CASE STUDY

Speech Outcomes of Children Using Cochlear Implants: Preliminary Results

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Long-term speech outcomes of children with at least 4 years of implant experience may be predicted, in part, on the basis of earlier speech skills. Two children participated in this preliminary study. Speech samples were recorded pre-implant and on a yearly basis after implantation with the Nucleus 22 channel device. Fifty words were transcribed using Reduced Aspect Feature Transcription (RAFT) analysis at each age interval. The child who became an intelligible speaker made dramatic changes in her speech sound repertoire from 12-24 months post-implant. The child who continued to present with severe speech intelligibility problems did not develop appropriate vowel targets, used primarily front voiced consonants in word attempts, maintained open syllable shapes and inappropriate word shapes, and the number and types of consonants did not increase over time.

In the 10 years since children were first implanted with multichannel cochlear implants many researchers have documented improvement in speech production abilities in these children compared to performance of children with hearing aids and tactile aids (Ertmer, Kirk, Sehgal, Riley, & Osberger, 1997; Osberger, Maso, & Sam, 1993). Gains in speech production have also been documented to occur over time with use of the device (Miyamoto, Kirk, Robbins, Todd, & Riley, 1996; Tobey & Hasenstab, 1991; Tye-Murray, Spencer, & Woodworth, 1995).

However, with over 100 children implanted at The University of Iowa Hospitals and Clinics (UIHC), there has been considerable variability in speech per-

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ception and production outcomes. Based on 4 years of experience with the device, three broad trends of the children's performance have been identified by researchers at UIHC. Children were grouped in these categories based on their speech production and perception skills (Tye-Murray, Tomblin, & Spencer, 1996). Children in Group A demonstrated speech perception skills characterized by detection of words in a structured context, and identification of words based on durational cues and vowel cues. These children were not able to identify words based on consonant features nor did they demonstrate open-set word recognition. In terms of speech production, children included in Group A exhibited very poor speech intelligibility. Few consonant sounds were acquired and neutralized vowel productions persisted. Many, but not all, of the Group A children received their cochlear implants late in childhood, which has been defined as at 8 years or older.

Children in Group B exhibited speech perception abilities characterized by the ability to identify familiar words in context and to identify words based on vowel and consonant features. Some of these children could identify a few words in an open-set format. In terms of speech production, children in Group B were able to accurately produce the correct number of syllables in words, had many intelligible words, and appropriate pitch and loudness during speech. However, these children continued to use sign language as their primary means of communication due to decreased speech intelligibility in conversation (Tye-Murray et al., 1996). A clear trend regarding age of implantation and membership in Group B could not be established due to the wide range of ages at which these children received their cochlear implants.

Children in Group C typically were able to identify words in open-set speech recognition tasks and were able to identify words and phrases in context. They were able to understand speech of unfamiliar listeners and used the telephone to a limited degree. In terms of speech production, the children included in Group C were highly intelligible (70-100% phonemes correct) in spontaneous speech. They produced the full range of vowels and many had acquired consonant blends. As a result, many of these children have discontinued their sign language use and rely on voice alone for daily communication. Many, but not all, of these children were implanted before their fifth birthday.

Although most children's speech perception and production skills are intimately related (good perceivers are good speakers), there are some children whose perception skills should predict better speech outcomes (Tye-Murray et al., 1996). Other researchers have also noted great variability in the speech production skills of children with cochlear implants (Dawson et al., 1995). Higgins, Carney, McCleary, and Rogers (1996) suggested that children with severe-to-profound hearing impairments often exhibited deviant motor patterns in their speech attempts. These motor patterns were acquired or learned due to the lack of an auditory feedback system and may serve to provide increased tactile feedback during speech. These motor patterns involve the laryngeal, respiratory, and oral motor systems. The authors found that despite the increased auditory information available, children with cochlear implants often needed extensive intervention to relearn speech patterns (Higgins et al., 1996).

This project was initiated to analyze the speech production skills of children with cochlear implants to attempt to account for the great variability of performance seen across children. Most importantly, it was an attempt to predict which children will need extensive help to acquire speech skills. The purpose of this study was to examine speech production skills of two children at pre-implant and each annual review in order to gain insight into why some children continue to exhibit deaf speech characteristics after implantation while others become intelligible speakers.

The following questions were addressed:

1. Can early speech production abilities of children with cochlear implants predict their outcomes at 4 years post-implant?
2. If so, what speech skills or features seem to be salient in the development of positive speech production outcomes?
3. What speech characteristics would point to the need for further or more intensive intervention?

METHOD

Participants

Two children were included in this preliminary study and were chosen randomly from the pool of children who had at least 4 years of experience with their implant. One child (Child 1) exhibited speech production and perception characteristics similar to Group A children previously described, and the other child (Child 2) would be included in Group C. There was a significant delay between the time of diagnosis and age of amplification for Child 1. Although no extenuating circumstances were noted in his history, one factor that may have contributed to the delay was the family's rural residence making access to diagnostic techniques and early preschool intervention difficult. In contrast, Child 2's family lived in an urban setting where speciality services for children with hearing impairment were more readily available. Neither child exhibited speech motor characteristics or a history of trauma which would indicate a neurological component to their speech development. Other pertinent information about the two children is included in Table 1.

Both children received a Nucleus 22 channel cochlear implant and had worn binaural amplification consistently prior to implantation. They each had full insertions of their device and no evidence of surgical complications which might have indicated poor performance with the device. As is common, both children received annual checks of their device and fine-tuning of their individual proces-

Table 1

Audiological and Medical Characteristics of the Two Participants of the Study

Child	Age at diagnosis	Age of first amplification	Age at implantation	Gender	Etiology
1	1 year, 3 months	3 years	10 years, 9 months	M	Meningitis
2	1 year, 2 months	1 year, 3 months	4 years, 3 months	F	Unknown

sor settings.

They were educated in the Iowa public schools with a simultaneous communication approach. Both children received support services from a speech-language pathologist and teacher of the hearing impaired. Specific auditory training, speech, and language goals for each child were determined by their local therapists and teachers with suggestions from UIHC implant team personnel. In addition, during the time period of this study, Child 1 received extensive speech and language support at home from a step-parent who was a speech pathologist. This step-parent was not part of the family unit at the time he lost his hearing.

Protocol

Each child was video-taped at pre-implant and annual follow-up appointments. For the first visit post-implant, Child 1 was seen at 10 months post-implant and Child 2 at 12 months post-implant. All other follow-up visits were conducted annually. Data from pre-implant through the 48-month post-implant evaluation were included in this study. Speech data were obtained from a story re-tell task in which the child re-tells a short story with the aid of picture cues. Six scripted stories were used. Throughout the 4 years of data collection a number of examiners gathered the data, however, all examiners followed the same protocol in data collection. Each story was presented in simultaneous communication to each child by the examiner. The children communicated with the examiner in sign and speech. They were specifically encouraged to use their voice. The first 50 words of the sample were submitted to a number of analyses.

First, each sample for each age interval was analyzed using Reduced Aspect Feature Transcription (RAFT) developed by Arlene E. Carney (Carney, 1996; Moeller & Carney, 1993). The RAFT procedure includes the coding of vowel tokens by height and place features. Consonants are coded by manner, place, and voicing features. The manner of articulation features included in this analysis included stop consonants /d, t, p, b, g, k/, continuants /s, z, l, r, h, w, ʃ, ɝ, ð/, and nasals /n, m, ŋ/. Unknown consonant or vowel features are coded as such. This procedure should allow for increased transcriber reliability in the analysis of deaf speech. It has been reported that even trained listeners of speech of the deaf can often achieve only fair reliability (73-74%) on a phoneme identification analysis (Tye-Murray et al., 1995). The RAFT procedure also accounts for the word shape a child produces in their speech attempts (e.g., V, CVC, CCVC).

Additional analyses performed included the number of consonants in a 50-word sample. In addition, for each vowel the closest identifiable IPA symbol was determined in order to evaluate the approximation of the vowel production to that of the target word. Target words were known through each child's sign productions. For the majority of the utterances the vowel productions would not be judged as typical for persons with normal hearing. However, each production was classified as correct, a good approximation, or error. A good approximation was defined as a vowel made in the correct place in the mouth (front, mid, or back) and only in error by one height place and was called the Vowel-Place-Height Criteria.

RESULTS

Consonant Production

At pre-implant both children exhibited a preponderance of front consonant productions. In word attempts front consonants accounted for 86% of productions for Child 1. A similar pattern was seen for Child 2 (98%). The majority of these productions were also voiced for both subjects: 65% for Child 1 and 78% for Child 2. By 24 months post-implant the two children were notably different in the variety of consonant types produced. Child 1 continued to produce 94% of consonants in the front of the mouth while Child 2 produced 77% of consonants in the front of the mouth. By 36 months the difference between the two subjects was dramatic. Child 1 continued to produce all of the consonants in the front of the oral cavity while Child 2 began to diversify the consonant type to approximate the target including medial consonant productions of nasals most often seen in the word *and* which accounted for 23% of the consonants in the sample. At 48 months post-implant Child 1 continued to produce only front consonants. Child 2 exhibited more diversity in her consonant productions in terms of a balance between voiced and voiceless consonants and the addition of medial and back consonants. Details of consonant production for both subjects are included in Table 2.

In terms of the number of consonants produced at each age interval, Child 2 consistently produced more consonants in a 50-word sample than Child 1. By 36 months the difference between the number of consonants produced by the subjects was dramatic (79 vs. 39). This finding relates to the growth of types of consonants used as well as the word shapes produced.

Vowel Production

At the pre-implant assessment both subjects used a mid-low vowel /ʌ/ most

Table 2

Percentage of Consonant Features for Both Participants
From Pre-Implant to 48 Months Post-Implant

		Front			Mid		Back		
Age interval	**Child**	**S**	**C**	**N**	**S**	**C**	**S**	**C**	**UK**
Pre-implant	C1	40	46	0	0	10	2	0	2
	C2	63	31	4	0	0	0	2	0
10-12 months	C1	32	68	0	0	0	0	0	0
	C2	47	31	16	0	6	0	0	0
24 months	C1	34	47	13	0	4	2	0	0
	C2	45	18	14	0	12	7	4	0
36 months	C1	51	44	5	0	0	0	0	0
	C2	36	27	23	0	3	2	9	0
48 months	C1	40	51	9	0	0	0	0	0
	C2	30	33	28	0	4	4	1	0

Note. Stop consonants are identified as S, continuants as C, nasals as N, and unknown features as UK. The results for Child 1 and 2 are in rows C1 and C2, respectively.

frequently. The /ʌ/ accounted for 44% of the vowel tokens for Child 1 and 55% of the tokens for Child 2. Child 1 showed a trend to diversify his vowel repertoire by 36 months; however, this diversification actually reflected a learned deviant motor pattern most notable in the words *boy* and *girl* in which he chose to use the high back vowel /u/ for both the diphthong /ɔɪ/ and mid-mid vowel /ɝ/. The high back vowel /u/ was also produced with increased pitch.

Child 2 steadily reduced reliance on the mid-low vowel from 12 months post-implant through 36 months while increasing use of the entire oral cavity to produce vowel sounds. At 36 months the mid-low vowel accounted for only 7% of the productions. At 48 months post-implant the use of the mid-low vowel accounted for 34% of the tokens, however this increase was a function of the vocabulary in the story re-tell task and not a decrease in correct productions or good approximations of vowel targets. Details of vowel productions for the two children can be seen in Table 3.

Using the Vowel-Place-Height Criteria there were notable differences between the two children even at pre-implant. As illustrated in Table 4, Child 2 consistently improved across time in the ability to produce correct vowels or good approximations of vowels. By 24 months post-implant, 84% of vowel productions of Child 2 were either in the correct place or classified as good approximations. By 48 months post-implant this percentage rose to 93%. Unfortunately, Child 1 did not make systematic gains in vowel production beyond 24 months post-implant. At least one-third of his productions were classified as an error in terms of

Table 3

Percentage of Vowel Features for Both Participants
From Pre-Implant to 48 Months Post-Implant

		Front			Mid		Back				
Age interval	**Child**	**H**	**M**	**L**	**M**	**L**	**H**	**M**	**L**	**UK**	**DT**
Pre-implant	C1	16	10	5	2	44	7	2	14	0	0
	C2	9	9	9	2	55	3	2	7	0	4
10-12 months	C1	1	5	2	7	59	17	1	5	3	0
	C2	18	2	18	2	38	2	5	9	0	6
24 months	C1	10	14	8	2	36	12	2	12	0	4
	C2	39	5	23	2	18	0	0	2	0	11
36 months	C1	11	2	15	2	26	21	4	15	0	4
	C2	29	23	4	2	7	0	9	12	0	14
48 months	C1	6	7	7	7	31	13	7	12	0	10
	C2	15	15	15	0	34	1	8	6	0	6

Note. High vowels are identified as H, middle vowels as M, low vowels as L, diphthongs as DT, and unknown features as UK. The results for Child 1 and 2 are in rows C1 and C2, respectively.

place and height of articulation of the vowel. This production pattern persisted overtime and some of these errors became rules of production for specific words indicating that learned deviant motor patterns of speech had not been replaced with more accurate patterns.

Table 4

Percentage of Correct, Good Approximation, and Errored Vowel Productions
for Both Participants From Pre-Implant to 48 Months Post-Implant

Age interval	Child	Correct	Good approximations	Error
Pre-implant	C1	27	18	55
	C2	45	10	45
10-12 months	C1	31	7	62
	C2	53	20	27
24 months	C1	47	11	42
	C2	71	13	16
36 months	C1	38	19	43
	C2	64	22	14
48 months	C1	56	7	37
	C2	80	13	7

Note. The results for Child 1 and 2 are in rows C1 and C2, respectively.

Word Shape

Both children used open word shapes at pre-implant. Of the words produced, Child 1 produced 74% with a CV or V word shape. Child 2 also produced a preponderance (72%) of open word shapes at pre-implant. Child 1 did not develop consonant closure on word shapes despite 4 years of device experience. The pre-implant and 48 month data for this child were virtually identical in terms of word shape. Inappropriate word shapes such as C, VV, VCV also persisted. For Child 1 the word shape produced did not appear to be related to the target word, with V and CV syllable shapes being the most prevalent.

Child 2 showed more appropriate and complex word shapes clearly by 24 months post-implant. At 36 months, complex word shapes made up 20% of the utterances (CVCVC, CCVC). This finding related well to the number of consonants found in the sample at 36 months. A total of 79 consonants were produced in this sample. Word shape data are found in Table 5.

DISCUSSION AND CONCLUSION

Results of this preliminary study suggested that detailed analysis of children's speech at pre-implant and in the first 2 years post-implant may reveal patterns of speech acquisition which could be used as prognostic indicators for future speech development. The data here suggested that the child who became a proficient speaker quickly made gains in vowel production and continued to improve in this area over time. Her errors in vowel production were more likely to be good approximations of the vowel target than the child who did not become a proficient talker. A phoneme-correct procedure alone would not be sensitive to these differences at pre-implant or 12 months post-implant. For example, Child 2 consistently made more productions which were in the correct place position of the

Table 5

Percentage of Correct, Good Approximation, and Errored Vowel Productions for Both Participants From Pre-Implant to 48 Months Post-Implant

Word shape	Pre-implant	12 months	24 months	36 months	48 months
CV	C1 - 44%	C1 - 36%	C1 - 40%	C1 - 42%	C1 - 44%
	C2 - 46%	C2 - 28%	C2 - 28%	C2 - 30%	C2 - 20%
V	C1 - 34%	C1 - 36%	C1 - 24%	C1 - 26%	C1 - 34%
	C2 - 26%	C2 - 36%	C2 - 24%	C2 - 6%	C2 - 18%
CVC	C1 - 8%	C1 - 4%	C1 - 12%	C1 - 4%	C1 - 12%
	C2 - 8%	C2 - 16%	C2 - 16%	C2 - 20%	C2 - 24%

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Table 5 *continued from previous page*

Word shape	Pre-implant	12 months	24 months	36 months	48 months
VCV	C1 - 4% C2 - 4%	C1 - 6%	C1 - 10% C2 - 2%	C1 - 4%	C1 - 2%
CVCV	C1 - 2% C2 - 6%	C1 - 2% C2 - 6%	C1 - 2% C2 - 6%	C1 - 2% C2 - 4%	C1 - 2%
CVCC		C2 - 2%		C2 - 2%	C2 - 2%
VC	C1 - 2% C2 - 6%	C1 - 8% C2 - 8%	C1 - 10% C2 - 14%	C1 - 12% C2 - 24%	C1 - 2% C2 - 16%
CVV	C1 - 4% C2 - 2%	C1 - 2% C2 - 4%	C2 - 2%		
CCV	C1 - 2%	C1 - 2%			C2 - 2%
VV	C1 - 2%	C1 - 4%		C1 - 4%	C1 - 4%
CVCVCV	C2 - 2%		C1 - 2%		
VCCVC			C2 - 2%	C2 - 4%	
VCC			C2 - 2%		
CCVC			C2 - 4%	C2 - 4%	C2 - 2%
CC				C1 - 2%	
C				C1 - 2%	
VVC				C1 - 2%	
CCVCC				C2 - 2%	C2 - 4%
CCVCCVC				C2 - 2%	
CCVCVC					C2 - 4%
CVCCVC					C2 - 2%
CVCCC					C2 - 2%
CVVC					C2 - 2%
CVCVC				C2 - 2%	

Note. The results for Child 1 and 2 are indicated by C1 and C2, respectively. Empty cells reflect no productions of that word shape in the sample.

mouth than Child 1. If the speech sample had been analyzed using a phoneme-correct procedure, the children would have appeared to have similar speech production skills at pre-implant and 12 months post-implant, and this is not the case.

In terms of consonant production, the data suggested that the child who became a good speaker (Child 2) diversified her repertoire of consonants to include back and medial consonants by 24 - 36 months post-implant. The child who did not become a proficient speaker continued to produce front consonants for all of his consonant tokens. Word shapes for Child 1 remained open, and deviant word shapes persisted (e.g., VV, C only, CC, VCV). For Child 1 learned deviant motor patterns persisted and became "phonological rules" for attacking the speech task. These deviant motor patterns will be individual for each child, therefore, careful analysis of speech will be necessary.

For the children who do not appear to be making progress in their speech development by 24 months post-implant, intensive speech intervention may be warranted at a specialized center or with a therapist who has considerable experience with children with profound hearing impairments. Children who receive a cochlear implant late in childhood may be at increased risk for maintaining deviant motor patterns of speech without intensive intervention. The data here would suggest that therapy goals for children with cochlear implants should concentrate on the development of vowels, addition of back and medial consonants, and closure of open syllable word shapes.

Regarding the procedures used in this study, the RAFT procedure and the Vowel-Place-Height Criteria for good approximation of vowel targets lend specific and detailed information regarding a child's speech not revealed by a phoneme-correct procedure. These procedures are particularly valuable when working with young children and children with unintelligible speech. One disadvantage to the procedures used in this study was that the words used in the analysis may not sample the entire vowel quadrilateral or all of the consonant features since the child's language skills determine the words used. Additional probes may need to be developed to counter this potential problem.

Additional research needs to be completed to verify these initial findings. Further studies will help identify the most salient speech features for predicting speech outcomes. Studies also need to be conducted to discover if children with deviant speech motor patterns and overall poor speech production can be helped with intensive treatment, when is the best time to intervene, and what types of therapy procedures and feedback are most appropriate.

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