was higher than predicted performance for the Silver HA users for both communication modes. For the Oral children (left panels), the regression lines predict that the difference between the Gold and Silver HA users decreases over time, and by approximately age 12, the difference in A+V speech perception between the two groups is negligible, and that performance for both groups should be approximately 100%. For the TC users (right panels), the regression lines predict that the Gold HA users obtain 25-50% more open-set sentence recognition than the Silver HA users. As expected, predicted performance for the A+V condition is greater than performance predicted for either the A or the V conditions alone.

B. *Cochlear Implant Users*

Of the 73 children with CIs tested with the Common Phrases Test, 59 (80.8%) acquired at least some [$P(C) > 0\%$] open-set sentence recognition under the auditory-only (A) condition at some point during testing. Of the 37 CI participants in oral communication programs, 35 achieved some open-set speech recognition during testing. Of the 36 CI participants in total communication programs, 24 achieved some open-set speech recognition during testing. The mean scores on the Common Phrases Test for the CI users at the different testing intervals are shown in Figures 5 - 8.

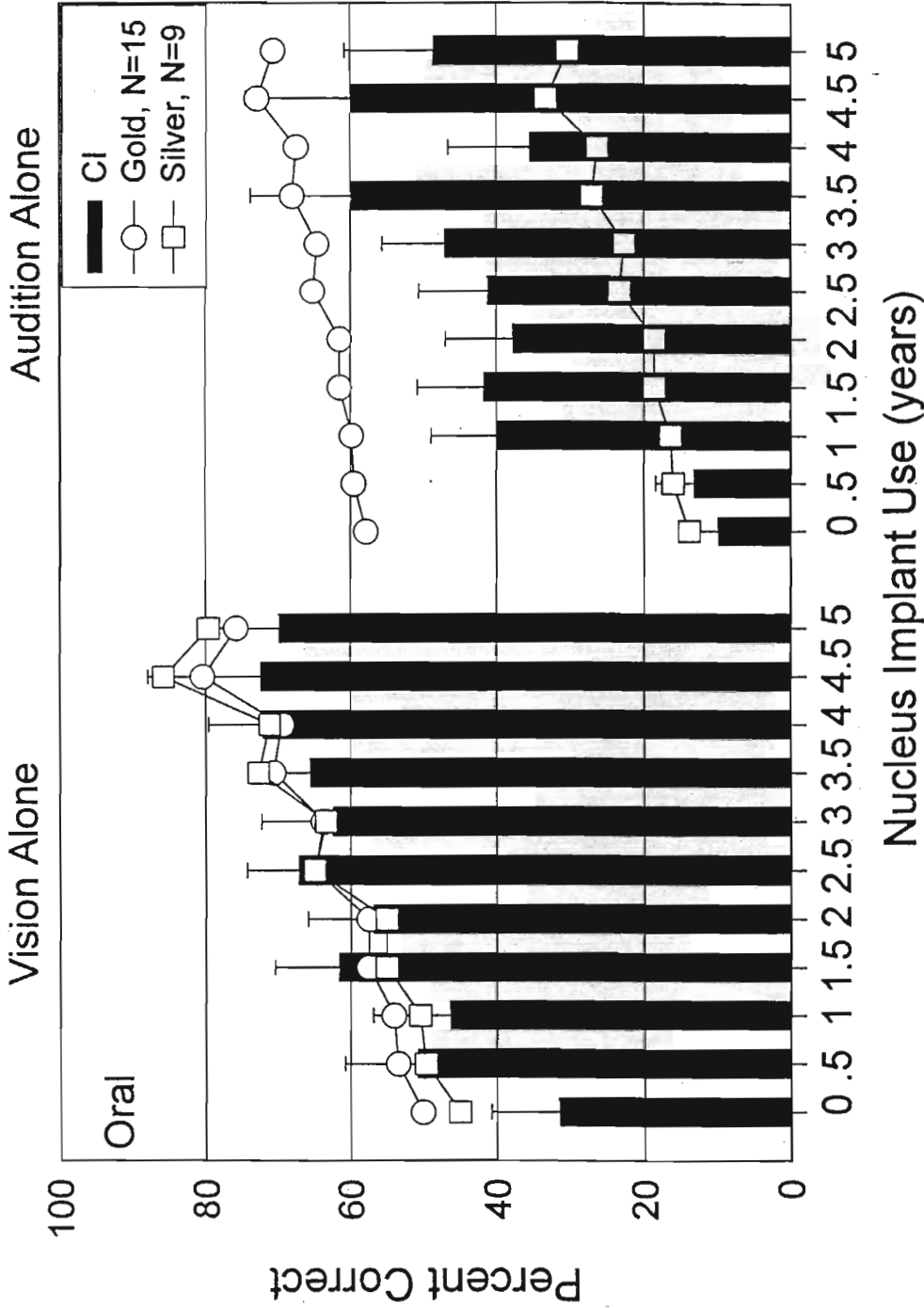
Insert Figures 5, 6, 7 and 8 about here.

As shown in Figures 5 through 8, performance on the Common Phrases Test increases over time for the CI users for the audition alone (A), vision alone (V), and the audition plus vision (A+V) conditions. Data from the Oral children are shown in Figures 5 and 6, and data from the children using TC are shown in Figures 7 and 8. Overall, the Oral children using CIs perform better than the TC children using CIs on the Common Phrases Test under all three conditions, the A, V, and the A+V conditions. The same result (Oral scores greater than TC scores) was seen in the predicted regression lines for the children using HAs in Figure 4.

1. *Oral* When the data from the Oral children in the audition alone (A) condition were analyzed (Figure 5 - right panel), the average score for the CI users at the pre-implant interval (10%) was below that predicted for the Silver HA users (15%). By one year of implant use, the average score for the CI users increased to a level (40%) that was much greater than that predicted for the Silver HA user (18%). The amount of benefit the children using CIs derive from their devices continues to be greater than that predicted for the Silver HA users over time, but scores on the Common Phrases Test under the A condition for the CI users remain approximately 20% less than the predicted scores for the Gold HA users. The predicted scores from the children in both HA groups improve at approximately the same rate (3-4% improvement per year). The estimated rate of improvement for the CI users is approximately 7% per year.

In the V condition (Figure 5 - left panel), the absolute scores as well as the rates of improvement are similar for both groups of HA users as well as the CI users. Scores increased from approximately 50% at one year post-implant to 70% at five years post-implant.

Common Phrases Test



CI Oral N = 11 12 11 12 13 11 12 7 9 4 7 16 18 17 17 19 15 14 7 9 5 7

Figure 5. P(C) vs. implant use for the Common Phrases Test - Oral children. The vision alone (V) condition is plotted on the left side of the figure. The audition alone (A) condition is plotted on the right side of the figure. Data for the Gold and Silver HA users are predictions from the linear regressions in Figure 4 based on the average age of the CI users at a particular testing interval. Error bars represent standard errors of the mean.

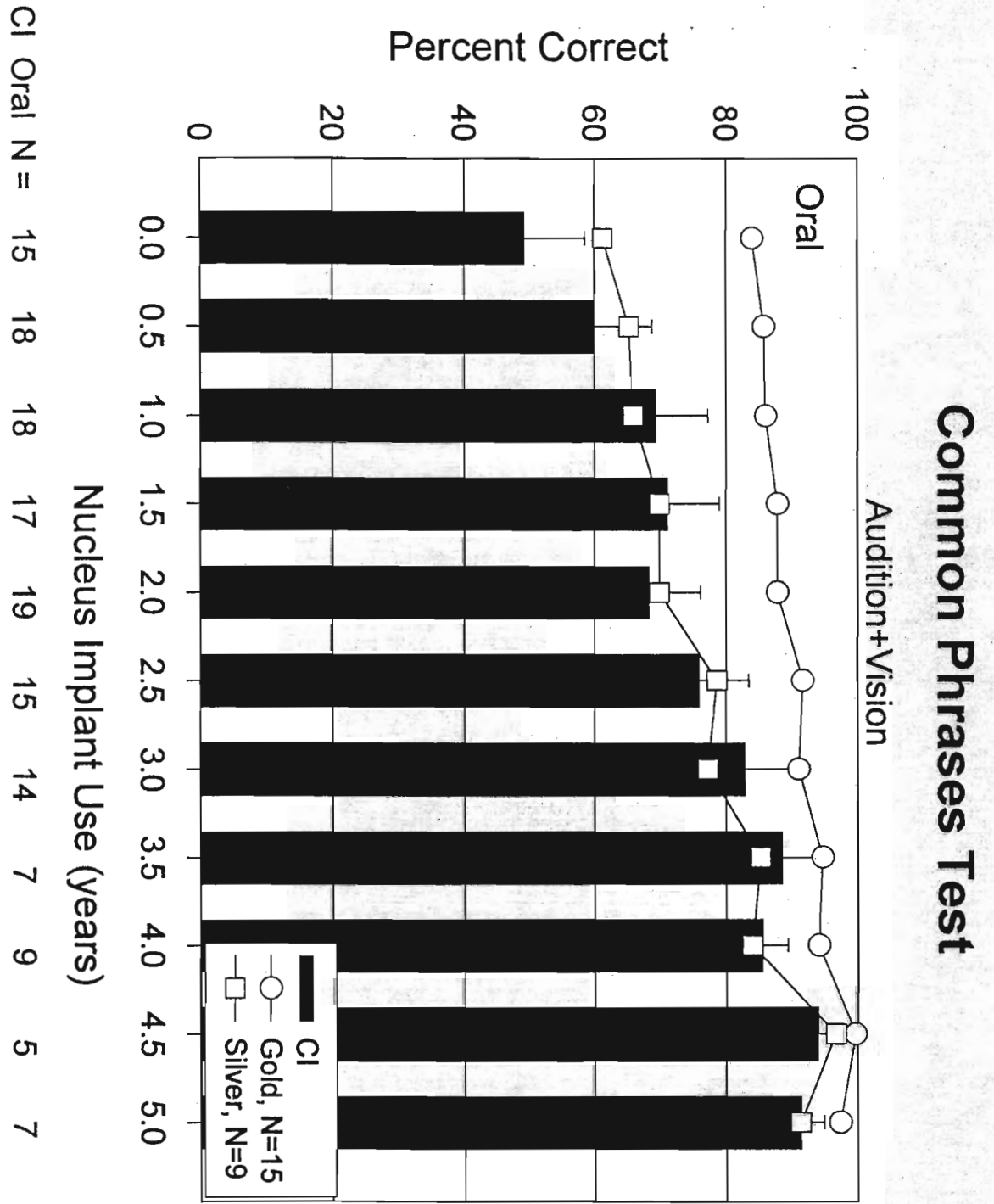


Figure 6. P(C) vs. implant use for the Common Phrases Test - Oral children in the audition plus vision (A+V) condition. Data for the Gold and Silver HA users are predictions from the linear regressions in Figure 4 based on the average age of the CI users at a particular testing interval. Error bars represent standard errors of the mean.

Common Phrases Test

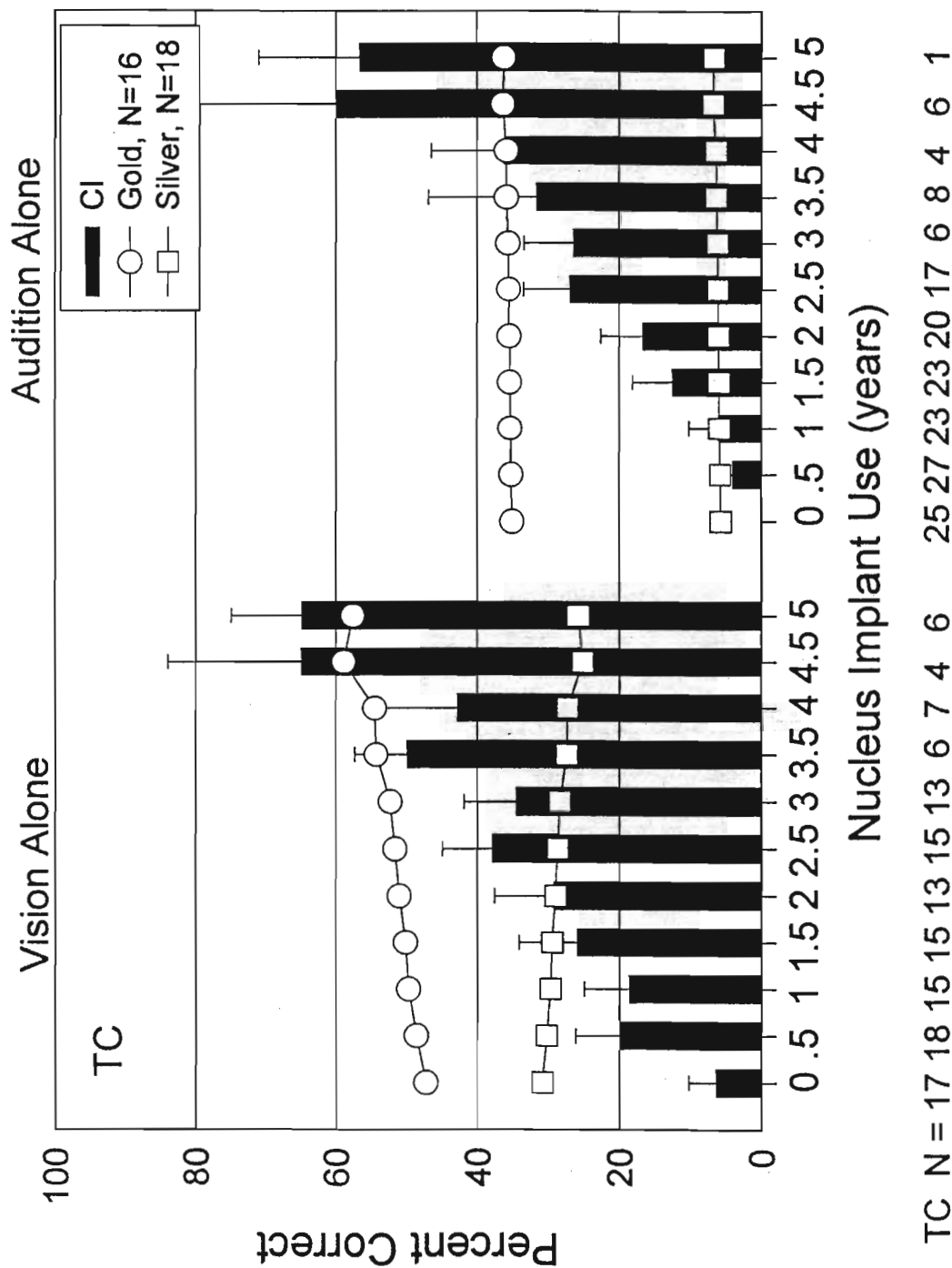


Figure 7. P(C) vs. implant use for the Common Phrases Test - TC children in the A and V conditions. The vision alone (V) condition is plotted on the left side of the figure. The audition alone (A) condition is plotted on the right side of the figure. The data for the Gold and Silver HA users are predictions from the linear regressions in Figure 4 based on the average age of the CI users at a particular testing interval. Error bars represent standard errors of the mean.

Common Phrases Test

Audition + Vision

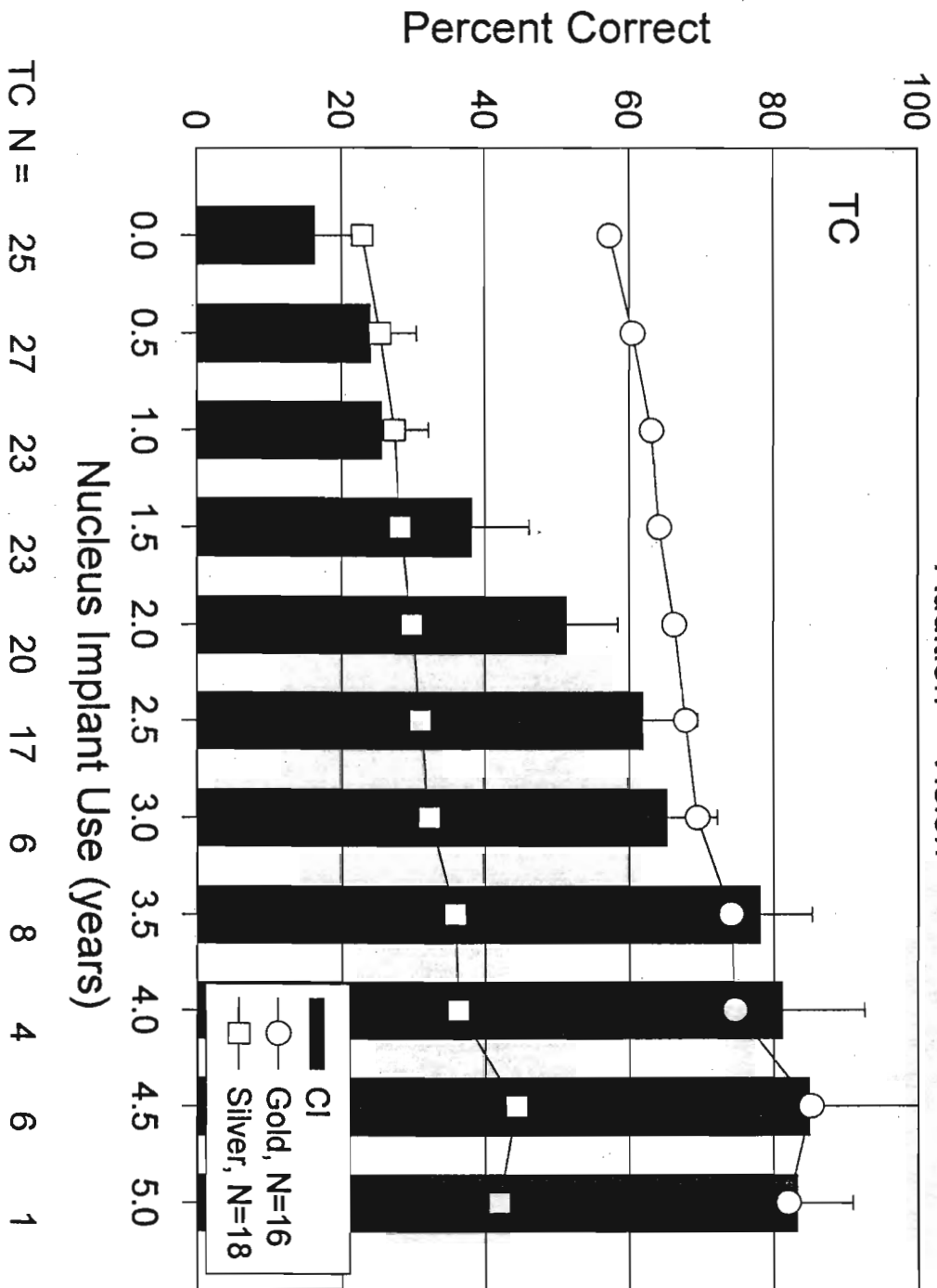


Figure 8. P(C) vs. implant use for the Common Phrases Test - TC children in the A + V condition. Data for the Gold and Silver HA users are predictions from the linear regressions in Figure 4 based on the average age of the CI users at a particular testing interval. Error bars represent standard errors of the mean.

In the A+V condition (Figure 6), the mean score for the CI users is approximately 50% at the preimplant interval, which is approximately 12% less than the predicted score for the Silver HA users (62%), and about 35% below the predicted score for the Gold HA users (85%). By one year postimplant, the mean score for the CI users has attained the level predicted for the Silver HA users, and by five years post-implant, the mean score for the CI users is approximately 90% and essentially equivalent to the predicted score for the Gold HA users. The rate of improvement observed for the CI users was similar to the rate of improvement predicted for the Silver HA users, and greater than that predicted for the Gold HA users. The relation between the scores for the different groups may be confounded by a ceiling effect for this particular test. The addition of visual cues to the auditory input improves performance on the Common Phrases Test a great deal, and after several years of device use (HA or CI), the children are, in general, performing very well on the test. Differences in performance between groups are difficult to assess under the A+V condition when average performance is nearly perfect.

2. *TC* When the data from the children using TC in the A condition are analyzed (Figure 7 - right panel), for both the Gold and Silver HA users, the performance under the A condition is not correlated with the age at testing ($r = 0.0$). The best estimate of performance is the mean of the test scores under this condition. The predicted (average) score for the Gold HA users is approximately 35%, and the average score for the Silver HA users is approximately 6%. Mean scores for the CI users surpass the average score for the Silver HA users after 1.5 years of use, and they reach the average score for the Gold HA group (35%) by approximately four years of implant use. The estimated rate of improvement seen in the TC CI users is high (12% improvement per year).

In the V condition (Figure 7 - left panel), scores for the CI users reach levels predicted for the Silver HA users by approximately 2 years of implant use and levels predicted for the Gold HA users after about 5 years of implant use. Scores for the TC CI users also improve at a fast rate (11% improvement per year).

When both auditory and visual cues (A+V) are available, the predicted scores for the HA users increase with age (Figure 8). The absolute scores for the Gold HA users are approximately 35% higher than scores for the Silver HA users. Scores for the children using CIs surpass the predicted scores for the Silver HA group after approximately 2 years of use, and they reach the levels of the Gold HA users by approximately 4 years of implant use. The predicted rate of improvement is similar for both Silver and Gold HA users (4-5% improvement per year), and the estimated rate of improvement for the CI users is greater (15% improvement per year) than that for either the Gold or the Silver HA users.

Discussion

In this study, we examined the relation between speech perception scores (Minimal Pairs Test - Closed Set, Common Phrases Test - Open Set) and age at testing for prelingually-deafened children who use hearing aids to estimate the increase in performance due to maturation in the absence of cochlear implantation. We grouped the children based on their mode of communication, Oral or TC, and computed regression equations. These predictions were compared to data obtained from prelingually-deafened children with cochlear implants. On the Minimal Pairs Test, the children with CIs obtained at least as much consonant feature recognition as the Silver HA users. On the Common Phrases Test, the scores from the children with CIs approached the scores predicted for the Gold HA users.

The findings from the present study and results from other research with prelingually-deafened children impact directly on the management of deaf children. We are trying to answer questions about the

expected speech perception benefits of hearing aids and cochlear implants to deaf children in different educational settings. Our results suggest that, on average, children with hearing losses in the 101-110 dB HL range (Silver HA users) would receive greater speech perception benefits from a CI than they do from their hearing aids irrespective of the mode of communication they are currently using. This result lends further support to the earlier study by Miyamoto, Osberger, Todd, Robbins, Karasek et al. (1994). They found that the speech perception scores of their implant users increased over time to be greater than the mean scores of their Silver HA users obtained at a single point in time. The present results demonstrate that even though the speech perception skills of Silver HA users increase over time, they do not keep pace with the average gains achieved by children who receive a cochlear implant. Similar results were also reported in a recent study by Geers and Brenner (1994) in which the speech perception of their CI users was similar to the speech perception of HA users with losses in the 90-100 dB HL range, and it was better than the speech perception of their HA users with losses greater than 100 dB HL.

Research concerning the speech perception skills of prelingually-deafened children also impacts directly on the issue of implantation candidacy. Decisions as to the audiological criteria used to determine which children should even be considered for a cochlear implant arise from this line of research. The current recommendations from the most recent NIH Consensus Conference on Cochlear Implants (NIH Consensus Conference, 1995) suggest that children with profound (>90 dB HL) bilateral sensorineural hearing loss and minimal speech perception may be considered for cochlear implantation. In a recent study, Zwolen et al. (1997) examined speech perception skills in two groups of prelingually-deafened children who received cochlear implants. The first group fit the recommended audiological criteria and had no open-set speech recognition prior to implantation. The second group also fit the recommended audiological criteria, but they had some open-set speech recognition prior to implantation. Both groups (including the children who had some open-set speech recognition prior to implantation) received a great deal more benefit from their implants than they did with their hearing aids. Although the authors did not attempt to estimate how these children would have performed if they had continued with hearing aids, they suggested that the child may benefit more from a CI than from continued HA use. Zwolen et al. further suggested that the selection criteria for CI candidacy should be broadened to include children who receive some open-set speech recognition.

The results from the present study support the suggestion of Zwolen et al. (1997) that the audiometric criteria for cochlear implantation might be broadened as our data indicate that CI users' speech perception skills exceed those of Silver HA users, and approach the skills of Gold HA users. However, although audiological criteria are important in the decision process for implantation, they are only a small part of the CI candidacy determination. CI candidacy is not an issue that should be taken lightly, and children should continue to be evaluated for a CI on an individual basis. Clinicians and parents of deaf children need up-to-date information as to the options available to them and the gains in communication skills they should expect to see for the children at different ages with the different devices in different educational settings. Without current data, it is even more difficult for the parents of deaf children to make the decisions that will impact the lives of their children.

The data clinicians need to help parents make decisions about implantation are often difficult to collect, report, and interpret. First of all, for ethical as well as logistic reasons, it is impossible to carry out a typical double-blind, randomized treatment vs. control study. Second, if children with CIs are the treatment group, it is not clear which children should be the control group. Should profoundly deaf children who use hearing aids, tactile aids, or no sensory aids act as a control group for children with CI? We chose children who use hearing aids as a control group for several reasons. Implant candidacy requires the child to participate in a hearing aid trial under close observation often for several months. The child's

performance with a hearing aid is closely monitored, and performance with the hearing aids must be less than the average performance of children with a cochlear implant. The children showing little-to-no gain with hearing aids are given the option of cochlear implantation. The children who demonstrate adequate gains in speech perception with the hearing aids (usually those children with more residual hearing, i.e., Gold HA users) do not, in general, receive a cochlear implant. Third, the logistics of these kinds of clinical studies make data collection difficult, and the reporting and interpretation of the results even more difficult. Typically, subject attrition occurs over time as families move, children stop using their implants or hearing aids, or patients choose to return for visits less over time. To demonstrate this point, a recent study from the University of Iowa (Fryauf-Bertschy et al., 1997) found that 14 of the 40 children (35%) who received a cochlear implant at their institution (all used Total Communication) were minimal or non-users of their devices. The children described as "minimal" or non-users tended to be older at the time of implantation, and performed at lower levels on speech perception tasks than the full-time implant users. It is difficult to determine from the University of Iowa data, however, whether lower scores on speech recognition tasks are directly attributable to the age at implantation, the lack of device use, or some other variable or combination of variables. It is also difficult to determine whether the lack of device use is a behavioral response to lack of usable auditory information, peer pressure, or another reason.

In the same light, it is also possible that families of children who perform better with a device may opt to return for more testing sessions than families with children who do not perform well or are unhappy with their device, thus biasing the study. Finally, many clinical studies, such as those involving cochlear implants, are dependent upon the technological advances arising in the field during the time period of the study. As newer speech processors and coding strategies are developed, device manufacturers want to offer their clients an improved product, and patients often change devices in hopes of receiving more clinical benefit. For these, and numerous other reasons, clinical comparisons across time for cochlear implant users are challenging. These difficulties exist at our institution and probably exist at all other institutions where clinical research on the benefit of cochlear implants is conducted.

Nevertheless, we have attempted to overcome some of the problems mentioned above by collecting and examining some longitudinal data from a control group of children using HAs as well as our treatment group of children with CIs. As the data from the HA users (or CI users) were not strictly longitudinal, we used linear regression analysis to predict improvements in speech recognition scores as a function of age or maturation for the children using HAs (control group). These predictions were compared to observed data from children with CIs to determine if use of a CI helps a child attain better speech perception scores than would be expected if the child were not implanted and used high-powered hearing aids instead. Using linear regression techniques is an improvement over past comparisons between the two subject groups (Miyamoto, Osberger, Todd, Robbins, Karasek et al., 1994), but more longitudinal data from children (both HA users and CI users) is needed to allow us to make better predictions about the potential benefit to speech perception from implantation.

We did not specifically test the effect of communication mode on speech perception scores. If a test of the effect of communication mode on test score would prove to be significant, one must be careful not to generalize the result to infer that a particular mode of communication is superior to another. It may be that children in Oral programs have more residual hearing than the children in TC programs and receive more auditory information through their hearing aids. For the children who receive little-to-no useful auditory information with a hearing aid and are implanted, the children in oral programs are more dependent upon the information they receive from the CI for communication than are the children in TC programs who can use and rely upon sign language for communication. It is also possible that the children in oral programs

receive more training focused on the development of particular auditory and speech skill assessed by the speech perception testing protocols than the children in TC programs (Quittner & Steck, 1991).

Many factors are involved in the decision about which communication mode a child will use. One of the most important factors in deciding upon a communication mode for a prelingually-deafened child is the willingness of the family to learn and use the chosen communication mode. The availability of education and rehabilitation services for the child are also important in deciding upon a mode of communication. If the child is not able to make adequate gains in language development or academic progress with a chosen mode of communication, then the family should consider a different communication mode for the child.

Summary and Conclusions

We examined speech perception scores using two measures, the Minimal Pairs Test, a closed-set speech discrimination test based on consonant feature perception, and the Common Phrases Test, an open-set sentence comprehension test, over time for prelingually-deafened children using CIs or HAs and either Oral or Total Communication. In general, scores for CI users were at least as high as scores for Silver HA users and approached scores for the Gold HA users after several years of device use.

On the Minimal Pairs Test, for the children using CIs, scores for both Oral and TC children improved at a rate comparable to the rate of improvement seen in the profoundly hearing-impaired children using HAs with the most residual hearing ("Gold") using the same mode of communication. Scores from both Oral and TC users are similar - Oral children performed only slightly better on the Minimal Pairs Test than did the children using TC. This is to be expected because the Minimal Pairs Test assesses speech discrimination based on single-feature minimal pairs in a two-alternative, forced-choice design (chance performance is 50%). Furthermore, the closed-set scores for the children with CIs are similar to and improve at a rate comparable to the rate of improvement seen in the Gold HA users. The number of subjects tested with long implant use (> 5 years) is quite small, and the associated data should be interpreted with some caution.

On the Common Phrases Test, the scores for the TC children with CIs approach and probably surpass scores for the Gold HA users in the A and A+V conditions after approximately 4 years of device use. The rate of improvement in scores over time for the TC children with CIs is greater than the rate of improvement predicted for the TC children using Gold HAs. The scores for Oral children with CIs improve at a rate greater than that predicted for the Oral Silver HA users, but their scores do not reach the levels of scores for the Oral Gold HA users after five years of implant use. The actual scores for the Oral children with CIs fall in between the scores for the Silver and Gold HA users in the Common Phrases Test in the A condition, and they are similar to the scores from the Silver HA users when visual cues are added (A+V).

Results from studies of speech perception, speech production, and language development are all needed to help clinicians determine the expected overall benefits to prelingually-deafened children from cochlear implantation versus hearing aid or other sensory aid. Speech intelligibility and language development have been examined by Svirsky (1996). His results, from an analysis similar to the one used in the present study, demonstrate that the intelligibility of the speech of children with CIs reaches the levels of intelligibility of the Silver HA users after 1-2.5 years of use, and moreover, the language scores of children with CIs improve faster than the language scores for the Gold HA users. It is apparent from the present study that prelingually-deafened children obtain higher speech perception scores with a cochlear implant

than they do with a hearing aid if the amount of residual hearing is in the Silver range (101-110 dB HL). Thus, in terms of improvements in overall communication skills, our data suggest that prelingually-deafened children with enough residual hearing to be classified as Silver HA users would benefit more from a CI than a conventional HA, and at least some of the children who would be Gold HA users might benefit more from a CI than from a HA. As the CI technology improves, newer implants and speech processors will help CI users achieve even greater communication benefit than they do now. It remains to be seen whether children with slightly more residual hearing [Gold HA users (90-100 dB HL), or even children with severely impaired hearing (70-90 dB HL)] will achieve greater overall levels of communication with a hearing aid or a cochlear implant.

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