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Treatment Effects on Phonological Acquisition in a Cochlear Implant Recipient[1]

Amy McConkey Robbins[2] and Steven B. Chin

Speech Research Laboratory
Department of Psychology
Indiana University
Bloomington, Indiana 47405

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[2]Also DeVault Otologic Research Laboratory; Department of Otolaryngology–Head and Neck Surgery; Indiana University School of Medicine; Indianapolis, Indiana 46202-5200.

Abstract

This paper presents a case study of phonological development in a young child wearing a multichannel cochlear implant. The purpose of the paper is twofold; first, a description is given of the training program carried out with this child. Hallmarks of the program included: a "motor-loaded" emphasis in the early stages of training; a cognitive-linguistic approach in the later stages of training, including the use of speech contrasts which change meaning (Elbert, Rockman, & Saltzman, 1980); utilization of a modified Cycles approach (Hodson & Paden, 1991); and systematic exposure to many different talkers. The paper also presents longitudinal data reflecting the subject's speech production skills prior to implantation and at regular intervals thereafter. Evidence is given of phonological patterns similar to those found in the developing phonologies of normally-hearing children.

Treatment Effects on Phonological Acquisition in a Cochlear Implant Recipient

Introduction

Cochlear implants are viewed primarily as devices which aid speech perception in profoundly deaf individuals. The role implants play in enhancing speech production has begun to receive considerable attention as well (Tye-Murray, Spencer, & Woodworth, 1995; Tobey, Geers, & Brenner, 1994; Osberger, Robbins, Todd, & Riley, 1994). Of particular interest is the question of whether multi-channel cochlear implants provide sufficient information about the acoustic speech signal to influence the developing speech production skills of deaf children wearing these devices. One method of doing this is to identify in implanted children the presence of developmental phenomena which are known to be dependent on audition. If one were to find similar auditory learning trends in normally-hearing and implanted children, this would provide compelling evidence that cochlear implants do replicate, albeit imperfectly, certain aspects of normal hearing.

The focus of this paper is the development of speech production skills in a child wearing a multi-channel cochlear implant. The paper is divided into two sections. In the first, a description is given of the training program carried out with this child. The second section presents data reflecting the subject's phonological development prior to and following implantation. The unique contributions of audition and training to this child's phonological development are reviewed.

Subject

The subject of this study, G.K., was a profoundly deaf (see Appendix) youngster whose etiology of deafness was Waardenberg Syndrome. She was three years, five months at the onset of the study, three years, ten months when her cochlear implant was first activated, and six years, four months at the end of the study. Her hearing loss was identified at age 11 months, and at 12 months of age she was fitted with amplification and began a parent-infant training program using Total Communication. Limited progress was reported in speech development, in spite of her family's faithful participation in the training program and G.K.'s acceptance of appropriate and powerful binaural amplification. G.K.'s participation in our laboratory began in May 1992. As traditional amplification did not seem to provide adequate auditory information for her, G.K. was fitted with a seven-channel Tactaid 7 device, and utilized this device on a full-time basis for six months. The *TARGO* (*Tactaid 7 Reference Guide and Orientation*; Robbins, Hesketh & Bivins, 1993) was used as a structured tactile curriculum for two one-hour sessions per week.

When G.K. entered our study, she was able to produce on demand no recognizable English consonants and only two English vowels: /ɑ/ and /u/. She was not aware when her voice was on, and therefore frequently communicated by using articulatory postures without voicing. At her initial assessment, several speech production measures were taken. First, a six-minute spontaneous sample of her speech was video- and audio-taped and then analyzed according to a procedure described by Osberger, Robbins, Berry, Todd, Hesketh, and Sedey (1991). The results showed a preponderance of tokens in the "Other" category, which was described as articulatory behaviors that are non-productive and should be eliminated from the child's repertoire. These included blowing, lip smacking, use of ingressive plosion, clicks, and articulatory posturing without voicing.

A second speech production measure was also administered. The Nonsense Imitative Test using Syllables (NITS; see description below) required G.K. to imitate CV syllables following an examiner's model while an audio-tape was recorded. No subject in our laboratory (out of 180 subjects) ever produced fewer vocalizations as did GK during the administration of the NITS. She attempted to imitate mouth posture and produced several non-speech attempts, but no she had no notion of her voice being turned on.

In November 1992, G.K. received a Nucleus-22 multiple-channel cochlear implant (Cochlear Corporation). Full electrode-insertion was achieved, and activation took place in December 1992. From that point, speech training was designed to take advantage of the newly introduced auditory signal from the cochlear implant.

Training Program Characteristics

A multi-sensory approach to therapy was utilized with this subject, and consisted of many of the traditional speech and listening techniques commonly used in aural rehabilitation. These will not be described in this paper as they are well known to readers. The foundation of the training program, however, was characterized by four components not typically combined for use with hearing-impaired children. Table 1 summarizes the four components of the training program.

Table 1: Components of the Phonological Training Program

1. Early motor-loaded emphasis: motor approach used to establish basic speech production system.

2. Later emphasis on speech contrasts: emphasizes that differences in sound segments can signal differences in meaning.

3. Use of a modified Cycles approach: guides selection and ordering of target speech sounds for training.

4. Use of multiple talkers during training sessions: exposes child to natural variability occurring across talkers.

1. Early motor-loaded emphasis

In the earliest stages of therapy with G.K., emphasis was placed on the production, rather than the perception aspects of speech. Using a method described by Osberger (1983), speech targets were addressed first using imitation, generally with a visual prompt of some sort. Shortly thereafter, production-on-demand and perception tasks were introduced using the same speech targets. This approach diverges from that which has often been prescribed for hearing-impaired children, the integration of production and perception tasks, an approach which these authors often advocate. For example, Robbins (1994) recently outlined speech training guidelines for implanted children which emphasized the intertwining of speaking and listening activities. Our decision to utilize a different approach, the motor-loaded approach, with G.K. was based upon the extremely limited speech skills she demonstrated initially, and upon her lack of prior experience with sound. A compelling rationale for using such an approach is the outcome of speech training studies (Osberger, 1983; Osberger, Johnstone, Swartz, & Levitt, 1978; Lieberth & Subtelny, 1978; Subtelny, 1983) which suggests that the ability to produce a speech pattern may precede and assist in the hearing-impaired child's perceptual decoding of the corresponding auditory signal. Thus, the auditory-feedback loop may be more readily established if the initial emphasis is placed on the motor, rather than the perceptual aspects of speech. This seems to be especially true for very young deaf children who have no auditory experiences prior to implantation. These youngsters do not appear to have the prerequisite listening skills upon which to build a perceptually-based speech program. Rather, they first need practice with the production aspects of speech sounds. Once some competence is gained in producing certain speech elements, more balance is needed in therapy, and perception and production tasks should be intertwined, an approach which makes efficient use of therapy time because several purposes may be accomplished with the same set of materials. Table 2 outlines the rationale for choosing a motor-loaded over an integrated approach in the initial stages of speech training.

Table 2: Rationale for Motor-Loaded Approach to Training

1. Child has no prior experience with sound.
2. Child does not demonstrate vocalization on demand.
3. Phonetic repertoire contains few or no recognizable vowels or consonants.

Motor-based approaches have been advocated by speech pathologists as treatment for speech errors which are articulatory, rather than linguistic in origin (Bernthal & Bankson, 1988). Our term "motor-loaded" is used to imply an approach which emphasizes the motoric aspects of phonology only on the front-end or early stages of training speech targets. The goal is to move on to a more cognitive-linguistic approach as soon as possible. The transition to a meaning-based approach was gradually made with G.K., as described below.

2. Later emphasis on speech contrasts that change meaning

This Cognitive-Linguistic approach was employed with G.K. later on in her rehabilitation program, once she had gained sufficient production practice with speech sounds. It represented a shift from the "motor-loaded" approach, described above, which was employed in the early stages of training. The use of speech contrasts in phonological training has been described by others, including Winitz (1975) who referred to it as "conceptualization training". The thrust of this approach is the child's use of speech sounds in a *contrastive* way. Therapy items include pairs of words with a target sound and a contrast sound. The target sound is the adult "form" of a word (such as 'him'), and this is contrasted to the child's incorrect production (such as 'hip'). This approach emphasizes the meaning that is conveyed by small changes in the sounds in words. Its premise is that the child will be more motivated to correct his speech errors if he realizes, through natural consequences, that those errors actually change the meaning of his message.

We began to employ meaningful contrasts within therapy as soon as G.K. was able to produce and perceive both the target and the contrast sound of a cognate pair. We used this method even while working on a "Motor-Loaded" approach with other sounds that needed production emphasis. Thus, the two approaches were not mutually-exclusive, but were used selectively depending on G.K.'s level of competence with the target sounds. For example, about six months post-implantation, we were addressing /d/ in therapy using a "motor-loaded" approach, as G.K. could not accurately and consistently produce this sound in a CV syllable on demand. At the same time, we were working on /m/ vs. /b/ using a contrastive approach ('Mom' vs. 'bomb'; 'my' vs. 'bye'; 'mall' vs. 'ball') because she had demonstrated the ability to produce both words in the pair, and to perceive the difference between them most of the time.

This type of contrastive approach would not have been practical to use with G.K. in the early stages of training due to the extremely limited nature of her phonetic repertoire. The approach is a logical one to use at a point in time when a child has the motoric skills to produce speech contrasts intentionally. As Bernthal and Bankson (1988) have noted, this type of approach does not dismiss the motoric requirements of the phonological system, but acknowledges that many speech errors are not motorically based. This was true in G.K.'s case in the area of final consonant deletion, for example. She failed to use a word-final consonant in certain words, but used that same consonant word-initially, or even word-finally in other words. For example, 'tea' and 'teeth' were used in therapy as a contrastive pair because G.K. produced both as an open syllable, /ti/. Useful clinical materials for addressing this included *Language Approach to Open Syllables* (Young, 1981), *Contrasts: The Use of Minimal Pairs in Articulation Therapy* (Elbert et al., 1980) and *Contrastive Word Pairs* (Kiernan & Zentz, 1985)

3. Use of a modified Cycles approach

Hodson and Paden (1991) described an approach to therapy in normally-hearing children with delayed phonology. An underlying premise of this approach is that children actively engage in absorbing new information, generalize this, and slowly alter their phonological system over time. Although the approach was not designed specifically for hearing-impaired children, many of its characteristics make it a suitable approach for this population. These include: (a) auditory bombardment; (b) the development of accurate kinesthetic images for speech (what Ling refers to as an oro-sensory-motor code); and (c) the use of time periods or cycles of training which guide the selection of targets. These three aspects of the Cycles approach were employed with G.K. as follows:

Auditory Bombardment. When a new sound was chosen as a production target, we first exposed G.K. auditorially to many examples of the sound, via rhymes, repetitive babbling and single words. According to Hodson and Paden (1991), this initial step of auditory bombardment draws a child's attention to a new speech sound and isolates it to enhance its salience. For example, this technique was used with the high front vowel /i/, which G.K. produced as a central, nasalized vowel. Correct production of /i/ is a critical goal for deaf children, as it is considered a point vowel, involving maximum excursion of the tongue (to the high front position). In addition, it is an important sound for speech intelligibility, because of its high frequency of occurrence in English. Early on in therapy, G.K. could not approximate this vowel, so we avoided choosing words for practice which contained it. Rather, we used auditory bombardment to expose her auditorially to the sound, requiring her to focus on that specific vowel. Auditory bombardment continued even after G.K. was stimulable for /i/ as a way of providing acoustic highlighting of target patterns.

Kinesthetic Images. This aspect of the Cycles approach emphasizes the importance of how speech "feels" as well as what it sounds like. Hodson and Paden (1991) state that a speaker's ability to use correct sound patterns in connected speech is dependent upon continual self-monitoring, not only by listening to one's own productions, but also by the kinesthetic sensations associated with articulation. In the case of profoundly deaf children, this kinesthetic feedback is critically important because the children's limited residual hearing may not allow them full auditory access to speech sounds. Ling (1976) referred to this mechanism as the oro-sensory motor code. He postulated that auditory feedback of one's own voice, as well as awareness of what speech feels like, were vital to developing intelligible speech in deaf children. This is one step in the process of self-monitoring which eventually allows children to self-correct and to prevent incorrect productions.

We approached the introduction of each new speech sound in G.K.'s training as an opportunity to develop a new kinesthetic pattern, or to correct a faulty one. If G.K. was unable to produce an approximation of a target after numerous attempts, we temporarily abandoned work on that sound, so as not to give her "negative practice" producing incorrect patterns. Only after G.K. demonstrated stimulability for a given speech sound was it addressed in training. Our emphasis was always on the *correctness* of her productions of a given sound. For example, when G.K. did become stimulable for /i/, she could produce it correctly only in the syllable /bi/. Therefore, that was the only context in which we addressed /i/, until she became stimulable for it in other contexts. In this way, her practice of /i/ was always 100% accurate, reinforcing the development of a correct kinesthetic pattern.

Use of time periods or cycles for training. Although the goal of the Cycles approach is to change the phonological patterns of a child, what must be targeted are specific phonemes or phoneme sequences that represent those patterns. The Cycles concept is meant to capitalize on a child's normal ability to generalize and takes into account that phonological acquisition is gradual. For these reasons, sounds are introduced for training, worked on, and then left, and other sounds are addressed. During "off" training times, it is hypothesized that some aspects of the target patterns may be incorporated into the child's phonology and/or may generalize to other targets. Sounds are generally "recycled" and addressed in future cycles until they are mastered. As stated earlier, only sounds for which the child is stimulable become targets for production training. In addition, phonetic contexts for targets are carefully chosen to enhance the likelihood of production accuracy.

These principles guided the selection and ordering of target sounds for G.K. and the contexts in which they were trained. For example, when G.K. was first stimulable for /m/, we avoided eliciting it in syllables with oral labials, such as /bɑm/ or /mæp/, as the nearby non-nasal consonants appeared to cause denasalization of the /m/. Similarly, her productions of /m/ were correct when adjacent to the rounded (labial) vowel /u/ but incorrect when adjacent to /ɑ/.

4. Use of multiple talkers during training sessions

The rationale for varying the talker was based upon the work of Logan, Lively, Pisoni, and colleagues (Lively et al., 1992, 1993, 1994; Logan et al., 1991, 1993). These investigators examined the progress of Japanese subjects who were learning to perceive and produce distinctions between /r/ and /l/. Subjects who listened to multiple talkers during their course of training showed better accuracy and generalization of skills than subjects trained with a single talker. These results suggested that variability during perceptual training was important for helping the listener establish broad, rather than narrow and rigid, phonetic categories.

Therapy sessions were set up so that a relatively large number of different people were involved, on a rotating basis. These included two therapists, the subject's mother, and her four siblings. A number of other laboratory staff also participated in the therapy sessions from time to time, thereby exposing G.K. to different talkers whose speech varied from each other across a number of dimensions, including rate, loudness, and fundamental frequency. As part of the "dialogue" rather than "tutor" format (Blank & Marquis, 1987; Robbins, 1994) which was utilized in therapy, the roles of speaker and listener were switched often. This meant that stimuli presented during listening activities were sometimes spoken by G.K.'s mother, other times by a clinician, still other times by a sibling, and finally, by G.K. The latter occurred during activities in which G.K. assumed the role of "teacher", where she produced the stimulus and a listener responded. Thus, this subject experienced the considerable variability that occurs across talkers by virtue of listening to so many different speakers. It was hypothesized that this experience with variability would make G.K.'s perception skills more flexible due to the breadth of her phonetic categories.

Phonological Measures

Nonsense Imitative Test using Syllables

Two measures were used to assess G.K.'s phonetic-phonological ability. The first, the Nonsense Imitative Test using Syllables (NITS, developed at the DeVault Otologic Research Laboratory, Indiana University School of Medicine) assesses the ability to imitate 68 CV syllables three times each. Productions are assessed first in terms of their speech characteristics ("speech, speech-like, non-speech") and second in terms of syllable shape and correctness of production of constituent sound segments. The first 11 items on the NITS consist of syllables formed of the voiced bilabial stop /b/ followed by the monophthongs /i ɪ ɛ æ u o ɑ/ and the diphthongs /eɪ aɪ aʊ ɔɪ/. The remaining 57 items on the test consist of 19 English phonemes followed by the point vowels /i ɑ u/. The second, described in more detail below, assessed production on demand through presentation of pictures of people familiar to the child.

The NITS was administered twice pre-cochlear implant and at regular intervals post-implant. It was first administered 6 months before implantation; at that interval, G.K.'s renditions of syllables were characterized almost exclusively as "non-speech", although there were isolated and apparently random occurrences of vowel-like productions approximating the extremely open /ɑ/. There was a uniform lack of voicing (necessary for correct production in every case, given the vocalic nucleus). G.K. appeared able to imitate bilabial articulation for a few target segments, but these postures were either released ingressively or were otherwise unaccompanied by either egressive pulmonic airflow upon release or by a following voiced vowel. In sum, there appeared to be lack of awareness of an articulation/sound relationship (speech), including voicing, and thus of syllable structure.

During the same month as, but subsequent to, the first administration of the NITS, G.K. was fitted with a seven-channel Tactaid-VII device, which she used for approximately six months. The second administration of the NITS took place subsequent to this six-month period and within a week prior to implantation. Rating of this administration revealed some improved knowledge of the articulation/sound relationship, with very few productions assessed as "non-speech", some as "speech", and most as "speech-like". Still lacking was evidence of knowledge of syllable structure, since almost all speech productions were isolated consonants or vowels. Production of consonants was generally limited to visually-salient ones, primarily labials, while vowels were uniformly low (open) ones (/æ ʌ ɑ/). Some productions still consisted solely of a completely unimpeded pulmonic egressive airstream forced through protruded lips, and all vowels were produced with creaky voice.

Implantation took place six days subsequent to the NITS administration just discussed, and the first post-implant NITS was administered six months later. Productions at this administration were almost all characterized as "speech", with very few (approximately 6%) characterized as "speech-like"; importantly, no productions were characterized as "non-speech". Nonspeech gestures such as blowing and smacking in place of speech productions, as well as creaky voice, were eliminated. Consonant productions consisted mainly of voiced bilabial stops, although there were isolated occurrences of stops at other places of articulation, as well as some instances of fricatives. Vowel productions included both low (open) vowels (as occurred pre-implant), but also some high (close) vowels such as /i ʊ/. Correct production of gross syllable structure (with segmental substitutions) obtained in virtually all cases for syllables initiated by labials; for other places of articulation, however, incorrect productions occurred with greater frequency.

Administration of the NITS at 2.0-years post-implant showed further development of speech, segmental, and syllabic characteristics. All productions were characterized as "speech", and except for some isolated cases, the CV syllable shape was produced correctly. Consonant production heavily favored voiced bilabial and alveolar stops, with some instances of fricative production. Vowel production showed evidence of awareness of height distinctions, so that the point vowels /i ɑ u/ were correctly produced in most cases. The situation 2.5 years post-implant was similar, with production of the correct syllable shape, of both voiced and voiceless consonants, of consonants at various places of articulation (including visually non-salient ones), and correct point vowels.

Picture-Naming Task

Steady improvement in performance on the NITS from pre-implant to post-implant intervals and through the post-implant intervals served as evidence of a growing awareness of the relationship between phonatory/articulatory gestures and sound production. Although the NITS is thus a good indicator of the degree of motoric ability to imitate speech, it nevertheless leaves aside the linguistic question of the relationship between sound and meaning. By 2.0 years post-implant interval, it was clear that G.K.'s speech production abilities had sufficiently progressed, so that another measure, of phonological production ability, was administered. Full details regarding this instrument, its administration, and results can be found in Chin, Pisoni, and Svec (1994), which is summarized here.

For this production-on-demand task, a set of 23 pictures was made, which depicted the faces of persons known to the child, including friends, teachers, and family members; these pictures served as stimulus items to elicit speech productions of each of the names (see Table 3) associated with the pictures. The use of names, rather than common nouns, addressed the question of whether the child's phonological (as opposed to sign) lexicon was of sufficient size to permit testing. It was predicted that at least names of familiar persons would be phonologically represented and available for speech production. This prediction was borne out at the first elicitation session.

During regular therapy sessions, the full set of 23 pictures was displayed one at a time to the child, who was asked to say aloud the name of the person depicted in the picture. When necessary, the child was prompted to say the name with a question such as "Who's that?" or "Can you tell me who this is?". No direct training on the names, except acknowledgment repetition during sessions or normal use of the names in everyday use was provided. The child's productions were tape-recorded and narrowly transcribed phonetically by a trained clinical phonologist. Five elicitation sessions were held near the 2.0-year interval, the first at 647 days and the last at 693 days post-implant.[3]

Table 3: Names for Picture-Naming Task

Orthography	Target Transcription	Orthography	Target Transcription
Alfred	['æl.frɨd]	Kris	[kʰrɪs]
Alice	['æ.lɪs]	Kristin	['kʰrɪ.stĩn]
Allyson	['æ.lɪ.sɨ̃n]	Marge	[mɑrʤ]
Amy	['ẽĩ.mi]	Nick	[nɪk]
Carly	['kʰɑr.li]	Patty	['pʰæ.ɾi]
Cathy	['kʰæ.θi]	Sarah	['sɛ.rə]
Debbie	['dɛ.bi]	Sawyer	['sɒɪ.jɚ]
Diana	[daɪ.'æ̃.nə]	Shanan	['ʃæ.nɨ̃n]
Dwayne	[də.'wẽĩn]	Tara	['tʰɛ.rə]
Haley	['heɪ.li]	William	['wɪl.jə̃m]
Josh	[dʒɑʃ]	Yvonne	[jɨ.'vɑ̃n]
Kim	[kʰĩm]		

[3]Less accurately reported in Chin et al. (1994) as 685 days and 731 days post-implant.

Although the nature of the stimulus set did not permit probing of all English segments, as Table 4 shows, for consonants, there was fairly good coverage of voicing and various manners and places of articulation. Table 5 shows the vowel segments contained in the probe list; although front and central vowels were well represented, there were, unfortunately, no occurrences of back rounded vowels in the names contained in the list. In addition to a relatively wide variety of segment types, the probe list of names also contained a variety of syllable structure types; importantly, it contained both opened and closed syllables. Results from the NITS had shown good control over production of CV syllables, and the picture-naming task further tested G.K.'s ability to combine consonants and vowels. Table 6 contains schematics and examples of the various syllable types contained in the names.

Table 4: Target Inventory of Consonants in Picture-Naming Task

Stops	pb			td			k[]	
Fricatives		fv	θ[]	s[]		ʃ[]		
Affricates						[]dʒ		
Nasals	m			n			[]	
Liquids			l		r			
Glides	w					j		h

Note: Phonetic symbol indicates that a segment was contained at least once in the name elicitation probe. Empty brackets indicate that the English segment at that position was absent from the probe.

Table 5: Target Inventory of Vowels in Picture-Naming Task

	Front	CentralBack	Diphthongs	Rhotacized
High	i ɪ	ɨ		
Mid	ɛ	ə	eɪ	ɚ
Low	æ	ɑ	aɪ ɔɪ	

The inventories of consonants and vowels produced in the five sessions are shown in Tables 7 and 8. At this early stage of development, the criterion used for inclusion of a segment in the phonetic inventory was one occurrence in any of the five elicitation sessions. Given the fairly close temporal range from first to last elicitation session (approximately 45 days, with from 5 to 22 days between sessions), it is possible to consider these sessions as repeated trials within a single interval rather than as longitudinal intervals.

Table 6: Target Syllable-Structure Types in Picture-Naming Task

Syllable Structure Type		Example
Open:	V	[æ] in 'Allyson'
	CV	[dɛ] in 'Debbie'
	CCV	[kʰrɪ] in 'Kristin'
	CVV	[daɪ] in 'Diana'
Closed:	CVC	[wɪl] in 'William'
	CCVC	[krɪs] in 'Kristin'
	CVVC	[wẽĩn] in 'Dwayne'
	CVCC	[mardʒ] 'Marge'

Consonant inventory. Table 7 indicates that G.K.'s consonant inventory exhibited a voicing distinction, as well as a full range of segments of different places and manners of articulation. Although the consonant inventory was relatively large, it was also true that it was not precisely an English inventory. One reason was the absence of specific segments contained in the probe list (e.g., /r/, which, however, also presents problems for hearing children). The lack of some segments from the probe list makes it somewhat difficult to assess their absence from G.K.'s productions (although she did produce some English segments that were absent from the probe list); this is especially true in the case of voiced fricatives. Second, there were a number of segments present in the inventory that do not occur in the English inventory. These included stops [ḅ d̺], central fricatives [s̺ ẓ s̻ ç], and a lateral fricative [ɬ].

Vowel inventory. As indicated in Table 8, the situation for G.K.'s vowel inventory was similar to that of the consonant inventory. Specifically, there was a wide range of vowels produced, including vowels of different tenseness, height, and backness. In general, G.K. was able to produce most of the vowels that were contained in the probe list (although not always in the right place); again, the absence of some vowels from the probe list (particularly back vowels) makes it difficult to assess their absence from G.K.'s inventory. As was the case with the consonants, there also occurred some non-English vowels (including nasalized vowels produced in the absence of following nasal consonants) and a front rounded vowel.

Table 7: Production Inventory of Consonants from Picture-Naming Task

Stops	bḅ			d̪	t d				k	ʔ
Fricatives		fv	θ	s̪	s ẓ		ʃʒ	ç		
Lateral Fricative					ɬ					
Affricates	pf bv			ts̪	ts dz	ts̬	tʃ dʒ			
Nasals	m				n					
Liquids					l					
Glides	w w̃						j			h

Table 8: Production Inventory of Vowels from Picture-Naming Task

	Front	Central	Back	Diphthongs
High	i ɪ			
Mid	e ẽ ɛ œ	əə̃	ɔ	eɪ əɪ
Low	a	ɑ		aɪ ao

Syllable structure. Phonological systems of hearing children at early stages of development very often have limits on the types of syllable structures that can occur, and very often the only syllable structure type that does occur is a consonant followed by a vowel (CV syllable, such as probed in the NITS). In addition to this simple syllable structure type, relatively well-developed phonological systems also exhibit more complicated structures, especially (1) syllables that end in consonants (i.e., "closed" syllables) and (2) syllables that either begin or end with clusters of consonants (CCV– or –VCC). As Table 6 indicates, the names on the probe list contained both relatively simple syllable structures and relatively complicated syllable structures.

In fact, G.K. was able to produce both simple and complicated syllable types, as indicated in Table 9. The forms in Table 9 indicate that G.K. was able to produce both open and closed syllables (e.g., CV vs. CVC), both light and heavy syllables (e.g., CV vs. both CVV and CVC), and both singletons and clusters (e.g., CV vs. CCV, and CVC vs. CVCC).

Table 9: Production Syllable-Structure Types from Picture-Naming Task

Syllable Structure Type		Example
Open:	V	[ɑ] in 'Allyson'
	CV	[dɑ] in 'Debbie'
	CCV	[kwɪ] in 'Kristin'
	CVV	[dəɪ] in 'Diana'
Closed:	CVC	[nɪç] in 'Nick'
	CCVC	[fwɪs̺] in 'Kristin'
	CVVC	[feɪʃ] in 'Dwayne'
	CVCC	[mɔʒʃ] 'Marge'

Substitution patterns. During the course of phonological acquisition by hearing children, there are normally a number of apparent substitutions of one sound for another (or "correspondences" between these sounds). In many cases, these are systematic, in that (1) all instances of a target sound have a common substitute sound (e.g., [t] for [k] in all cases, and (2) substitutions affect natural classes of sounds rather than individual sounds (e.g. stops substituting for fricatives). In addition, many substitution patterns are common across a number of children (e.g., alveolars for velars), while others are less common (e.g., velars for alveolars). G.K. exhibited a number of substitution patterns that were both systematic (to a degree) and common. These included unaspirated stops for aspirated ones, stops or affricates for fricatives, an alveolar stop for a lateral. One substitution pattern showed a voiceless alveopalatal fricative [ʃ] for a number of target nonlabial segments, including [s t k].

Lexical representations. A clear indication of acquisition of an ambient phonological system is consistently correct production of forms in a variety of linguistic environments. Just two years post-implant, G.K.'s phonological system could not be expected to be English-like in all aspects, but some signs of awareness of a sound-meaning relationship was the ability to produce forms without imitation and the relative stability of at least some lexical representations across trials. Additionally, a number of productions were very close to being correct. Thus, of the 23 names elicited, the following were close to correctly produced and furthermore appeared to be fairly stable: 'Amy, Debbie, Haley, Nick, Patty, Sarah, Tara'. Productions of these forms showed fairly small distances from the intended target in terms of marking of segmental slots (maintenance of syllable structure) and phonetic and phonological similarity between target and response. Other productions were fairly stable across trials, but segments showed greater phonological distances from targets; these were 'Alfred, Alice, Cathy, Dwayne, Josh, Kris, Kristin, Marge, William'. The remaining names of the list were produced in such a way as to indicate either relatively unstable lexical representations or greater phonological distance between target and response.

Thus, on a number of measures (segment inventory, syllable structure, substitution patterns, lexical representations), G.K.'s phonological system appeared to be developing in the desired direction.

Treatment Effects

The goal of the treatment program incorporating the four characteristics discussed previously (early motor-loaded emphasis, later cognitive-linguistic approach, modified 'Cycles' approach, and use of multiple talkers) was to facilitate speech production in such a way as to enhance the overall development of a target-appropriate phonological system, as well as the development of communicative abilities. Although it is probably too early to judge the overall effects of the treatment program on phonological and communicative development, specific components of the treatment program appear to be at least conceptually related to various characteristics of G.K.'s present speech production abilities. Evidence for such relationships comes from both observations made during treatment sessions as well as data collected from the NITS and picture-naming task. We review some of these relationships below:

1. Motor-loaded emphasis

Recall that this approach was chosen early on in therapy due to the extremely limited phonetic repertoire that G.K. demonstrated. Its goal was to allow G.K. extensive and purposeful motor practice with new speech targets, in order to expand her phonetic repertoire. Evidence of the usefulness of this approach may be seen when comparing the number of sounds (9 vowels, 14 consonants) G.K. produced on imitation at her 6-months post-implant interval to those she produced prior to the initiation of training and fitting of the implant (3 vowels, 6 consonants).

2. A cognitive-linguistic approach in later stages of training

Evidence of the effectiveness of this technique may be found in G.K.'s ability to learn, relatively quickly, new contrastive pairs with similar patterns to earlier-trained pairs. For example, the contrast 'row' vs. 'rope' was introduced within the first year of training and the presence of a word-final consonant was tied to the meaning conveyed. Once this pair was mastered, G.K. required very little training to distinctly produce 'hoe' vs. 'hope', 'sew' vs. 'soap', and later, 'toe' vs. 'taupe'. The word-final /p/ also generalized to pairs with different preceeding vowels (e.g., 'Sue' vs. 'soup' and 'key' vs. 'keep'), suggesting that the sound was not constrained to appear only in the context of certain vowels.

Although minimal pairs such as those just cited are a traditional indicator of the use of sounds or features contrastively, other evidence can be adduced to show linguistic use of various phonological structures. In the picture-naming task, for instance, there were near-minimal pairs such as 'Cathy/Patty' and 'Amy/Debbie', as well as pairs of names differing in the number of syllables, such as 'Kris/Kristin'. Differential production of the members of these pairs serve as evidence of the awareness of the need to mark contrasts (even if not target-appropriately). Thus, across the five repetitions of 'Cathy', productions of the initial consonant differed from those of renditions of 'Patty'. Similarly, 'Amy' was always produced with a nasal intervocalic consonant, whereas 'Debbie' was produced with an oral consonant. Finally, 'Kris' was always produced as a monosyllable, while the related form 'Kristin' was always produced with two syllables.

3. Use of a modified "Cycles" approach

Elements from the "Cycles" approach were utilized as a systematic way of determining which sounds to introduce into training, and when. As stated earlier, Hodson and Paden (1991) recommend that sounds not be addressed in drills until the child can at least produce a correct approximation of the sound. This avoids the negative practice that may result from drilling sounds that are incorrectly produced by the child. The Cycles approach is time-efficient in that no time is wasted in working on sounds the child cannot produce.

G.K. showed excellent retention of correct productions over time, which appeared to be a result of the use of the Cycles approach. Some speech training methods involve introducing sounds for training based upon a pre-determined schedule, regardless of the child's ability to approximate those sounds. This often results in a child's being able to produce a sound during the time it is being directly drilled, but yielding no carry-over over time. Thus, speech sounds are "lost" from the child's repertoire anytime they are not being actively trained.

Evidence for retention of phonological knowledge was to be found in both the NITS and picture-naming task results. Successive post-implant administrations of the NITS showed not only the addition of new sounds but also the retention of old ones. In the picture-naming task, correct productions of sounds contained in the names persevered across sessions, indicating stability of both the sounds themselves and the lexical representations in which they were contained.

4. Use of multiple talkers

The benefit of this technique with G.K. may be seen both in informal observation and in empirical test results. Informally, G.K. is observed to adjust easily to new and different speakers, including those with foreign accents and different dialects of English. Her flexibility with different talkers is seen empirically in her periodic testing, conducted every 6 months. This testing was always performed by an examiner who did not work regularly with G.K. and the examiner varied from test interval to test interval. That G.K.'s speech perception and production scores improved steadily over time (with no evidence of a plateau in performance) is testimony to the fact that her skills were not tied to one talker. The set of names used in the picture-naming task were introduced simply in the course of daily living and, importantly, were introduced from multiple sources by different people. G.K.'s ability to associate names with faces and to produce them, in many cases, correctly attests to the viability of using multiple talkers in training.

A recently-designed stimulus set will be administered to G.K. in the near future. The set consists of two types of recorded word lists. On the first, the child hears one talker say all the stimuli, whereas on the second, she hears multiple talkers (Kirk, Pisoni, Osberger, 1995). Comparison of G.K.'s performance on the single- vs. multiple-talker lists will further define the extent of her flexibility with different talkers.

Conclusions

In this paper, we have outlined a therapeutic program designed to advance development of a phonological system by a child with a cochlear implant. This program contains four main component characteristics, each of which targets a specific area of the phonological system: (1) early motor-loaded emphasis to establish a basic speech production system, (2) later emphasis on speech contrasts to increase awareness that different sound segments can signal differences in meaning, (3) the use of a modified Cycles approach to guide the selection and ordering of specific training targets, and (4) the use of multiple talkers to training sessions to expose the child to the natural variability that occurs across speakers in the community. Although the child described here is still at a relatively early stage in the development of a spoken linguistic system generally and a target-appropriate phonological system specifically, preliminary speech production data from periodic intervals following implantation indicate that phonological abilities are developing in the desired direction, in terms of phonetic inventory and syllable structure. Additionally, this child's lexical representations indicate an awareness of the basic linguistic principle that specific combinations of sounds correspond to specific meanings.

It would perhaps be premature to advance here the strong claim that the treatment program we have described is solely (with the exception of the prosthesis itself) responsible for whatever advancements in phonological ability this child has achieved; we would hope, however, that the descriptive report we offer here is sufficiently detailed to allow other researchers to compare both their own treatment methods and measures of phonological ability with ours.

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Appendix

Combined audiogram for unaided (X, O; headphone response), hearing-aided (A), and cochlear-implant (CI; sound-field response) conditions for G.K.