Speech Perception and Spoken Language in Children with Impaired Hearing

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ABSTRACT

Fifty seven children with impaired hearing aged 4-12 years were evaluated with speech perception and language measures as the first stage of a longitudinal study. The Clinical Evaluation of Language Fundamentals (CELF) and Peabody Picture Vocabulary Test (PPVT) were used to evaluate the children's spoken language. Regression analyses indicated that scores on both tests were significantly correlated with chronological age, but delayed relative to children with normal hearing. Performance increased at 45% of the rate expected for children with normal hearing for the CELF, and 62% for the PPVT. Perception scores were not significantly correlated with chronological age, but were highly correlated with results on the PPVT and CELF. The data suggest a complex relationship whereby hearing impairment reduces speech perception, which slows language development, which has a further adverse effect on speech perception.

1. INTRODUCTION

Over the last 25 years, technological advances in hearing aids and cochlear implants have made it possible for children with severe (70 to 90 dB HL) and profound (over 90 dB HL) hearing losses to hear speech sounds at conversational levels. This does not guarantee that they will develop normal spoken language, and a wide range of speech perception and language abilities are typically found for this population. The factors affecting performance and the relationship between hearing abilities and language development are under investigation in a longitudinal study being conducted in Melbourne and Sydney on a group of primary-school-aged children. The general hypotheses to be addressed in the study are that:

- There is a critical age (estimated to be around 6 years) beyond which good open-set speech perception cannot be established.
- There is a critical level of hearing below which good open-set speech perception cannot be established.
- Hearing such that no aided thresholds fall within the normal speech amplitude range for frequencies of 1500 Hz or above is hypothesized to be below the critical level.
- Hearing with a cochlear implant is hypothesized to exceed the critical level.

Children using cochlear implants are especially interesting as there are reasonably large numbers who have been deaf since birth, whose auditory capacity is suddenly and dramatically improved. Study of this population is likely to result in new insight into the adaptability and/or limitations of the developing human brain, as well as direct benefits to hearing-impaired children through improved habilitation methods.

2. METHODS

Data collection for the longitudinal study referred to above commenced in 1997. The study will eventually include about 100 children of primary-school age, and will involve five annual evaluations of speech perception, language and speech production for each child. This paper reports and analyses all data collected prior to May 1998.

2.1. Subjects

Fifty seven children with severely or profoundly impaired hearing had participated in the study prior to May 1998. The children were aged from 4y 2m to 12y and were all enrolled in oral/aural programs in preschools or primary schools. Twenty four children used the 22-electrode cochlear implant produced by Cochlear Limited [1] and thirty three were fitted with hearing aids. Two of the implant users became deaf at ages one and three years, and all other children had impaired hearing from birth.

	Cochlear implant users	Hearing aid users
Number of children	24	33
No. with congenital loss	22	33
Mean age at device fitting	3.6 (1.7) years	unknown
Mean age at evaluation	7.7 (1.9) years	8.4 (2.2) years
Hearing loss pre-op.	> 100 dB HL	81 (17) dB HL

Table 1: Children's details. Values in brackets are standard deviations.

2.2. Evaluations

Speech perception was evaluated with a monosyllabic word test (CNC words [2]) and a sentence test (BKB sentences [3]) presented with audition alone (A condition) and with audition plus vision (AV condition). The tests were presented with live voice at a comfortable listening level at a distance of about 1 metre from the child. The child's responses were videotaped and scored off-line independently by two scorers. In a few cases, older children gave written responses. CNC words were scored by whole words correct. BKB sentences were scored by key words correct, using a strict criterion which required the complete word to be produced correctly including morphological markers for plurality, tense, etc. 100 CNC words and 32 sentences containing 100 key words were presented in each condition for most children. Half this amount was presented to 17 children whose evaluation needed to be completed within a single day.

The Clinical Evaluation of Language Fundamentals (CELF-3 and CELF-Preschool [4]) and the Peabody Picture Vocabulary Test (PPVT-R and PPVT-III [5]) were used to evaluate the children's spoken language. Both tests have been normed with large groups of normally-hearing children and each score may be expressed as an equivalent age, ie the age at which an average normally-hearing child would attain the given score.

3. RESULTS

3.1. Speech Perception

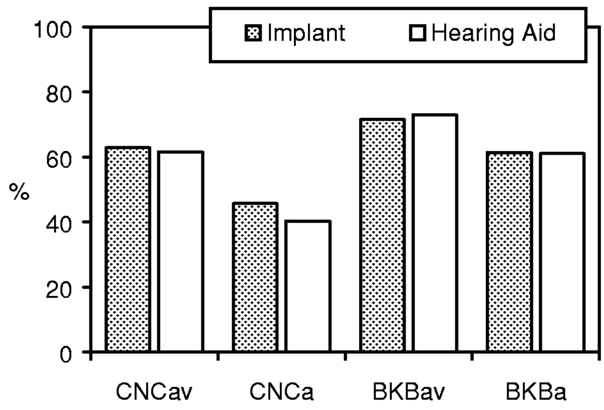

Figure 1: Mean speech perception scores.

Figure 1 shows the mean scores for each perception test for the A and AV conditions with the children separated into implant and hearing aid users. There was no significant difference between the implant and hearing aid users in the mean speech perception scores for either perception test in either condition (p>0.05).

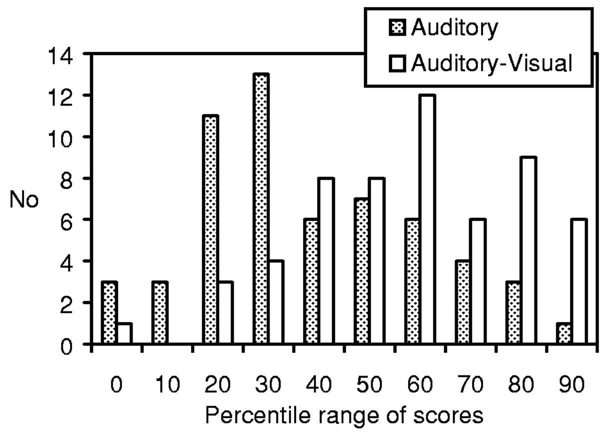

Figure 2: Number of children grouped by CNC word scores.

Figure 2 shows the distributions of scores on the CNC Word Test in the A and AV conditions for implant and hearing aid users combined. Scores were spread over extremely wide ranges for both conditions, and this applied to the BKB sentence test and CNC phoneme scores in both conditions also. Although each perception test yielded a wide range of scores, there were no strong correlations with the chronological ages of the children (Table 2). As an example, Figure 3 shows the BKB Sentence scores in the A condition as a function of age.

Regression line	r^2	p
CNC AV = 3.5 x Age + 34.0	0.12	0.008
CNC A = 1.2 x Age + 33.4	0.01	0.4
BKB AV = 3.6 x Age + 43.6	0.13	0.005
BKB A = 2.7 x Age + 39.8	0.05	0.08

Table 2: Regression analyses of perception scores in % versus chronological age in years.

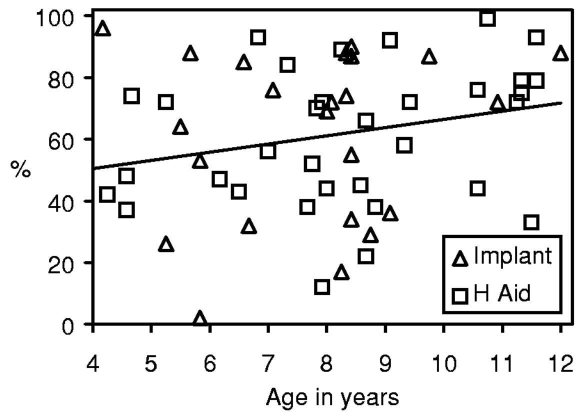

Figure 3: BKB Sentence scores in the auditory condition. The equation of the regression line is given in Table 2.

3.2. Spoken Language

Mean chronological ages and equivalent ages for the PPVT and CELF language measures are shown in Figure 4 for the children divided into implant and hearing aid user groups. The CELF-3 is designed for ages 6 and over, and the CELF-Preschool for ages up to 7 years. All children were evaluated with the more appropriate of the two CELF tests according to their language abilities, and many were tested with both. The bars labelled "CELF" use the more appropriate of the two tests (ie, if a child's equivalent language age was measured to be within the range for the CELF-Preschool, then this test score was used. If the child's equivalent age was greater than 6 years, the CELF-3 score was used.) There were statistically significant differences (p<0.05) between the implant and hearing aid users for all three sets of CELF scores. These probably arose because the hearing aid users were older on average and had probably been fitted with hearing aids earlier than the implant users, giving them longer to learn to use the auditory signals. The scores on the PPVT and CELF were very highly correlated ($r^2 = 0.85$, $p<0.001$).

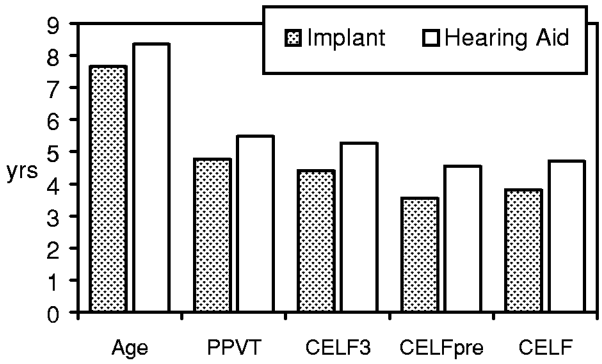

Figure 4: Mean chronological ages and equivalent ages for language measures.

The subtests of the CELF-3 and CELF-Preschool can be classified as "receptive" or "expressive" and a standard score of 100 is assigned to average performance of normally-hearing children at each age, with a standard deviation of 15 units. Thus it is expected that 68% of children with normal hearing will obtain scores between 85 and 115 (within one standard deviation of the mean). Figure 5 shows that only 17 out of 57 children in this study had receptive language scores greater than 85, and only 11 had expressive language scores in this range. Mean standard scores for receptive and expressive language are equal by construction for the normally-hearing population, but there was a significant difference in this study. The mean for receptive was 75, and the mean for expressive was 70 ($p<0.05$), indicating that expressive language was delayed more than receptive language in this group.

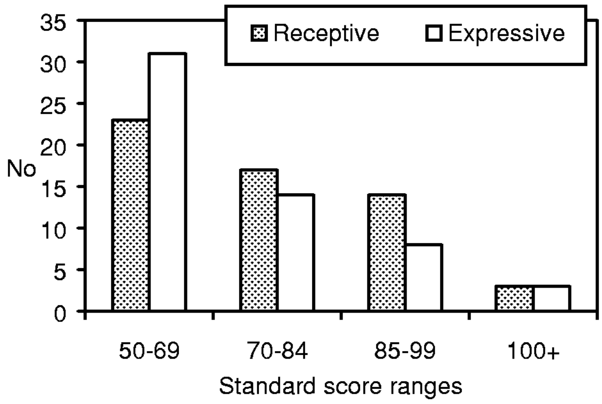

Figure 5: Number of children grouped by standard scores for the receptive and expressive subsets of the CELF.

In contrast to the perception scores, the equivalent ages for CELF and PPVT were significantly correlated with chronological age. These regression lines are shown in Figures 6 and 7, together with lighter lines with slope equal to 1 which indicate the mean performance for children with normal hearing. Equations for the regression lines are given in Table 3.

The steeper slope of Figure 6 compared to Figure 7 suggests that the children are more advanced in their vocabulary knowledge as measured by the PPVT than they are in other aspects of spoken language as measured by the CELF. This conclusion is consistent with the observation that the mean standard score for the Word Associations subtest of the CELF-3 was within the normal range, while mean scores for most other subtests fell below the normal range. Boothroyd et al [6] reported a regression analysis with a similar slope of 0.6 for 188 children with hearing losses between 90 and 104 dB HL.

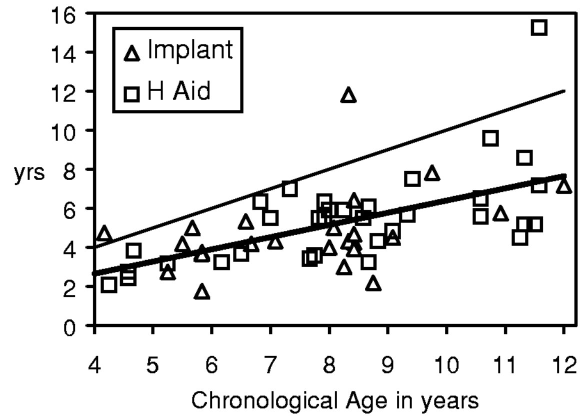

Figure 6: Equivalent age for the PPVT vs chronological age.

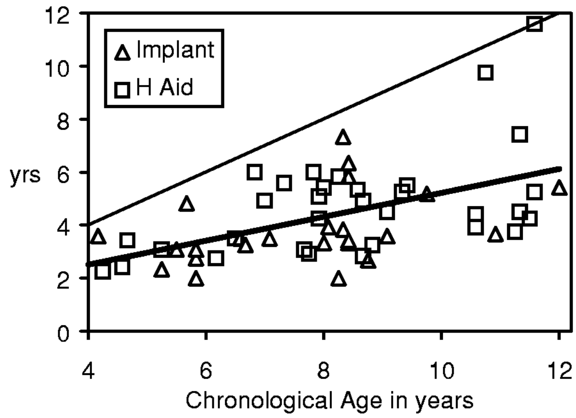

Figure 7: Equivalent age for the CELF vs chronological age.

Regression line	r^2	*p*
CELF Age = 0.45 x Age + 0.71	0.28	0.001
PPVT Age = 0.62 x Age + 0.16	0.32	0.001

Table 3: Regression analyses of PPVT and CELF equivalent ages in years versus chronological age in years.

3.3. The Relationship between perception & language

As shown in Table 4, there were strong correlations between all the perception scores and the equivalent ages derived from the PPVT and CELF language measures. For example, Figure 8 shows the BKB sentence scores in the AV condition plotted against PPVT equivalent ages. Note that a small number of cases with BKB scores close to 100% and PPVT equivalent ages greater than 8 years were omitted from the regression because of the ceiling effect at 100% for the perception test.

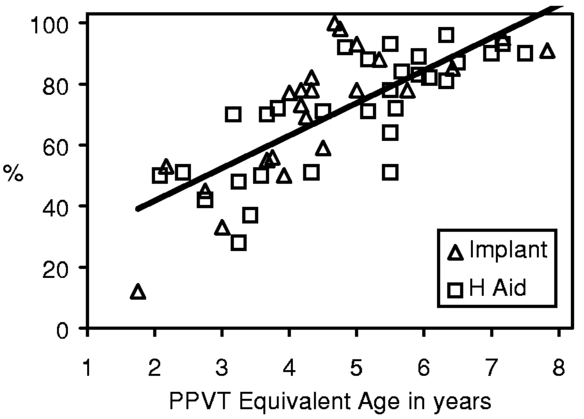

Figure 8: BKB audio-visual scores vs PPVT equivalent age.

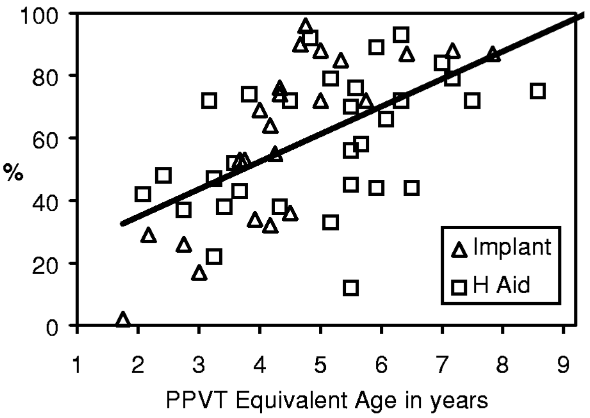

Figure 9: BKB audition alone scores vs PPVT equivalent age.

Regression line	r^2	*p*
CNC AV = 9.7 x CELF Age + 21.3	0.39	0.001
CNC AV = 8.1 x PPVT Age + 21.5	0.42	0.001
CNC A = 5.9 x CELF Age + 17.1	0.24	0.001
CNC A = 4.5 x PPVT Age + 19.0	0.24	0.001
BKB AV = 13.2 x CELF Age + 18.1	0.59	0.001
BKB AV = 10.7 x PPVT Age + 20.4	0.59	0.001
BKB A = 12.2 x CELF Age + 10.7	0.37	0.001
BKB A = 8.8 x PPVT Age + 17.1	0.37	0.001

Table 4: Regression analyses of perception scores in % versus CELF and PPVT equivalent ages in years.

Figure 9 shows the corresponding BKB Sentence analysis for the A condition. The overall scores tend to be lower and there is more variation than in the AV condition. The regression coefficient is still highly significant although it accounts for a smaller proportion of the variance.

4. CONCLUSIONS

Most of the children in the study began using an implant or hearing aid before the age of six, most have aided thresholds within the normal speech range for frequencies above 1500 Hz, and most demonstrate a good level of open-set speech perception in accord with the hypotheses listed in the introduction.

Language skills seem to have a major effect on the speech perception scores of these children. It is likely that poor speech perception slows the development of spoken language skills, so that there is an interactive effect rather than a causal relationship between these two variables. In the future, if individuals follow the trends displayed by the group, it is likely that their language skills will improve (at about half the normal rate) and their speech perception scores in the AV and A conditions will increase as a consequence. Average BKB AV scores should approach 100% for PPVT equivalent ages of 8 years and over (Fig 8), which corresponds to a chronological age of about 13 years (Fig 6).

In the audition alone condition, perception scores are strongly dependent on language skills, but show greater variability than in the AV condition, possibly reflecting the different levels of residual hearing, auditory experience, and other factors within the groups of hearing aid and implant users.

5. ACKNOWLEDGMENTS

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