RESEARCH ON SPOKEN LANGUAGE PROCESSING
Progress Report No. 19 (1993-1994)
Indiana University

An Emerging Phonetic-Phonological System Two Years Post-Cochlear Implant: A Preliminary Linguistic Description[1]

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[1]This work was supported by NIH (NIDCD) Training Grant 00012-15 and NIH (NIDCD) Research Grant 00111-17 to Indiana University at Bloomington. We are grateful to Karen Iler Kirk, Allyson Riley, and Amy M. Robbins of the Department of Otolaryngology–Head and Neck Surgery, Indiana University Medical Center, for their invaluable assistance on this project.

Abstract

This report is a description of an emerging phonetic-phonological system as manifested in the productions of a prelingually deafened child approximately two years after fitting with a Nucleus 22-Channel Multi-Electrode Cochlear Implant. A probe list consisting of 23 proper nouns known to the child was used to elicit samples of her speech; stimulus materials consisted of photographs of those persons (friends and family members) whose names were included in the probe list. Analysis of the production data included determination of the phonetic inventory of consonants and vowels, determination of phonotactic constraints apparent in the productions, and analysis of production correspondence patterns. Results showed a non-age-appropriate phonetic-phonological system, comparable, however, in many aspects to normally developing systems at much earlier stages or to functionally misarticulated systems at somewhat earlier stages.

An Emerging Phonetic-Phonological System Two Years Post-Cochlear Implant: A Preliminary Linguistic Description

Introduction

The past two-and-a-half decades have witnessed a widespread proliferation of cochlear implants as auditory prostheses for children with severe or profound sensorineural hearing losses (see House, 1991). An obvious benefit of these devices is that perception of sound, both speech and nonspeech, is enhanced. Recent research has demonstrated that there is a significant increase in performance on standardized tests of speech perception from pre-device testing to post-device testing (e.g., Miyamoto, Robbins, Osberger, Todd, Riley, & Kirk, 1995). Less often investigated have been the production abilities of children using these devices, especially analysis within a linguistic framework, either descriptive or theoretical.

This report is a description of an emerging phonetic-phonological system as manifested in the productions of a prelingually deafened child approximately two years after fitting with a Nucleus 22-Channel Multi-Electrode Cochlear Implant. A probe list consisting of 23 proper nouns known to the child was used to elicit samples of her speech; stimulus materials consisted of photographs of those persons (friends and family members) whose names were included in the probe list. Analysis of the production data included determination of the phonetic inventory of consonants and vowels, determination of phonotactic constraints apparent in the productions, and analysis of production correspondence patterns. Results showed a non-age-appropriate phonetic-phonological system, comparable, however, in many aspects to normally developing systems at much earlier stages or to functionally misarticulated systems at somewhat earlier stages.

Methods

Subject

The subject GK (not initials) was a white female, age 5;8 (years;months) at the time of first phonetic-phonological elicitation (described below). Deafness was congenital and attributed to Waardenburg Syndrome. Bilateral hearing-aid fitting (Phonak Pico-Forte PPC-L) took place at 0;10. Fitting of the right ear with a Nucleus 22-Channel Multi-Electrode Cochlear Implant (see Clark, et al., 1987) was performed at the Indiana University Medical Center (Indianapolis, Indiana) at age 3;10.

An unaided pure-tone audiometric analysis under headphones was performed approximately 4 months pre-cochlear implant. Because the subject refused to continue wearing the headphones, analysis was performed for pure-tone frequencies only between 250 and 2000 Hz. However, even these partial results indicated a severe to profound bilateral loss; all tested frequencies showed thresholds ≥85 dB HL for both ears, and thresholds increased as frequency increased. Thresholds for the right ear appeared slightly higher than for the left, and at 750 Hz the threshold was >120 dB HL. Tympanometry of equal date was within normal limits.

Materials

Stimulus materials consisted of 23 pictures of faces known to the subject, including those of friends, family members, and laboratory staff members. Stimulus materials were digital reproductions of 3-inch x 5-inch color photographs produced with Adobe Photoshop software. The photographs were scanned on a UMAX UC1260 scanner, and for each face a digital file was created. The digitized

images were edited on a Macintosh Quadra 840AV in order to remove all background images, so that only the head and upper torso (including headwear and clothing) remained. A Tektronix Phaser 200E wax transfer printer was used to generate suitable color stimulus materials. The images were then trimmed, mounted individually on white stock for presentation, randomized, and bound in a looseleaf notebook.

The use of proper nouns for the probe list addressed the question of lexical development in a child with profound hearing loss and the resulting severe delay in onset of phonetic-phonological production. Although the child was able to sign with some facility (although this showed some delay), it was not clear whether the development of a phonologically-based lexicon had kept pace, and it was equally unclear whether any items other than names would be present in that lexicon, i.e., whether specific semantic concepts had corresponding phonological representations. Thus, in order to avoid possible training effects with unknown lexical items, it was assumed that names of persons known to the child would be present already in her lexicon and therefore available for elicitation in a non-imitative production task.

Procedure

During regular therapy sessions, the book of pictures was shown to the subject, who was asked to say aloud the name of the person pictured on each page. If a verbal reaction was not forthcoming spontaneously, the subject was prompted by the clinician with questions such as 'Who's that?' or 'Can you tell me who that is?' No training on the names, except acknowledgment repetition during elicitation sessions or normal use of the names in everyday use, was provided. Elicitation sessions were tape-recorded, and from these tape-recordings narrow phonetic transcriptions were made by a trained linguist.

The first elicitation session took place 685 days post-implant, and further elicitations followed after that. Elicitation sessions below are referred to by the number of days post-implant that they took place. Five elicitation sessions are reported here.

Phonetic and Phonological Targets

Target Phonetic and Phonological Representations of Names

The 23 names associated with the 23 faces and their target pronunciations were as in Table 1 (somewhat broadly transcribed). Syllabification in this table is based upon a simple principle of onset maximization, with the single qualification that resulting syllable onsets must also be permissible word-initially.

Insert Table 1 about here

Target Phonetic Inventory and Distribution of Segments

Consonants. The target inventory of consonant (more exactly, nonsyllabic or nonvocalic) segments contained in the elicitation probe is listed in Table 2. A phonetic symbol indicates that the segment

Table 1

Twenty-three Names Corresponding to Faces Used as Production Stimuli

Orthography	Target Transcription	Orthography	Target Transcription
Alfred	['æl.frɨd]	Kris	[kʰrɪs]
Alice	['æ.lɪs]	Kristin	['kʰrɪ.stĩn]
Allyson	['æ.lɪ.sĩn]	Marge	[mɑrdʒ]
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.nĩn]
Dwayne	[də.'wẽĩn]	Tara	['tʰɛ.rə]
Haley	['heɪ.li]	William	['wɪl.jə̃m]
Josh	[dʒɑʃ]	Yvonne	[jɨ.'vɑ̃n]
Kim	[kʰĩm]		

was contained at least once in the name elicitation probe; empty brackets indicate that the English segment at that position was absent from the elicitation probe.

Insert Table 2 about here

Not elicited in this probe were thus the following six English segments: the voiced velar stop /g/, the voiced fricatives /ð z ʒ/, the voiceless affricate /t ʃ/, and the velar nasal /ŋ/. Additionally, not all consonant segments were elicited in all possible word positions. Table 3 shows the nine word positions in the probe in which consonant segments could occur, as well as the number of segments that actually did occur in those positions. In this table, 'X' indicates any segment not a word-boundary. For instance, the three medial consonants in 'Alfred' were considered to be two two-segment clusters, so that their components were distributed as follows: [l] occurred X __ C X (i.e., initial in [l f]); [f] occurred X C __ X and X __ C X (i.e, final in [l f] and initial in [f r]); and [r] occurred X C __ X (i.e., final in [f r]).

Insert Table 3 about here

Vowels. Table 4 shows the target vocalic segments that were included in the elicitation probe. Oral and nasal versions are collapsed under the oral representative.

Insert Table 4 about here

Table 5 gives the number of occurrences of each of the vowels and diphthongs in the target probe list.

Insert Table 5 about here

Target forms in the probe included 5 monosyllabic names, 16 disyllabic names, and 2 trisyllabic names. In total, the probe list contained 27 open syllables and 16 closed syllables and contained the syllabic structure types indicated in Table 6.

Insert Table 6 about here

Table 2

Target Inventory of Consonant Segments Contained in Elicitation Probe

Stops	pb			td		k[]		
Fricatives		fv	θ[]	s[]	ʃ[]			
Affricates					[]ʤ			
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 3

Number of Target Consonant Segments Occurring in Elicitation Probe at Each of Nine Word Positions

	#_v	#_c	#c_	x_cx	v_v	xc_x	_c#	c_#	v_#
p	1								
b					1				
t	1				1	1			
d	3								1
k	2	2							1
g									
f				1		1			
v					1				
θ					1				
ð									
s	2			1	1				1
z									
ʃ	1								1
ʒ									
tʃ									
dʒ	1							1	
m	1				1				2
n	1				2				4
ŋ									
l				2	3	1			
r			2	1	2	1	1		1
w	1				1				
j	1				1	1			
h	1								

Note: 'x' indicates any segment not a word-boundary.

Table 4

Target Vowel Segments Contained in Elicitation Probe

	Front	Central	Back	Diphthongs	Rhotacized
High	i ɪ	ɨ			
Mid	ɛ	ə		eɪ	ɚ
Low	æ	ɑ		aɪ ɒɪ	

Table 5

Number of Target Vowel Segments Contained in Elicitation Probe

Front		Central		Diphthongs				Rhotacized	
i	6	ɨ	4						
ɪ	7								
ɛ	3	ə	4	eɪ	3			ɚ	1
æ	7	ɑ	4	aɪ	1	ɒɪ	1		

Note: No high or mid back vowels were contained in the elicitation probe.

Table 6

Syllable Structure Types Contained in Elicitation Probe

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	[mɑrdʒ] 'Marge'

Results

Transcribed renditions of the 23 names from the five elicitation sessions are listed below in Table 7. In a few cases, two clear responses appeared on the tape recording; both of these were transcribed and appear in Table 7.

Insert Table 7 about here

Segmental Inventory

Inventory of Consonants. The production inventory of consonants for the forms listed in Table 7 are given in Table 8. As this table indicates, GK's consonant inventory contained a number of non-English segments: non-English stops included [ḅ ḍ]; fricatives included [ʂ ʐ s̪ ç] and the voiceless lateral fricative [ɬ]; additionally, the inventory contained the nasalized glide [w̃]. English consonants absent from the inventory included the voiceless bilabial stop [p] (although there were occurrences of affricate-like [pf] and [pv]), the voiced velar stop [g], the fricatives [ð z], the velar nasal [ŋ], and the liquid [r]; of these, /p/ and /r/ appeared in the probe list, while /g ð z ŋ/ were absent.

Insert Table 8 about here

Inventory of Vowels. The production inventory of vowels for the forms listed in Table 7 are given in Table 9. As this table indicates, GK's vowel inventory contained a number of non-English segments or segments not included in the target probe list of names. Non-English segments included the nasal vowels [ẽ ə̃] (i.e., nasal vowels produced in the absence of following surface nasal consonants) and the front rounded vowel [œ]. Somewhat marginal English segments (e.g., occurring in dialects not the ambient one for this child) were the monophthongal [e] and [a] and the diphthongal [əɪ] and [ao]. Finally, GK produced the back vowel [ɔ], even though it was not considered to be included in the target probe list.

Insert Table 9 about here

Summary Discussion. An examination of these production data reveals a fairly large inventory of consonants and vowels in this child's phonological system. All manners of articulation were represented at least once in the consonant inventory, and in fact, some manners were overrepresented: the fricative series, for instance, included a voiceless dental, a voiceless retroflex, and a voiceless true palatal. Additionally, the affricate series included both a voiceless and voiced labial, a voiceless dental, and voiceless and voiced alveolars, in addition to the correct voiceless and voiced alveopalatal affricates.

Table 7

Transcriptions of Twenty-Three Names as Produced in Five Elicitation Sessions

Name	685	690	697	718	731
Alfred	abvi	abvi	aḅvə	abvɪ	ɑbvɪ
Alice	ʔade	ɑˈlə	ɑlə	ɑl	ɑṣɪ
Allyson	ɑli	ɑːʰdə	ɑṣə	ɑɬɪ	ɑɬɪ
Amy	hɑw̃ĩ	ʔaˈmi	ʔɑmi	hɑmʔi	ɑːmɪ
Carly	ədəɪ	pfɑli	tɑji	tɔːi	dɑɪ
Cathy	ɑti	ati	ɑti	atiç	ɑti
Debbie	dəˈbi	ḍəbi	ʃːdəbi	dəˈbi	daˈbi
Diana	nːɑ	daʰnə	nɑdɑ	ṣɑːnɑ	ʃəbəwə
Dwayne	fwɪm	fɪʃ	fəɪʃ	fɪẓ	vẽ
Haley	adɪm	ɑˈdi	ɑdi	ɑˈdi	ɑdi
Josh	dɑʃ	dʒɔbə	pvɑʃ	dɑtʃ	dzɑt
Kim	ʃɛ̃m	ɑːdi æ̃dʒɛm	ɑ̃mʃĩm	ɑhi	əmkɪb*
Kris	fwɪṣ	fɪ	fəʔ	hɪʔ	bəʔ

Table 7- Continued

Transcriptions of Twenty-Three Names as Produced in Five Elicitation Sessions

Name	685	690	697	718	731
Kristin	kʷɪdɪn	wətsɪ	ʃeɪb kʷɪʃɪ	kʷɪtʂɪ	kwɪsɪʔ
Marge	mɔɜʃ	mə	bɑʃ	mɔɜʃ	mɑo
Nick	niç	nɪʰ	nɪç	nɪʔ	ni
Patty	badɪm	barɪdi	bɑˈti	paçiʔ	pəçiʔ
Sarah	ʃːtɛwə	tʃɛwə	ʃɛwə	ʂəwə	çɛw
Sawyer	təwə	tʂəː	təjə	dzɔː	dzəː
Shanan	tɑnɑ	tsəjɛm	pfeɪʃ	θɬɪ	çɬɪ
Tara	ʃɛwə	ʃɪwə	tsɛwə	dɛwə	tɛwə
William	hiːjəm mɪnəm	mɪmə̃m mɪnɛm	nə̃	mɛm	mələm
Yvonne	dadœ	ɛbvə	bvəbvə	bvəbvə	bvɑbvɑ

Notes: Column heading numbers indicate number of days post-cochlear implant.

*Some productions may correspond to 'Aunt Kim'.

Table 8

Production Inventory of Consonant Segments From Five Elicitation Sessions

Stops	b	b̥					ḍ	t	d					k	ʔ
Fricatives			f	v	θ		s̪	s	z̪			ʃ	ʒ	ç	
Lateral Fricative								ɬ							
Affricates	p	f	b	v			t̪s̪	t	s	d	z	t̪s̪	t	ʃ	dʒ
Nasals		m						n							
Liquids								l							
Glides	w	w̃										j			h

Table 9

Production Inventory of Vowel Segments from Five Elicitation Sessions

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

In addition to the occurrence of expected forward, i.e., visible, consonants such as labials and dentals, less visible consonants also occurred, including (alveo-)palatals and velars. Forms for names such as 'Josh', 'Kristin', 'Marge', and 'Nick' indicate the development of non-visible sounds as well as visible ones. This serves as evidence that production indicators were being transmitted by the prosthesis and not just through the visual channel alone.

The absolute inventory of vowel segments was also fairly complete. Although it appears that back rounded vowels were for the most part absent, as indicated in Table 9, it is also the case that these vowels were absent from the probe list itself, as shown in Table 4.

Phonotactic Constraints

Syllable Structure. As illustrated in Table 6 above, the target probe list contained two relatively marked types of syllable structure: syllables with consonant clusters and closed syllables. Although it might be reasonably expected that GK's productions would fail to evidence productions of this type, an examination of the data in Table 7 does not bear out such an expectation. In fact, GK's productions did in fact contain both consonant clusters and closed consonants. With regard to initial consonant clusters, there were a number of consonant sequences that could be regarded as affricate-like (i.e., a stop followed by a homorganic fricative), among them, [pf] in 'Shanan' at 697, [pv] in 'Josh' at 697, [bv] in 'Yvonne' at 731, [ts] in 'Shanan' at 690, [dz] in 'Josh' at 731, and [tʃ] in 'Sarah' at 731. The exact analysis of these sequences is problematical, especially as many of these initial sequences are not considered to be affricates in English. However, when these problematic cases are set aside, there do remain initial consonant sequences that must be regarded as clusters; these include [fw] in 'Dwayne' and 'Kris' at 685, [θɻ] in 'Shanan' at 718, [ʃ:t] in 'Sarah' at 685, [ʃ:d] in 'Debbie' at 697, and [çɻ] in 'Shanan' at 731.

With regard to the occurrence of closed syllables, it is also true that these relatively marked structures were by no means absent from GK's productions. Given the limitations of the probe list itself (only 37% of the syllables in the probe list were closed), it appeared that a number of different types of consonants could occur in the coda: nasals (e.g., 'Haley' at 685, 'Kristin' at 685); fricatives (e.g., 'Cathy' at 718, 'Josh' at 697); affricates (e.g., 'Josh' at 718); and stops (e.g., 'Josh' at 731, 'Kristin' at 697).

Evidence from functional misarticulating children has indicated that in some cases, particular classes of segments may be limited to specific syllable or word positions in developing phonological systems (see Dinnsen, Chin, Elbert, & Powell, 1990). The data here indicated that manners of articulation were generally not restricted to specific syllable positions (i.e., either only onset or only coda). Noncontinuants could appear either syllable-initially or syllable-finally; this included both stops (e.g., 'Debbie' at all probe intervals and 'Kristin' at 697), and affricates (e.g., 'Sarah' at 690 and 'Josh' at 718). Fricatives were likewise unrestricted in their syllable position occurrences and could appear initially (e.g., 'Tara' at 685 and ''Marge' at 697). Finally, nasals could appear in both a syllable onset (e.g., 'Marge' at 731) and a syllable coda (e.g., 'Patty' at 685).

Phonotactic constraints in GK's system thus allowed a number of sequencing patterns that approximated the target system. Two relatively marked structures, i.e., initial consonant clusters and closed syllables, appeared in her productions, and consonants appeared not to be restricted to specific syllable positions.

Correspondence Patterns

Although the elicitation probe used for this study was a relatively limited one, it did reveal a number of correspondence ('substitution') patterns that were comparable to those evident in the

phonetic-phonological systems of other children developing language. In particular, a number of correspondences appeared similar to those used in early acquisitional stages by hearing children acquiring the language normally and hearing children with delayed phonological development (see Bernthal & Bankson, 1993; Elbert & Gierut, 1986; Stoel-Gammon & Dunn, 1985).

One such correspondence pattern showed an unaspirated stop where the ambient language shows an aspirated stop. Examples from GKs productions include target 'Patty', which has an initial aspirated stop, but which was produced by GK variously as [badɪm] (685) or [baɪdi] (690) or [bɑ'ti] (697), with an initial unaspirated stop. A second correspondence pattern, also evident in younger, hearing children, showed noncontinuants where the ambient system shows continuants, i.e., stops or affricates corresponding to target fricatives. Examples from GK's productions included [təwə] 'Sawyer' (685), [tɑnɑ] 'Shanan' (685), [ɑti] 'Cathy' (685, etc.), and [bvəbvə] 'Yvonne' (697, etc.), in which an affricate appeared where the target form has a fricative.

A third correspondence pattern showed a nonsonorant nonlateral (i.e., a [d]) where the ambient language shows a sonorant lateral (i.e., an [l]). Examples of this pattern included [ɑ'di] 'Haley' (690, etc.), [ʔade] 'Alice' (685), and [a:^{h}di] 'Allyson' (690). Finally, the voiceless alveopalatal fricative [ʃ] often appeared where the target system has a nonlabial: [ʃ:ɛwə] 'Sarah' (697), [ʃɛwə] 'Tara' (685), and [ʃɛm] 'Kim'. Note that this latter corresondence pattern appeared to neutralize a variety of ambient places and manners of articulation.

Representations

As mentioned previously, the decision to employ proper nouns as the responses in this task was based upon the assumption that, among possible lexical items, representations for names of familiar people in GK's environment would most likely be already present in GK's lexicon. Evidence that this was borne out includes the relatively spontaneous (i.e., unprompted) nature of responses on this task, and the stability of productions across the five elicitation sessions.

Among the 23 names elicited, a number of these appeared to be very nearly correct in their production, and were furthermore relatively stable over time. These included productions of 'Amy', 'Debbie', 'Haley', 'Nick', 'Patty', 'Sarah', and 'Tara'. In these cases, especially, the phonological distance between target and response appeared to fairly small. Here may be invoked the two criteria that all consonantal slots were marked, and that the consonants produced were phonetically or phonologically similar to the target segments. A second group of productions showed fairly stable productions across the elicitation sessions but also showed greater phonological distance between target and response than the first group. This second group included 'Alfred', 'Alice', 'Cathy', 'Dwayne', 'Josh', 'Kris', 'Kristin', 'Marge', and 'William'. Finally, a third group showed either relatively unstable representations or greater phonological distance between target and response than in the first two groups. Names in this last group included 'Allyson', 'Carly', 'Diana', 'Kim', 'Sawyer', 'Shanan', and 'Yvonne'.

Discussion

The relatively small corpus of data elicited for this study limits linguistic analysis to descriptions of surface phenomena and to a large extent precludes a more detailed discussion of such phonological attributes as levels of representation, morphophonemic alternations, and phonological rules. However, for purposes of a preliminary linguistic description of an emerging phonetic-phonological system, the data elicited can at least shed some light on the acquisition of language by a child with a cochlear implant.

The emerging phonological system described here is one for a child almost 6 years old; in comparison with hearing children of that age, this system is clearly not age-appropriate: several segments appear to be missing from the consonant and vowel inventories, several non-English sounds appear, and some productions are unstable across elicitations. However, the system that is emerging here appears to be subject to a number of the same constraints that define the development of phonology in normally hearing children, both with and without phonological delay. Although segments are missing from the phonetic inventory, many of these are the same segments that would be expected to be absent from other developing systems, e.g., voicing congeners of consonants already present and back consonants. Furthermore, a number of correspondence patterns in this child's production system, although not always highly systematic, are, in fact, similar to those found in the developing phonologies of children with normal hearing. Among these are the correspondence of unaspirated stops to target aspirated ones, the correspondence of stops and affricates with target fricatives, and the correspondence of a voiced stop with a target lateral liquid. Finally, although a number of productions appear to have changed across the various elicitation sessions, a good number remained quite stable, provide some evidence that this child is beginning to associate concepts (in this case, concepts of people) with phonetic-phonological representations.

As mentioned earlier, the cochlear implant is designed primarily as an aid for perception of sound, both speech and nonspeech. Although in young children the evidence for the relationship between perception and production ranges from equivocal to controversial, the description here provides evidence that the cochlear prosthesis has aided the development of speech production abilities. A comparison of GK's performance on tests of speech perception with the type of production data presented here will more fully answer the question of how perception and production are related in her emerging phonetic-phonological system.

This report has been a very preliminary study of the emergence of a phonetic-phonological system at a very early stage of development, and further production data are currently being gathered using the elicitation probe described here. However, in order to truly probe the depths of phonetic-phonological development in this child, more detailed and more far-ranging elicitation instruments are being developed, in order to tap more fully this child's growing awareness of the relationship between sound and meaning.

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