# The Central Institute for the Deaf Cochlear Implant Study: A Progress Report

## Étude du Central Institute for the Deaf sur l'implant cochléaire: Rapport d'étape

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### Abstract

The Central Institute for the Deaf (CID) has completed 3 years of a 6 year study to compare the effectiveness of the Nucleus 22 Channel cochlear implant, the Tactaid, and the conventional hearing aid for helping profoundly hearing impaired children learn to talk. This preliminary report describes results obtained from 18 children in the first 6 matched groups of Nucleus 22 Channel cochlear implant, Tactaid, and hearing aid users after 1, 2, and 3 years of device use. Results indicate that the Nucleus 22 implant, in combination with intensive auditory and speech training, resulted in larger improvements in speech perception, lipreading enhancement, and speech production skills than were observed in matched subjects with Tactaids or hearing aids. Differences in spoken language acquisition were less clear, with greater improvement in both implant and Tactaid subjects when compared to their hearing aid matches.

### Résumé

*Le Central Institute for the Deaf (CID) vient de terminer les 3 premières années d'une étude de 6 ans sur la comparaison de l'efficacité de l'implant cochléaire Nucleus 22 canaux, du Tactaid et d'une prothèse auditive conventionnelle de façon à aider les enfants avec surdité profonde à apprendre à parler. Le rapport préliminaire décrit les résultats obtenus de 18 enfants des six premiers groupes d'utilisateurs de l'implant cochléaire Nucleus 22 canaux, du Tactaid et de prothèses auditives après un, deux et trois ans d'utilisation. Les résultats indiquent qu'il y a eu une amélioration considérable de la perception de la parole, de la lecture labiale et de l'articulation chez les sujets qui ont utilisé l'implant cochléaire Nucleus 22, combiné à un entraînement intensif de l'audition et de la parole, comparativement aux sujets étudiés qui ont utilisé le Tactaid ou une prothèse auditive. Les différences dans l'acquisition du langage étaient moins évidentes, et la plus grande amélioration a été observée chez les sujets qui ont reçu l'implant cochléaire ou qui ont utilisé le Tactaid, comparativement aux sujets qui ont utilisé la prothèse auditive.*

## Introduction

The purpose of this article is to report on the speech perception, speech production, and language performance of profoundly hearing impaired children using three types of assistive listening devices: multi channel cochlear implants, tactile aids, and hearing aids. Data are drawn from a longitudinal study being conducted at the Central Institute for the Deaf (CID) examining the effectiveness of each of these devices in combination with long-term intensive speech training in the oral program at CID.

Children who have received the Nucleus 22 Channel cochlear implant since 1987 have become the focus of considerable research as investigators attempt to establish what kind of benefit may be expected and for which children. Past research studies have focused primarily on auditory speech perception and speech production skills and have documented the benefit obtained from the Nucleus 22 Channel implant in two ways: (1) by comparing post-implant performance with scores obtained with a hearing aid before implantation and (2) by comparing scores of Nucleus 22 Channel implant users with those of children wearing other devices. Following is a summary of the questions addressed in these articles and some of the answers reported.

### Speech Perception

*Can the children hear speech better with the Nucleus 22 Channel implant than they could with hearing aids?*

Staller, Beiter, Brimacombe, Mecklenburg, and Arndt, (1991) analyzed speech perception results for 142 children who had worn a Nucleus 22 Channel implant for at least one year, 65 who had worn it for 2 years, and 12 children after 3 years of implant use. When listening to words in a closed set, 54% of the children showed significant improvement during the first year, 63% after two years, and 71% after three years. Some of the children could understand a few words in an open set: 43% after one year, 55% after two years, and 67% after three years.

*Can children understand more speech when lipreading with the Nucleus 22 Channel implant than they could without it?*

Staller et al. (1991) compared lipreading only scores with lipreading and listening scores for 43 children. After a year with the implant children averaged 51% correct on CID sentences in the lipreading only condition and 71% in the lipreading plus listening condition, an average increase of 20%.

*Are speech perception scores of children with Nucleus 22 Channel cochlear implants better than those of tactile aid, hearing aid, and 3M/House single channel implant users?*

Osberger, Chute, Pope, Kessler, Carotta, Firszt, and Zimmerman-Phillips (1991a) compared speech perception scores of four groups of 11 children fitted with single channel and multichannel implants, tactile aids, and hearing aids. As a group, Nucleus 22 Channel implant users obtained significantly higher speech perception scores on both closed and open set materials than the following comparison groups: (1) Tactaid II (two-channel tactile aid) users; (2) 3M/House single channel cochlear implant users and; (3) hearing aid users with unaided thresholds greater than 110dB HL.

On the other hand, average speech perception scores of Nucleus 22 Channel implant users were not significantly better than those of profoundly hearing impaired children who obtain some benefit from hearing aids. Specifically, Nucleus 22 Channel implant users did not differ from children with better ear unaided thresholds between 100 and 110 dB (Somers, 1991). Also, Nucleus 22 Channel implant users scored significantly below children with unaided thresholds of 90-105 dB throughout the frequency range (Osberger et al., 1991a).

*What factors are most important in predicting which children will obtain significant auditory benefit from the Nucleus 22 Channel implant?*

The factors which have been related to successful implant use in recent studies are: later onset of deafness (Staller et al. 1991); shorter duration of deafness (Staller et al., 1991); oral training (Staller et al., 1991; Osberger et al.,1991a; Somers, 1991); and full electrode insertion (Staller et al., 1991). However, data supporting some of these predictive factors are inconsistent. For example, although Staller's data indicate that the more language and sensory experience a child had before losing hearing, the better the prognosis for early post-operative development of speech perception and lipreading skills, Osberger did not find these factors to be significant predictors of performance. Although in all studies, implant users in oral programs developed significantly better speech perception skills than those enrolled in total communication (TC) programs, when children were matched for age at onset of deafness, the Oral/TC differences in speech perception scores were eliminated (i.e., oral programs tended to have more children with later onset) (Staller et al., 1991). However, in another study Somers (1991) compared 13 oral and 13 TC implant users who all lost their hearing before age 3. The oral children scored significantly higher on all speech perception measures.

## Speech Production

*Do the children imitate more speech sounds when wearing an implant than they did when wearing a hearing aid?*

Tobey, Angelette, Murchison, Nicosia, Sprague, Staller, et al., (1991) analyzed scores of 78 implanted children on the *Ling Phonetic Level Evaluation.* Almost 70% of the children showed a "clinically significant" improvement in their ability to imitate phonemes after one year with the implant, and their performance continued to improve during the second year.

*Is the ability to imitate prosodic cues (duration and pitch) improved significantly for implanted children?*

Although Tobey et al., (1991) report significant changes in the imitation of nonsegmental features following implantation, this skill appeared to plateau within one year after implantation. Only about 30% of the implanted children studied by Tobey showed clinically significant improvement in suprasegmental skills.

*Do imitative speech skills developed at the syllable level in conjunction with the implant generalize to better production in sentences and connected discourse?*

Speech intelligibility, measured on the McGarr sentences, increased an average of 10% after a year's experience with the Nucleus 22 Channel implant. Analysis of Phonologic Level evaluations for 36 children indicated increased accuracy of speech sounds produced in a spontaneous speech sample after 12 months of implant use (Tobey et al., 1991).

*Do speech skills of Nucleus 22 Channel implant users improve more rapidly than those of tactile aid, hearing aid, and single channel implant users?*

Osberger, Miyamoto, Zimmerman-Phillips, Kemink, Stroer, Firszt, and Novak (1991b) analyzed spontaneous speech samples of 7 children with 3M/House single channel implants, 7 with Nucleus 22 Channel implants, 7 with Tactaid IIs, and 7 hearing aid users with unaided thresholds greater than 110 dB HL. After one year, Nucleus 22 Channel cochlear implant users produced more recognizable English phonemes in a language sample than did children with similar or greater duration of experience with the other three devices.

*What are the effects of training on the rate at which speech is acquired with the Nucleus 22 Channel implant?*

The studies reported so far do not adequately control for the effects of training. Training may account for none, some, most, or all of the documented changes which are attributed to the cochlear implant (Geers & Moog, 1986b). For many of the children studied in the FDA clinical trials, the amount of time devoted to speech and auditory training dramatically increased at the time, or shortly before, they were implanted. This is due to the rehabilitation program implemented by all investigational sites which participated during FDA trials.

In one attempt to control for training effects Osberger, Robbins, Berry, Todd, Hesketh, and Sedey (1991) compared speech production gains in groups of children with implants and tactile aids who received the equivalent of 30-45 minutes per week of additional speech training outside of their total communication setting for a period of 6 months post-implant. Results of this study indicated that children with the Nucleus 22 Channel implant made more speech gains than either Tactaid II or 3M/House single channel implant users with the same amount of out-of-school training, suggesting that it was the device rather than the training that made the difference. On the other hand, all subjects showed more improvement during the first 6 months (during training) than during the last 6 months after the extra training was discontinued, indicating that training does play a major role in helping children improve their speech regardless of the device used.

### Language

*Do children improve their ability to understand and produce spoken language after using a cochlear implant?*

There is very little group data with regard to spoken language performance with the Nucleus 22 Channel implant. One study, which documented mean length of utterance before and after wearing a multichannel implant for one year, showed no significant change on this variable (Tobey et al., 1991).

## The CID Study

The purpose of the CID study (Geers & Moog, 1986a) is to compare the effectiveness of cochlear implants, tactile aids, and hearing aids when used with long-term intensive auditory and speech training in the oral program at CID. This program is designed to teach hearing impaired children to use residual hearing in combination with lipreading to understand spoken language and to talk intelligibly.

The auditory gains which have been documented in children wearing the Nucleus 22 Channel implant, while significant, are quite limited. Even after 2-3 years of implant use, most children still rely primarily on visual cues (lipreading and/or signing) for comprehension. However even a small amount of residual hearing can be useful in helping hearing impaired children learn to talk and understand speech with lipreading (Geers & Moog, 1988; Geers & Moog, 1989). It has yet to be demonstrated whether the information provided by a Nucleus 22 Channel cochlear implant or a Tactaid is more useful than that provided by hearing aids for the development of spoken language.

### Method

The design of the CID study requires that each child using a cochlear implant be matched with two other children, one using a tactile aid and the other using conventional hearing aids. Preimplant matching characteristics included all of those factors which are considered to be the most important predictors of rate of spoken language acquisition (Geers & Moog, 1987). Once matched groups have been selected, all participants are enrolled in the CID program and are evaluated over a three year period.

Enrollment of all children in the same educational program will permit examination of the effects of these devices on spoken language development over and above the gains normally achieved with oral instruction. Three years will provide an opportunity for the children to learn to interpret the signal delivered by their new device. These children are evaluated before they receive their device and then at regular intervals throughout the three year period on a battery of tests of speech perception, visual enhancement, speech production, and spoken language acquisition.

#### Subjects

There are 16 matched sets or a total of 48 children currently enrolled in the CID study. The focus of this report will be the 18 children in the first six sets who have completed more than one year of the study. Four of these groups (12 children) have completed three years, one set (3 children) has completed two years, and the other set (3 children) has completed one year.

All of the implanted children are wearing the Nucleus 22 Channel implant. A full insertion of the electrode was achieved for all except two subjects, who each had 10 electrodes inserted. Four of the six children use the wearable speech processor (WSP) and two use the mini speech processor (MSP).

The tactile aid subjects first wore the Tactaid II, a two-channel vibrotactile device that separates high frequency (consonant) sounds from low frequency (vowel) sounds. In November, 1990 a new seven-channel tactile aid, the Tactaid

**TABLE 1. Pretest Characteristics of Matched Subjects in the Six Experimental Triads**

| Subject | Age | SFA* | Lang %ile | IQ | % Speech Sounds | Age H.L Diagnosed | Etiology |
|---|---|---|---|---|---|---|---|
| CI-1 | 7;3 | 123 | 85 | 100 | 55 | 1;4 | Meningitis |
| TA-1 | 7;7 | 122 | 90 | 111 | 31 | 0;1 | Genetic |
| HA-1 | 7;7 | 115 | 83 | 100 | 45 | 0;8 | Genetic |
| CI-2 | 10;8 | 120 | 50 | 100 | 69 | 3;10 | Meningitis |
| TA-2 | 9;10 | 112 | 65 | 112 | 60 | 0;9 | Genetic |
| HA-2 | 12;2 | 123 | 65 | 126 | 49 | 1;3 | Unknown |
| CI-3 | 6;3 | 123 | 20 | 107 | 14 | 1;6 | Meningitis |
| TA-3 | 5;8 | 110 | 50 | 93 | 20 | 1;8 | Unknown |
| HA-3 | 6;6 | 113 | 20 | 122 | 20 | 1;5 | Unknown |
| CI-4 | 2;5 | 123 | 78 | 92 | 6 | 2;1 | Meningitis |
| TA-4 | 1;8 | 112 | 59 | 97 | 1 | 1;5 | Meningitis |
| HA-4 | 1;9 | 113 | 63 | 90 | 2 | 1;5 | Unknown |
| CI-5 | 4;0 | 125 | 50 | 111 | 2 | 1;5 | Unknown |
| TA-5 | 3;0 | 110 | 33 | 112 | 1 | 1;4 | Unknown |
| HA-5 | 3;6 | 122 | 33 | 91 | 2 | 0;7 | Genetic |
| CI-6 | 4;6 | 110 | 88 | 112 | 29 | 1;2 | Unknown |
| TA-6 | 5;2 | 108 | 77 | 107 | 21 | 1;3 | Unknown |
| HA-6 | 5;6 | 100 | 77 | 119 | 35 | 1;3 | Ototoxicity |

*Speech Frequency Average (500, 1000, 2000 Hz) dB, HL

**Table Legend**
SFA = Better ear frequency average at 500, 1000, and 2000 Hz (dB, HL); Lang % ile = percentile rank re hearing impaired age-mates on the age appropriate level of the Grammatical Analysis of Elicited Language test series; IQ = intelligence quotient on an age appropriate nonverbal test; % Speech Sounds = total score on the *CID Phonetic Inventory*.

VII, became available. This device represented improved technology over the Tactaid II. Instead of dividing the speech signal into only two frequency bands, the Tactaid VII divides the speech signal into seven frequency bands, which are delivered to seven vibrators mounted on the sternum. This new array is more analogous to the Nucleus 22 Channel cochlear implant in terms of its potential for delivering formant information about speech. Therefore all tactile aid subjects were fitted with the Tactaid VII, which had been in use by these subjects for almost one year at the time of this report.

The hearing aid subjects continued to wear two powerful hearing aids just as they had since their deafness was first identified. In addition, all of the tactile aid subjects and most of the cochlear implant subjects continued to wear a hearing aid on at least one ear.

Preimplant characteristics of the 18 subjects are summarized in Table 1. Tactile aid and hearing aid subjects were matched as closely as possible to the cochlear implant subject on age, hearing loss, language level, intelligence, speech skills, and family support.

### Training Program

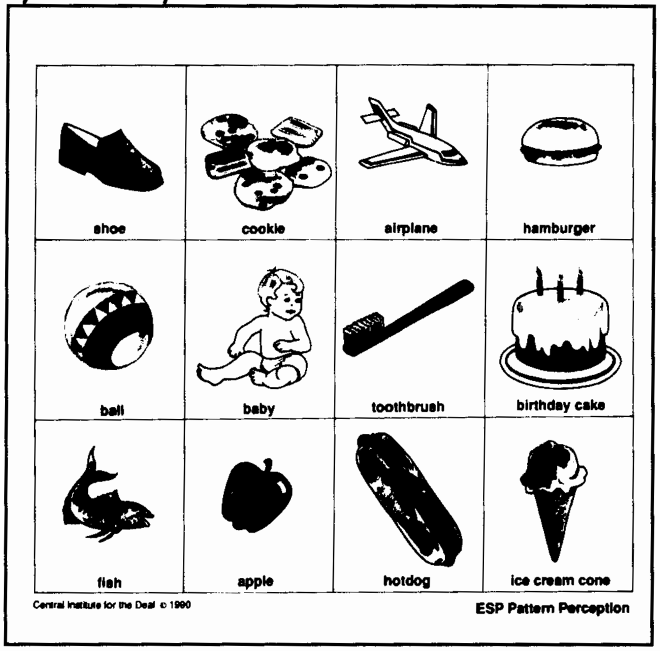
All children at CID receive auditory training as a part of their regular school program. Each child receives some auditory training associated with work on speech production and some associated with comprehension of spoken language. Children enrolled in the study received about 15 minutes daily extra auditory training in addition to that normally provided within the school program. The analytic portion of the auditory training curriculum was individualized to capitalize on the unique speech information provided by each device (Moog, Davidson, Brenner, & Geers, 1991). As soon as the child had acquired some ability to discriminate words and phrases and had sufficient language skills to understand sentences, this analytic training was accompanied by more global practice, first in identification of sentences and then on a tracking task.

### Speech Perception Tests

*The CID Early Speech Perception Test* (Moog & Geers, 1990).

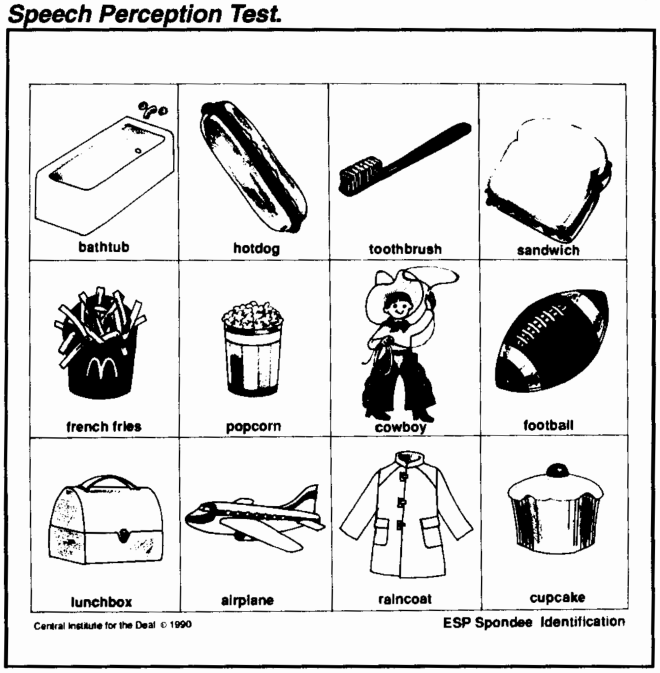
This test measures the ability of children to choose a pictured word or object based on selected auditory distinctions. The ESP is composed of three subtests: (1) The Pattern Perception subtest (Figure 1) contains words that differ in number of syllables or stress pattern (i.e., monosyllable, trochee, spondee, 3 syllable word). A response to any word in the same stress column as the stimulus word is counted as correct. This is the easiest auditory task because it requires that the child be able to detect sound, but does not require that he/she discriminate sounds of different spectral characteristics. Even children with no residual hearing can be trained to use vibratory patterns to make these types of distinctions. (2) The Spondee Identification subtest (Figure 2) evaluates the child's ability to tell the difference between words with the same stress pattern in a closed set response task. This requires some

**Figure 1. Pattern perception subtest of the *CID Early Speech Perception Test.***




ability to identify spectral cues—a true test of hearing for a profoundly hearing impaired child (Erber, 1979). Two syllable words provide the child with two opportunities to identify the correct choice. For example, if the child hears either *bath* or *tub* he can correctly identify the word *bathtub* from the choices provided. (3) The Monosyllable Identification subtest (Figure 3) requires even better speech recognition abilities because the perception is based on only one syllable; words differ from one another primarily in the vowel sound.

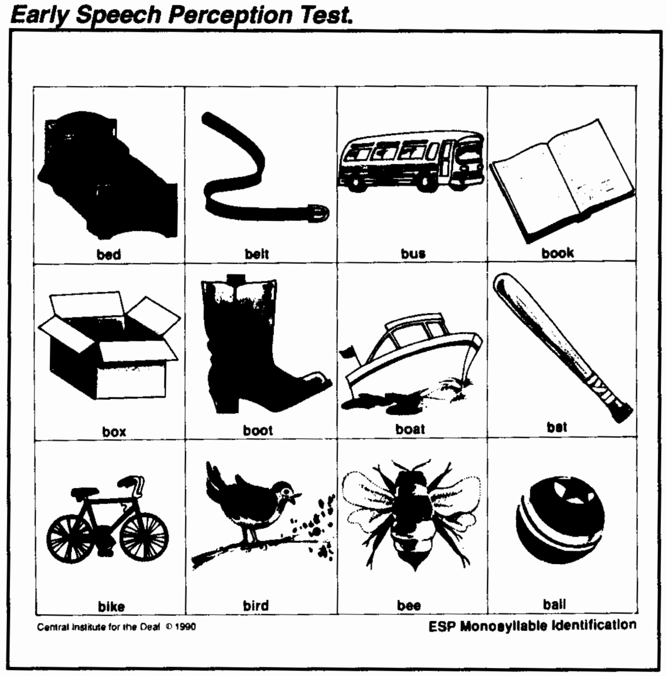
**Figure 2. Spondee identification subtest of the *CID Early Speech Perception Test.***




*Northwestern University Children's Speech Perception Test (NU-CHIPS)* (Elliott & Katz, 1980).

This is a 4-choice closed set speech perception test that requires both vowel and consonant discrimination ability in order to select the correct word from its foils. For example, the choices *coat, soap, boat,* and *stove* all have the same vowel sound but differ in initial and final consonants. However the choices *watch, witch, fish,* and *frog* differ in both vowel and consonant sounds.

**Figure 3. Monosyllable identification subtest of the *CID Early Speech Perception Test.***




*Word Intelligibility by Picture Identification Test (WIPI)* (Ross & Lerman, 1971).

This is a 6-choice closed set speech perception test that primarily requires consonant discrimination ability (e.g., *hair, pear, stair, ear, bear, chair*).

*Kindergarten Phonetically-Balanced Word List (PBK)* (Haskins, 1949).

This test samples the child's ability to understand words in an open set. The child who can repeat 2 or more words from this set of 50 unrelated words was judged to have developed some open set speech perception.

*Phonetic Task Evaluation* (Mecklenburg, Shallop, & Ling, 1987).

Instead of using words, this test uses contrasting syllables to evaluate perception of selected segmental and suprasegmental aspects of speech: pitch (high-low), manner (*ha-ka; ba-ma; wa-ba*), place (*ga-ba; ja-wa; na-ma*), voicing (*ga-ka; pa ba; da-ta*), and vowels (*a - i - u*).

**Visual Enhancement Tests**
This is a term that refers to the increase in speech perception scores obtained when audition is added to lipreading. In order to accommodate children with different levels of lipreading ability, enhancement was always measured using a task on which the child achieved a lipreading only score above 40% (indicating the ability to speechread some of the items) and below 75% (indicating that there is still room for improvement in performance when auditory cues are added) (Geers & Moog, 1989). Therefore a variety of materials were used to measure visual enhancement. For younger children, the battery consisted of closed set tasks such as the *Craig Lipreading Inventory* (Craig, 1964). Once children achieve 75% lipreading scores on closed set tasks, open set lists, such as the *CID Everyday Sentences* (Davis & Silverman, 1978), are presented and scored in terms of the number of key words the child identified. The percentage of audiovisual gain is then normalized by the potential benefit possible given an individual's speechreading score, as proposed by Tyler, Tye-Murray, Woodworth, and Gantz (1990).

**Speech Production Tests**
Speech skills were measured at the phonetic level in syllable imitation and at the phonologic level in a spontaneous speech sample. All speech evaluations were conducted by an independent evaluator who was not the child's speech teacher.

*The CID Phonetic Inventory* (Moog, 1989).

This test provides scores in six skill areas: suprasegmentals, vowels, and four consonant skills. All scores are obtained from a clinician who rates the child's syllable imitations. Each syllable is administered in a developmental sequence so that if a child imitates a speech sound in a single syllable (ba), the clinician elicits that sound in a repeated syllable (ba, ba,) and then presents that speech sound in combination with another in alternated syllables (ba, be, ba, be).

*Phonologic Level Speech Evaluation* (Ling, 1976).

This form evaluates the transfer of learned sounds to spontaneous speech. A 50 utterance speech sample is analyzed for nonsegmental aspects (normal or faulty), vowels and diphthongs, simple consonants and consonant blends (used consistently, inconsistently, or not at all), and percent of intelligible utterances.

**Language Tests**
*Developmental Sentence Scoring (DSS)* (Lee & Koenigsknecht, 1974).

This is a syntax-based scoring procedure that was used to analyze spontaneous language samples elicited from each child. In most cases the analysis is based on 50 utterances.

*Peabody Picture Vocabulary Test (PPVT)* Dunn & Dunn, 1981).

This test evaluates receptive (spoken) vocabulary. Test performance is expressed as an age score in relation to normal hearing children.

*Expressive One Word Picture Vocabulary Test (EOWPVT)* (Gardner, 1979).

This test evaluates expressive (spoken) vocabulary. Test performance is expressed as an age score in relation to normal hearing children.

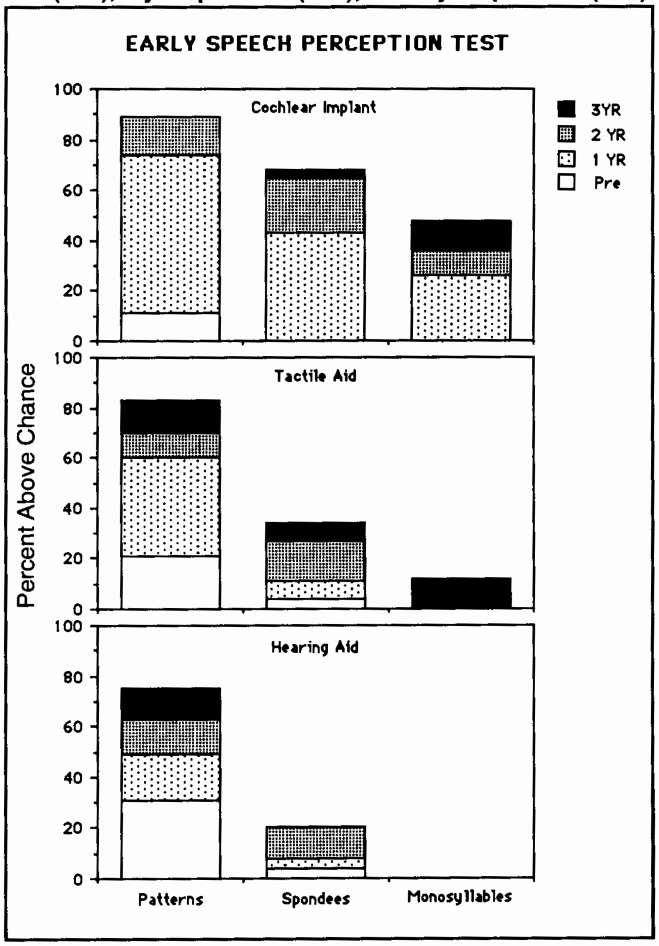
## Results

Results are presented for each measure in terms of pretest performance level and change in score achieved after 1 year, 2 years, and 3 years in the study. It should be noted that six groups are included in the pretest and one year data, but only five of these are included in the two year data, and four are included in the three year data.

**Speech Perception**
The three histograms in Figure 4 represent average scores on the three subtests of the ESP battery corrected for chance responding. The top histogram presents results for the implant subjects, the middle for the tactile aid subjects, and the bottom for the hearing aid subjects. The bottom white portion of each bar represents the average score of each subject set at pretest. The next dotted portion represents the average percent improvement from pretest to one-year posttest. The next shaded portion of each bar represents average change from one-year posttest to two-year posttest. The darkest portion of each bar represents change from two-year to three-year posttest.

A longer period of time was required to show improvement for the more difficult speech perception tasks. The implant subjects made progress on all 3 subtests during the first year with the largest gain observed for the pattern perception subtest. Improvement by the implant subjects during the third year was primarily in their ability to identify monosyllable words, which requires differentiating vowels based on spectral cues. Although the tactile aid and hearing aid subjects

**Figure 4. Average above chance scores on the 3 subtests of the *CID Early Speech Perception Test* obtained by Nucleus 22 Channel cochlear implant users, tactile aid users, and hearing aid users at pretest (n=6), 1-year posttest (n=6), 2-year posttest (n=5), and 3-year posttest (n=4).**



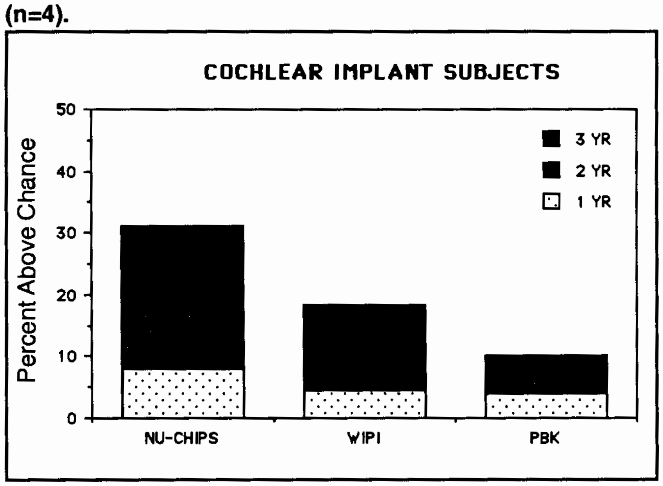

attained pattern perception scores by the third year that were close to those achieved by implant subjects, they displayed much less progress in their perception of spondees and monosyllables.

Figure 5 represents the average above chance scores of the cochlear implant subjects on the NU-CHIPS, the WIPI, and the open set PBK list. None of the tactile aid or hearing aid subjects were able to perform above chance on these tests. Cochlear implant subjects were able to perform above chance after they had worn the implant for one year, and they continued to show improvement during the next two years so that the most recent results show a 30% increase in NU-CHIPS, a 20% increase in WIPI, and a 10% increase in PBK scores.

Although average performance of the implanted children shows progress on all speech perception tests, there was considerable variability in the amount and the rate of change that was observed across subjects. In Figure 6, growth in speech perception ability is plotted by number of months post-implant for each of the six implanted children. The white portion of the bar indicates that the child showed no evidence of perceiving spectral cues during this period. The dotted portion indicates the period during which the child was performing above chance on the closed set word identification tasks. The lined portion at the end indicates the achievement of open set word recognition.

Although all but one of the cochlear implant subjects achieved open set word recognition, they differed in their rate of developing speech perception skills. Subject 6 acquired

**Figure 5. Average above chance scores of Nucleus 22 Channel cochlear implant users on the *Northwestern University Children's Speech Perception Test*, the *Word Intelligibility by Picture Identification Test* and the *Kindergarten Phonetically Balanced Word List* at 1-year posttest (n=6), 2-year posttest (n=5), and 3-year posttest (n=4).**




closed set word identification at 4 months and open set word recognition ability after only 8 months with the implant. Subject 1, although able to recognize words in a closed set after 4 months, did not achieve open set word identification until 24 months post-implant. Subject 3 never acquired closed set word identification skills at all, even after 36 months of implant use.

Performance of these subjects was not always predictable from factors known to be associated with implant benefit. Subject 3, with the poorest speech perception skills, had a partial electrode insertion, but so did subject 4 who achieved open set speech recognition. Subjects 5 and 6, both with congenital hearing impairments, achieved open set speech perception skills before any of the post-meningitis sub-

Figure 6. Change in speech perception performance over time by 6 subjects after receiving the Nucleus 22 Channel cochlear implant.

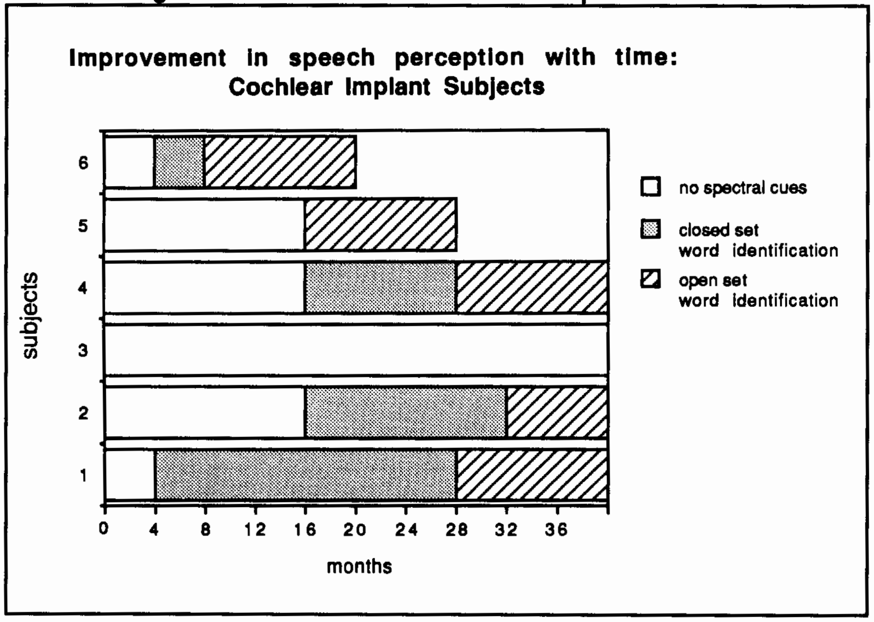
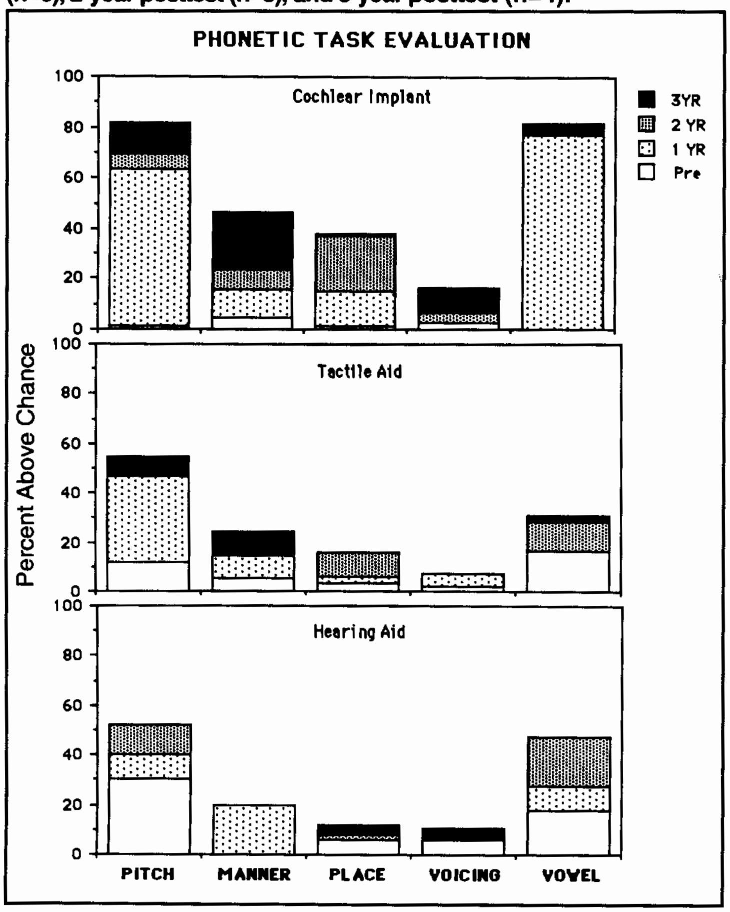



Figure 7. Average above chance scores on 5 subtests of the *Phonetic Task Evaluation* by Nucleus 22 Channel cochlear implant users, tactile aid users, and hearing aid users at pretest (n=6), 1-year posttest (n=6), 2-year posttest (n=5), and 3-year posttest (n=4).




jects. Subject 2, with the latest age at onset (3 yrs 10 mos), achieved open set later than all of the other cochlear implant subjects (except subject 3).

Figure 7 depicts change (corrected for chance) in perception of the 5 features of speech evaluated by the *Phonetic Task Evaluation* (Mecklenburg et al., 1987). The bottom histogram depicts the percent of change that may be anticipated in children with this degree of profound deafness who are wearing hearing aids and receiving intensive auditory training. Pitch, manner, and vowel perception each improved about 20% over 2 years and then reached asymptote. During the 3rd year, perception of place and voicing cues began to improve slightly. The tactile aid subjects did not achieve any better performance in discrimination of any feature than was exhibited by subjects wearing only hearing aids.

The cochlear implant subjects, however, far exceeded their matches in perception of all 5 features. Perception of pitch and vowel information improved about 80% with most of the gains achieved during the first year post-implant. Consonant perception categories showed later improvement: place of articulation in the second year and manner and voicing cues during the third year.

The general picture that emerges of auditory speech perception changes over time with a cochlear implant is that temporal pattern and vowel perception are the first skills to emerge and are achieved largely during the first year with the implant. More subtle vowel discriminations and some consonant discriminations are acquired during the second year. The third year's progress is apparent primarily in the further development of consonant discrimination ability.

### Visual Enhancement

Visual enhancement scores are summarized for the three device groups in Figure 8. After a year, the implant subjects had improved almost 40% in the advantage they achieved when lipreading with their implant. After the second year, the implant subjects improved another 10%, with no further improvements observed after the third year of the program. The tactile aid subjects averaged a 5% benefit at pretest, and the hearing aid subjects a 10% benefit after the first year. The tactile aid and hearing aid subjects displayed no further improvements during the second and third year posttests.

When the visual enhancement gains for the cochlear implant subjects are viewed in relation to their auditory speech perception gains discussed above, it appears that the suprasegmental and vowel discrimination ability acquired during the first year of implant use enhanced their ability to speechread. The consonant discrimination skills added during the second and third years provided

**Figure 8. Average visual enhancement scores, corrected for speechreading ability, obtained by Nucleus 22 Channel cochlear implant users, tactile aid users, and hearing aid users at pretest (n=6), 1 year posttest (n=6), 2-year posttest (n=5), and 3-year post-**

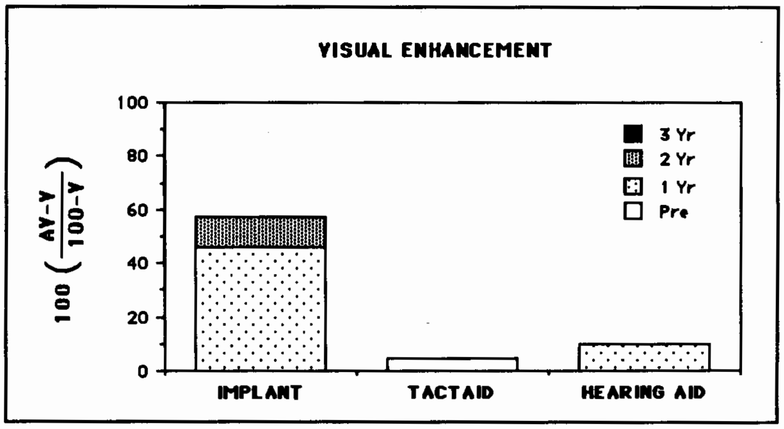
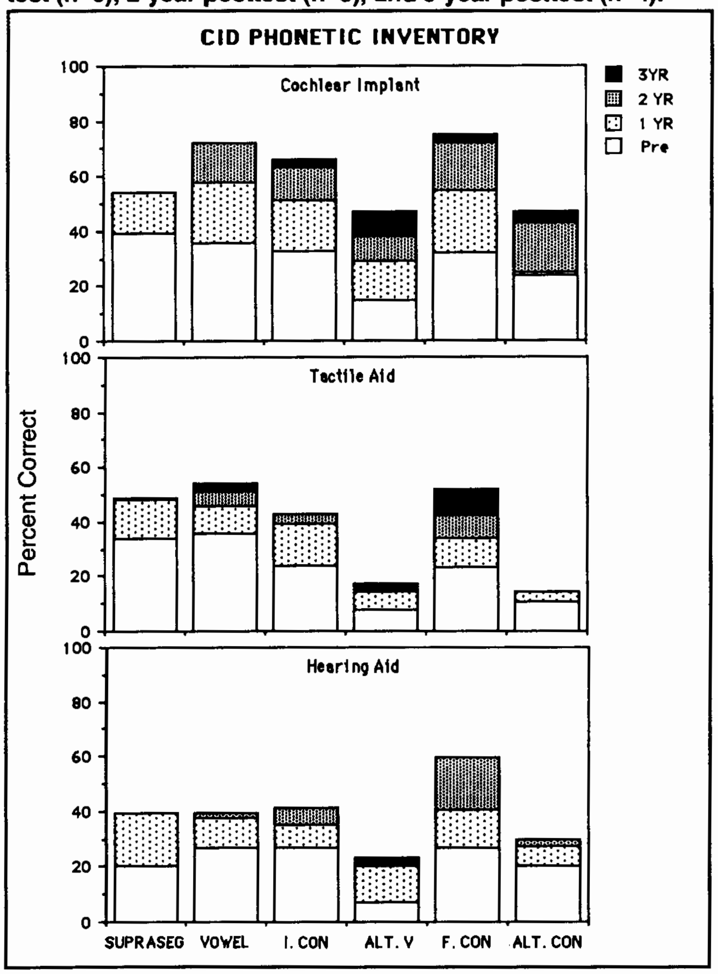



**Figure 9. Average percent correct scores on 6 subtests of the *CID Phonetic Inventory* (Suprasegmental Features, Vowels, Initial Consonants, Initial Consonants in an Alternating Vowel Context, Final Consonants, and Alternating Consonants) obtained by Nucleus 22 Channel cochlear implant users, tactile aid users, and hearing aid users at pretest (n=6), 1-year posttest (n=6), 2-year posttest (n=5), and 3-year posttest (n=4).**




some additional benefit to speechreading, but the additional information may have been redundant with the visual cues. Thus, the gains in auditory skills did not result in large improvements in visual enhancement. Teachers and testers noted that the implant subjects required less effort in speechreading after the first year, a trend that continued two and three years post-implant.

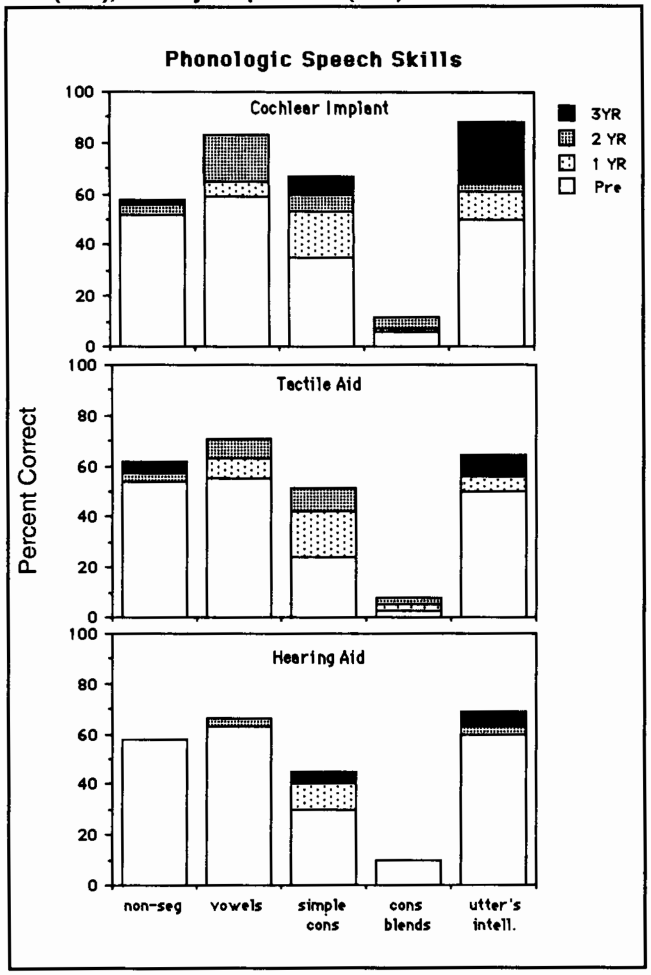
### Speech Production

Results on the *CID Phonetic Inventory* are presented in Figure 9. Again the bottom histogram may be viewed as a control group (i.e., progress achieved over a 3 year period by children wearing hearing aids). The tactile aid subjects did not differ from those wearing hearing aids in their phonetic speech progress. Both groups averaged about 20% across all categories at pretest and improved about 15% over three years.

The cochlear implant group scored about 10% higher than the other two groups at pretest. Their average improvement across all categories was about twice that of the other two groups (30%). As was the case for perception, vowel production skills reached asymptote after two years, but consonant production skill continued to improve into the third year.

Figure 10 represents change in the use of speech skills in spontaneous speech. The largest gain for hearing aid subjects is in simple consonants, which increased by about 15% over three years. In the remaining categories the hearing aid subjects showed relatively little transfer of the skills they learned at the phonetic level to their spontaneous speech.

**Figure 10. Average percent correct scores on 5 subtests of the Ling *Phonologic Level Evaluation* (Nonsegmentals, Vowels, Simple Consonants, Consonant Blends, Intelligible Utterances) obtained from Nucleus 22 Channel cochlear implant users, tactile aid users, and hearing aid users at pretest (n=6), 1-year posttest (n=6), 2 -year posttest (n=5), and 3-year posttest (n=4).**




The tactile aid subjects in the middle panel showed considerably more improvement at the phonologic level than did their hearing aid matches. They exhibited almost 20% growth in vowels and a 30% growth in simple consonants produced in their spontaneous speech over three years (compared to 3% and 15%, respectively, for hearing aid subjects).

The implant subjects averaged only about 5% more improvement than the tactile aid subjects in vowel and consonant sounds, but showed the biggest increase in their percent of intelligible utterances. A comparison with hearing aid subjects concerning improvements in intelligibility indicates that the cochlear implant has made a real impact on the ability of these children to talk and to be understood.

**Language**

Results for the two vocabulary measures are presented in Figure 11 expressed as age scores in months. The white portion of each bar represents average pre-implant vocabulary age and each segment above this represents change occurring during the three years of device use.

The cochlear implant does not appear to provide as large an advantage in the acquisition of receptive vocabulary (as measured by the *PPVT*) as it does for speech perception and speech production skills. All three device groups averaged about 15 months growth in receptive vocabulary over the three years. However, expressive vocabulary growth (as measured by the *EOWPVT*) is close to age level expectations for normal hearing children (i.e., 36 months increase in vocabulary age over 36 months time) in both the cochlear implant and the tactile aid subjects, while the hearing aid control subjects averaged only about 23 months growth in the same time period.

Developmental sentence scores (DSS) for the three device groups are plotted in Figure 12. Both the implant and the tactile aid subjects exhibited an advantage over the hearing aid subjects in their rate of acquisition of syntax. In both vocabulary and expressive syntax, the tactile aid subjects appeared to make the greatest growth during the third year.

## Conclusions

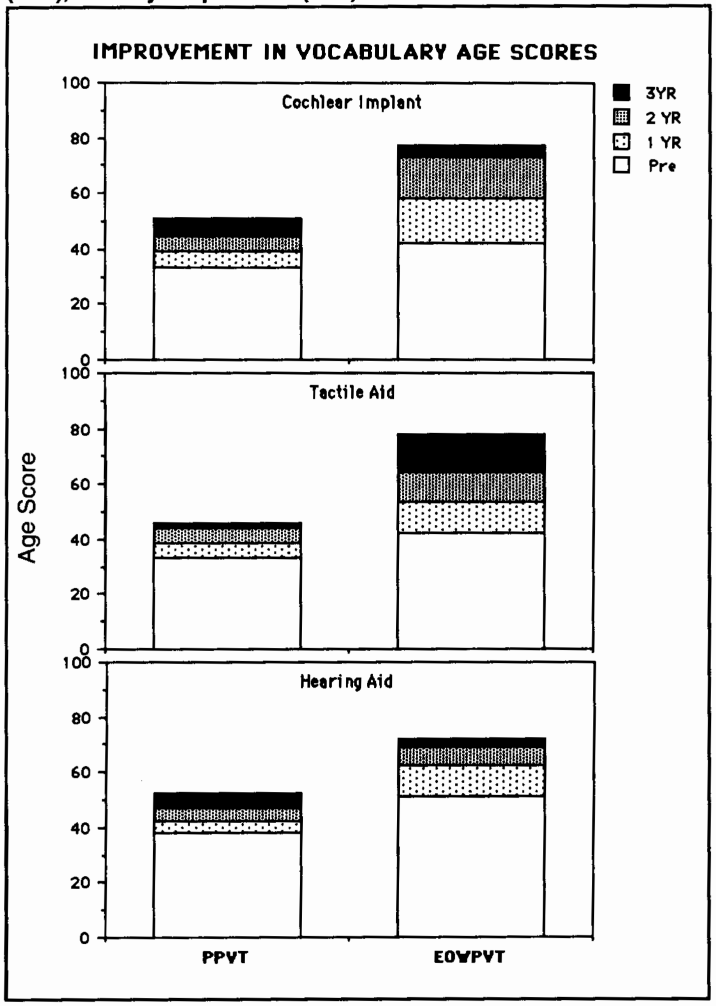
Based on the data accumulated for the first 6 sets of subjects in the CID Cochlear Implant study the following tentative conclusions may be made.

1. The Nucleus 22 Channel cochlear implant, in combination with intensive auditory training, enabled most of these profoundly hearing impaired children to distinguish stress and pitch in speech. Furthermore, the implant provided access to considerable vowel and even some consonant recognition that enhanced their speechreading ability and, for five out of six children, permitted some understanding of speech through audition alone.

2. Tactile aid and hearing aid subjects improved their closed set speech perception performances but did not display significant improvements in their visual enhancement or open set speech perception scores.

3. The auditory advantage provided by the Nucleus 22 Channel cochlear implant, when combined with intensive speech training, resulted in improved segmental speech skills (i.e., more accurate production of vowel and simple consonant sounds). This change occurred in both imitated and spontaneous speech and was associated with larger

**Figure 11. Average vocabulary age scores on the *Peabody Picture Vocabulary Text (PPVT)* and *Expressive One-Word Picture Vocabulary Test (EOWPVT)* obtained by Nucleus 22 Channel cochlear implant users, tactile aid users, and hearing aid users at pretest (n=6), 1-year posttest (n=6), 2-year posttest (n=5), and 3-year posttest (n=4).**




improvements in speech intelligibility when compared to tactile aid and hearing aid subjects.

4. Gains observed in the cochlear implant subjects' ability to perceive and produce speech were less clear in spoken language development. Expressive vocabulary and syntax development improved in both Tactaid and Nucleus 22 Channel cochlear implant users when compared to hearing aid users. As noted above, the subjects wearing Tactaids changed from the 2-channel to the 7-channel version of this device during the third year of the study. In fact, at the time of testing, they had been wearing it for less than a year, so the extent to which the gains in language development are attributable to the Tactaid VII is not yet clear.

5. A sudden change in speech perception ability, as provided by the cochlear implant, may require more than three years to measurably affect language test scores. Nevertheless, these preliminary results suggest that the Nucleus 22 Channel cochlear implant provided a distinct advantage for all areas evaluated in these children.

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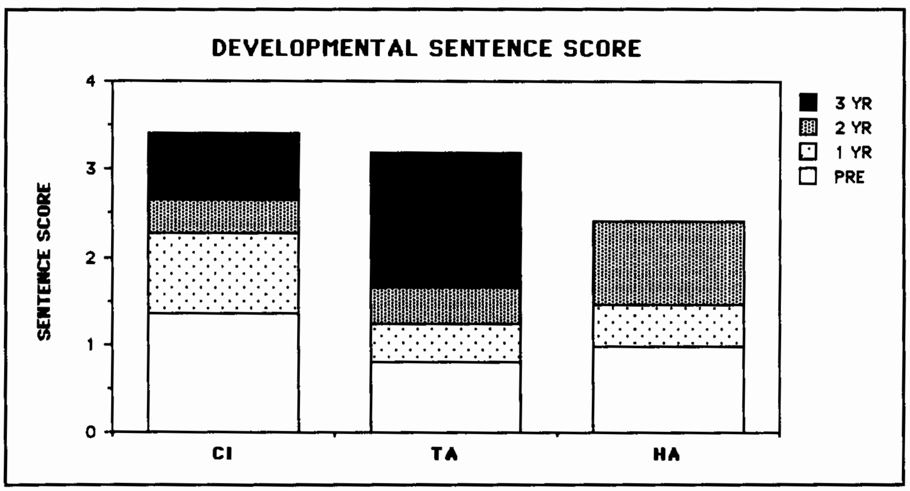
**Figure 12. Average developmental sentence score (DSS) obtained from a 50 utterance spontaneous sample by Nucleus 22 Channel cochlear implant users, tactile aid users, and hearing aid users at pretest (n=6), 1-year posttest (n=6), 2-year posttest (n=5), and 3-year posttest (n=4).**



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