ON WORD-INITIAL VOICING: CONVERGING SOURCES OF EVIDENCE IN PHONOLOGICALLY DISORDERED SPEECH*

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The purpose of this study is to bring related sources of data, i.e., phonological and acoustic phonetic, to bear on the characterization of two children's disordered phonological systems. Auditorily-based phonological analyses indicated that the children exhibited a superficially similar pattern of error involving the voice contrast in word-initial obstruent stops, even though both children accurately produced the voice contrast in post-vocalic stops. Acoustic phonetic analyses indicated, however, that one of the children systematically effected the voice distinction using closure duration and voice onset time, whereas the other child did not. Despite the similarity of their errors as assessed by auditorily-based phonological analyses, the children had very different productive knowledge of word-initial voicing in stops. These findings have implications for the clinical assessment and treatment of children with phonological disorders.

Keywords: voicing, disorders, universals, clinical

INTRODUCTION

Studies of both normal phonological acquisition (Barton and Macken, 1980; Kornfeld and Goehl, 1974; Macken and Barton, 1977, 1980; Menyuk, 1972) and phonological disorders (Hoffman, Stager and Daniloff, 1983; Maxwell, 1981a, 1981b; Maxwell and Weismer, 1982; Weismer, Dinnsen and Elbert, 1981) have indicated that young children often produce contrasts among sounds that are not perceived by adult listeners. Children mark phonological contrasts by producing phonetic distinctions, which may or may not be comparable to those used by adults. Fine-grained acoustic phonetic analyses are needed in such cases to determine whether a systematic distinction is being made. Phonetic distinctions in the absence of perceptible phonological contrasts have been taken as evidence that children have more knowledge of the sound system than is immediately apparent to listeners at an auditory level. A child's knowledge of the sound system, as used herein, refers specifically to *productive knowledge* or the ability to produce systematic phonetic (articulatory and/or acoustic) distinctions among sounds for the purpose of marking phonological contrasts in the language. A child's knowledge

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of the sound system can also be evaluated on the basis of other skills, such as speech perception (cf. Menn, 1983). These skills, however, lie outside of the domain of speech production and are possibly even independent processes (cf. Dinnsen, 1984, 1985; Straight, 1980).

For phonologically disordered children, in particular, these findings are relevant to the clinical assessment and treatment of speech sound errors. With regard to clinical assessment, these findings suggest that, in some cases, auditorily-based descriptions of a child's speech sound errors may be inaccurate (Maxwell and Weismer, 1982; Weismer, 1984; Weismer *et al.,* 1981). Maxwell and Weismer (1982), for example, reported the case of a child who did not evidence a voice, place, or manner contrast among word-initial obstruents; phonologically, this child only produced [d] in word-initial position. Acoustic phonetic evidence, however, indicated that the child produced a three-way distinction among obstruents. This child demonstrated more productive knowledge of the sound system than was available from the phonological analysis. Conventional data for the phonological analysis were not sensitive enough to identify these subtle, systematic phonetic differences among word-initial obstruents.

With regard to clinical intervention, these findings suggest that children with similar patterns of error may have very different productive knowledge of sounds, and therefore, may require different treatments. For example, Weismer, Dinnsen and Elbert (1981) observed three children who displayed superficially similar phonological errors involving omission of word-final obstruents. Acoustic phonetic data indicated that two of the children marked final obstruents in terms of vowel duration differences, even though final obstruents were omitted. These children evidently had productive knowledge of final obstruents,[1] but used a phonological rule of word-final deletion.[2] The third child, on the other hand, did not produce or otherwise acoustically mark final obstruents. This child exhibited a pattern of error characterized by inaccurate lexical representations of morphemes (relative to the target); that is, the child apparently represented morphemes without post-vocalic obstruents. Consequently, a rule of word-final deletion would not be applicable. Notice that these three children all displayed superficially similar errors, but their productive knowledge of sounds was different. It is expected that these differences in productive knowledge would affect the goals of treatment, such that two of the children would need to be taught to eliminate a phonological rule, while the third child would need to alter the underlying lexical representation of morphemes.

Phonological evidence and acoustic phonetic evidence serve an important function in the accurate assessment of a phonologically disordered child's productive knowledge of the sound system and in the identification of an appropriate treatment plan. To date,

[1] Another possible interpretation of these results, that was not considered by Weismer *et al.* (1981), is that the children demonstrated knowledge of a phonemic vowel length distinction rather than knowledge of final obstruents. This interpretation, however, would have other theoretical consequences that are problematic, i.e., phonemes with defective distributions.

[2] The claim that a phonological rule deleted final obstruents was further motivated by morphophonemic alternations for these two children but not for the third child.

however, there have been relatively few studies that have reported the use of related sources of data in the assessment or treatment of phonological disorders. With the exception of Weismer *et al.,* there have been no other studies that have established differences in productive knowledge for children exhibiting similar patterns of error; moreover, differences in productive knowledge have not been reflected in subsequent treatment goals. Thus, the purpose of this paper is two-fold: (1) to present related sources of data (phonological and acoustic phonetic) in descriptions of the sound systems of two misarticulating children, and (2) to identify differences in productive knowledge and treatment despite superficial similarities in error pattern. Two studies follow. The first study analyzed phonologically the speech of two children and, thus, established the similarity of their error pattern. The second study was motivated by the first and, thus, analyzed acoustically the apparent phonological similarity between the two children.

SUBJECTS

Two children, Aaron, age 4 years, 6 months, and Becca, age 4 years, 3 months, participated as subjects. Both children were functional misarticulators, producing errors on several sounds from different sound classes, as determined by performance on the *Goldman-Fristoe Test of Articulation* (Goldman and Fristoe, 1969). The children were especially suited for this study given the similar nature of their errors in production of the voice contrast in word-initial stops. The children were from monolingual English-speaking homes, and had no previous history of language, hearing, cognitive, or motor disorders.

PHONOLOGICAL ANALYSES

Data collection

A spontaneous speech sample, 30 minutes in duration, was elicited individually from each child in varied situations, such as play and story-telling. The spontaneous speech sample was supplemented by a probe sample. The probe sample consisted of single-word spontaneous productions elicited through picture- and object-naming tasks. The probe sample ensured that each child had ample opportunity to produce all target English sounds; it also allowed for the elicitation of potential minimal pairs and morphophonemic alternations.

All speech samples were tape-recorded, then narrowly transcribed (IPA notation) and glossed by the first author. If utterances could not be glossed, transcriptions were still included in the data set, providing information about the occurrence and distribution of sounds.

Data analysis

Standard generative phonological descriptions were developed for each child, consistent with procedures outlined by Dinnsen (1984), Kenstowicz and Kisseberth (1979), and Maxwell and Rockman (1984). Each child's sound system was described in terms of the phonetic and phonemic inventories, distribution of sounds, lexical representation of morphemes, phonological rules, and phonotactic constraints.

Intrajudge reliability

Ten percent of each child's spontaneous speech sample used in the phonological analysis was retranscribed by the first author approximately nine months after it was obtained. Point-to-point intrajudge reliability was calculated for all consonants produced. Mean intrajudge agreement for Aaron's sample was 85% (N = 459 segments), and for Becca's sample, 94% (N = 431 segments).

Results

Aaron's phonological system. Aaron maintained a limited phonetic inventory with regard to the target sound system. His phonetic inventory included the sounds:

m	n	ŋ	
pb	td	kg	ʔ
	s		
	t̂s d̂z		
w			h
	r		

Of the fricatives, Aaron never produced [f, v, θ, ð, z, ʃ] in any word position; instead, he used [s]. In fact, [s] was the only fricative Aaron ever produced. Affricates were produced, i.e., [t̂s, d̂z]; however, they were not those of the adult sound system, i.e., [tʃ, dʒ].

Stops were produced in intervocalic and final positions, and these sounds did not alternate, as shown in the following forms:

Target [p]	[wipi]	~	[wip]	'zipping' – 'zip'
	[tupi]	~	[tup]	'soupy' – 'soup'
Target [b]	[wʌbɪŋ]	~	[wæp]	'rubbing' – 'rub'[3]
	[kɔbi]	~	[kɔp]	'cobby' – 'cob'
Target [t]	[buɾi]	~	[but]	'bootie' – 'boot'
	[bætɚ]			'butter'
	[laɪ̂t]			'light'

[3] The underlying representation of the morpheme *rub* is /wæb/; *cob* is represented as /kɔb/. An optional rule of word-final devoicing applied to this child's sound system; thus, the phonetic forms of these morphemes do not have final voiced segments, resulting in the productions [wæp] and [kɔp].

Target [d]	[badi]			'body'
	[pa̯ɪdɚ]			'spider'
	[a̯ɪd]			'hide'
	[da̯ɪd]			'find'
Target [k]	[dæki]	~	[dæk]	'duckie' – 'duck'
	[kɪkuən]	~	[kɪk]	'kicking' – 'kick'
Target [g]	[dɪgi]	~	[dɪg]	'digging' – 'dig'
	[ɛgi]	~	[ɛg]	'egg-i' – 'egg'

Moreover, a voice contrast[4] was maintained for intervocalic and final stops as illustrated by these minimal and near minimal pairs:

'supper'	[dʌpɚ]	–	[d͡zʌbu]	'jumping'
'tape'	[tep]	–	[seb]	'shave'
'water'	[ɔtɚ]	–	[odɚ]	'over'
'ice'	[a̯ɪt]	–	[a̯ɪd]	'hide'
'leggy'	[ɛki]	–	[ɛgi]	'egg-i'
'frog'	[pwɔk]	–	[pwæg]	'flag'

In word-initial position, Aaron also produced stops. However, there was no evidence of a voice contrast in that position; voiced and voiceless stops freely varied:

[p] ~ [b]	[pɪgi]	~	[bɪgi]	'piggie'
	[pinæ̃t]	~	[binæ̃t]	'peanut'
	[pwʌsən]	~	[bwʌtən]	'brushing'
[t] ~ [d]	[ti]	~	[di]	'teeth'
	[top]	~	[dop]	'soap'
	[teobo͡ʊ]	~	[deobo͡ʊ]	'sailboat'
[k] ~ [g]	[kom]	~	[gom]	'comb'
	[kɛt]	~	[gɛt]	'catch'
	[kɔt]	~	[gɔt]	'got'

The absence of a word-initial voice contrast was also evident in the child's homophonous production of potential minimal pairs:

'pie'	[ba̯ɪ]	–	[ba̯ɪ]	'bye'
'pig'	[bɪg]	–	[bɪg]	'big'

[4] The "voice contrast" or "voicing," as used throughout this paper, refers to a phonological distinction between voiced and voiceless obstruents. This phonological voice distinction is, of course, implemented phonetically in a variety of ways in various contexts in different languages.

'tie'	[da̯ɪ]	–	[da̯ɪ]	'die'
'town'	[da̯ʊn]	–	[da̯ʊn]	'down'
'coat'	[ko̯ʊ]	–	[ko̯ʊ]	'goat'
'cow'	[ka̯ʊ]	–	[ka̯ʊ]	'gown'

These data indicate, among other things, that Aaron maintained a phonemic voice contrast among stops in the intervocalic and final positions of words, but not in word-initial position.

Becca's phonological system. Becca maintained a relatively complete phonetic inventory with regard to the adult system. Her phonetic inventory included the sounds:

m		n			ŋ	
pb		td			kg	ʔ
fv	θð	sz	ʃ			
			tʃ	dʒ		
w				j		h
		l		r		

Becca produced the target fricatives [f, v, θ, ð, s, z, ʃ] in post-vocalic positions. She did not, however, produce these sounds in word-initial position; stops were used instead. The affricates patterned in a similar manner to the fricatives; [tʃ, dʒ] were used post-vocalically but not word-initially.

Like Aaron, Becca produced stops in the intervocalic and final positions of words. These stops did not alternate, as shown in the forms:

Target [p]	[tupi]	~	[tup]	'soupy' – 'soup'
	[dɪpi]	~	[dɪp]	'chippy' – 'chip'
Target [b]	[tʌbi]	~	[dʌb]	'tubby' – 'tub'
	[wo̯ʊbi]	~	[wo̯ʊbs]	'robe-i' – 'robes'
Target [t]	[bæɾi]	~	[bæt]	'fatty' – 'fat'[5]
	[ba̯ɪɾɪn]	~	[ba̯ɪt]	'biting' – 'bite'
Target [d]	[widɪn]	~	[wid]	'reading' – 'read'
	[mʌdi]	~	[mʌd]	'muddy' – 'mud'
Target [k]	[bʊki]	~	[bʊk]	'book-i' – 'book'
	[wɔki]	~	[wɔk]	'rocky' – 'rock'
Target [g]	[bægi]	~	[bæg]	'baggy' – 'bag'
	[hʌgɪŋ]	~	[hʌg]	'hugging' – 'hug'

5 The alternation between [ɾ] and [t] is consistent with adult productions. This child, like adult speakers of English, used a rule of intervocalic flapping.

Moreover, in intervocalic and final positions, a phonemic voice distinction was maintained among stops, as illustrated by the following minimal and near minimal pairs:

'soapy'	[do̯ʊpi]	–	[wo̯ʊbi]	'robe-i'
'cup'	[tʌp]	–	[dʌb]	'tub'
'because'	[ditɑ]	–	[didɚ]	'teacher'
'cut'	[dʌt]	–	[mʌd]	'mud'
'chicken'	[dɪkɨn]	–	[dɪgi]	'ziggy'
'back'	[bæk]	–	[bæg]	'bag'

In word-initial position, Becca also produced stops. However, voiced and voiceless stops were in free variation, as in the forms:

[p] ~ [b]	[pe̯ɪ]	~	[be̯ɪ]	'play'
	[pɪks]	~	[bɪks]	'fix'
	[pe̯ɪdʒi]	~	[be̯ɪ:tʃ]	'page-i' – 'page'
[t] ~ [d]	[ti:]	~	[di]	'see'
	[tɪd]	~	[dɪθ]	'kid(s)'
	[tʌmpɪn]	~	[dʌmpɪn]	'something'
[k] ~ [g]	[kɔf]	~	[gɔfɪŋ]	'cough' – 'coughing'
	[ko̯ʊm]	~	[go̯ʊmi]	'comb' – 'comb-i'

A voice contrast was evidently not maintained among word-initial stops. This was further illustrated by Becca's homophonous productions of potential minimal and near minimal pairs:

'pig'	[bɪg]	–	[bɪg]	'big'
'pie'	[ba̯ɪ]	–	[ba̯ɪt]	'bite'
'to'	[du]	–	[du]	'do'
'tear'	[dɪə]	–	[dɪə]	'deer'
'coat'	[go̯ʊt]	–	[go̯ʊt]	'goat'

These data indicate that Becca used voicing contrastively in the intervocalic and final positions of words; however, she did not use this contrast word-initially.

Thus, the results of the phonological analyses indicated that both Aaron and Becca exhibited a similar pattern of error with regard to their use of obstruent stops. Stops were produced in all word positions. However, a voice distinction was only maintained for post-vocalic stops; word-initially, voicing was not systematically contrastive for either child.

This particular property of the phonological systems of these two children is unusual in that their pattern of production is an apparent violation of a known substantive universal, the voice contrast hierarchy (Dinnsen and Eckman, 1975, 1978). This universal, which is based on phonological contrasts (and not strictly phonetic parameters), states that the presence of a voice contrast word-finally implies the contrast word-medially, and that in turn, implies the contrast word-initially. The universal hierarchy predicts that a language that maintains a voice contrast in any word position will also maintain the contrast in all implied positions, but not necessarily in implying positions. Initial position (least marked) is the most favored position for a voice contrast, and final position (most marked) is the least favored position for a voice contrast.

Typological evidence from primary (first acquired, natural) languages has indicated that there are languages with no voice contrast in any position, e.g., Korean.[6] There are languages with a voice contrast initially, but not intervocalically or finally, e.g., Corsican and Sardinian. There are languages with a voice contrast initially and intervocalically, but not finally, e.g., Polish and German. Of course, there are languages with a voice contrast in all positions, e.g., English. The universal excludes the possibility that a primary language will maintain a voice contrast in intervocalic and final positions without also maintaining this contrast word-initially. No known primary languages have shown patterns contrary to this observed relationship.

To date, there are no available data from normal language acquisition that bear upon this universal. While there have been numerous reports on the acquisition of voicing by children of different languages (Gilbert, 1977; Kewley-Port and Preston, 1974; Krause, 1982; Locke, 1983; Macken, 1980; Macken and Barton, 1977, 1980; Raphael, Dorman and Geffner, 1980; Smith, 1978; Zlatin and Koenigsknecht, 1976), these investigations have only focused on the use of the voice contrast in one word position. Development of the voice contrast across word positions for individual children is an area of investigation that needs further attention.

Similarly, there are no available data from misarticulating children that bear upon this universal. The potential violation of this universal by the two children of this study serves as additional motivation for examining their disordered sound systems in greater detail. While phonological data indicate that these children did not produce a word-initial voice contrast, perhaps acoustic phonetic evidence would show that this contrast was being systematically marked, as has been observed in at least one stage of acquisition of the voice contrast by normally developing children (Barton and Macken, 1980; Macken and Barton, 1977, 1980). If an acoustic analysis revealed that a systematic distinction was being produced by the children (although not detected by the writers of the phonetic transcriptions), these data would be in agreement with the universal voice hierarchy. Given the apparent phonological similarity of the sound systems of these two children and given the apparent uniqueness of this error pattern, an acoustic phonetic study was designed to further investigate word-initial voicing.

[6] Superficially, it may appear that Korean is not an appropriate example of this point since both voiced and voiceless obstruents occur between vowels. The voiced obstruents, however, correspond to and alternate with lax voiceless unaspirated stops in other positions and are thus entirely predictable by an allophonic rule. Phonologically all stops in Korean are described as voiceless, i.e., tense and lax unaspirated stops, and aspirated stops (Martin, 1951; Moon, 1974).

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ACOUSTIC PHONETIC ANALYSES

Data collection

A naming game was developed to elicit comparable utterances from each child for measurement purposes. Before the actual test session, each child participated individually in a pretraining session in order to instruct him or her in this game. The game required that the child embed the name of an object or picture in the carrier phrase, "Say _____ again." The game proceeded in a manner similar to "Simon Says," with pictures and objects presented in sequence and the child spontaneously producing the desired phrase. The child stayed "in" the game and earned points for saying the entire utterance with the embedded target word, e.g., "Say sun again." The child was "out" of the game if only the target word was named, e.g., "Sun," only part of the carrier phrase was produced, e.g., "Sun again," or there was a pause between "say" and the target word, e.g., "Say (pause) sun."

The actual test session proceeded in much the same manner as pretraining. Six minimal pairs were selected as test items for spontaneous production. Test items were common, picturable words familiar to the children. Two exemplars for each voiced and voiceless stop in each place of articulation were used: *pig – big, peach – beach* (bilabial stops); *town – down, tear – deer* (alveolar stops); *coat – goat, curl – girl* (velar stops). These items were randomly presented to each child for production in the carrier phrase, "Say _____ again." Each test item was elicited 15 times, for a total sample size of 180 tokens per child. Samples were collected individually for each child and tape-recorded in a sound-insulated clinical treatment room over three consecutive days.

Data analysis

Wide-band spectrograms (300 Hz filter) with high frequency shaping were made on a Voice Identification Series 700 Sound Spectrograph. Measurements were made relative to the vowel in the carrier word *say* and the following stop and vowel in the test word. Measurements were made to the nearest 5 milliseconds (msec) for two different timing intervals: stop closure duration and voice onset time (VOT). Stop closure duration was defined as the interval from the offset of periodic vertical striations in the first and second formants of the vowel in the word *say* to the sudden spiked vertical increase in amplitude, indicating a stop release burst. VOT was defined as the interval from the stop release burst (as above) to the onset of periodic vertical striations in the following first formant. These particular parameters were selected for measurement since they have been cited as two cues to the voice distinction in word-initial stops (Delattre, Liberman and Cooper, 1955; Flege and Port, 1980; Lisker and Abramson, 1964, 1967; Malécot, 1968; Stathopoulos and Weismer, 1983; Zlatin, 1974). In English, closure duration may not be a primary cue to the voiced-voiceless contrast in prestressed stops (for review of relevant literature, see Flege and Brown, 1982). However, closure duration is a cue to voicing in prevocalic stops in other languages (e.g., Arabic). Since children may produce phonetic distinctions that are unlike those used by adults, it is plausible that closure duration functioned as a cue to the voice contrast for the two children of this study.

For each child, several measurements had to be discarded from the original data set.

The measurements were discarded because of poor recordings, including a child's production being spoken too softly or with extraneous noises, such as hand clapping or table tapping; or because the closure duration exceeded 250 msec, indicative of a pause between the carrier word *say* and the following test word. In any of these cases, measurement of the noted parameters would prove unreliable (Maxwell, 1981a, 1981b; Maxwell and Weismer, 1982). This resulted in approximately 16% of the 180 tokens for Aaron being discarded; 152 tokens were subjected to analysis. For Becca, approximately 37% of the tokens had to be discarded; 114 tokens were suitable for analysis.

Analyses of variance were calculated for closure duration and VOT for each child. A 2 (voice) × 3 (place of articulation) unbalanced factorial design was used. The criterion for significance was set at $p < 0.025$ for each comparison.

Intrajudge reliability

An estimate of measurement reliability was calculated for 10% of each child's tokens used in the acoustic analysis. Spectrograms were remeasured by the first author approximately nine months after the original measurements were obtained. Intrajudge reliability was determined by calculating a mean difference score (msec) between the initial measurements and the remeasurements (cf. Charles-Luce, 1985) for both closure duration and VOT. For Aaron, the mean difference scores were +/− 5.67 msec for closure duration and +/− 0.67 msec for VOT. For Becca, mean difference scores were +/− 6.67 msec for closure duration and +/− 4.58 msec for VOT.

Results

Aaron's acoustic analysis. Mean values for closure duration and VOT for voiced and voiceless stops in each place of articulation are presented in Figures 1 and 2; means and standard deviations are reported in Table 1.

For closure duration, the results of the analysis of variance indicate no significant main effect for voice [$F(1, 146) = 1.34$] or interaction between voice and place of articulation [$F(2, 146) = 1.00$]. There was, however, a significant main effect for place of articulation [$F(2, 146) = 16.65$, $p < 0.025$]. Closure duration values for place of articulation generally followed the sequence noted for adults (Flege and Port, 1980; Stathopoulos and Weismer, 1983), with bilabials being of longer duration than alveolars or velars.

The results of the analysis of variance for VOT also indicated no significant main effect for voice [$F(1, 146) = 2.05$] or interaction between voice and place [$F(2, 146) = 2.67$]. There was a significant main effect for place of articulation [$F(2, 146) = 13.57$, $p < 0.025$]. Again, place trends approximated those reported for adults (Klatt, 1975; Lisker and Abramson, 1964, 1967; Port and Rotunno, 1979); i.e., velars have longer VOT values than alveolars which, in turn, have longer VOT values than bilabials.

The results of the acoustic analysis for Aaron indicated neither closure duration nor VOT was used to mark a voice distinction for word-initial stops. It may have been the case, however, that this child used another parameter, such as amplitude of the burst or fundamental frequency of the following vowel, to achieve the voice contrast. Methodo-

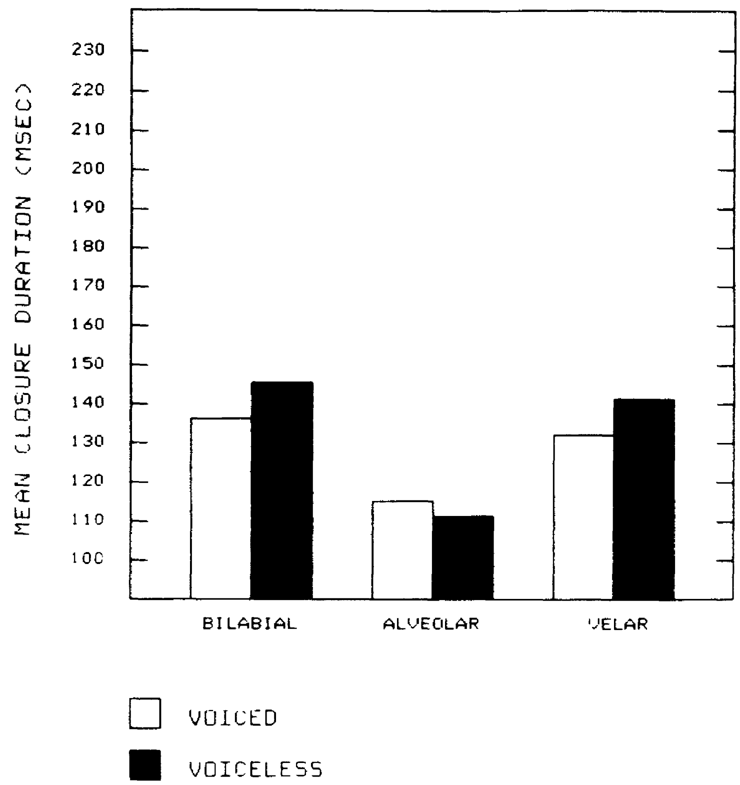

Fig. 1. Mean closure duration values (msec) for voiced and voiceless stops in each place of articulation for Aaron.

TABLE 1

Means and standard deviations for closure duration and VOT in msec for each place of articulation for Aaron

Place of Articulation		Closure Duration			VOT		
		n	$\bar{x}$	σ	n	$\bar{x}$	σ
Bilabials	+voice	22	135.68	20.08	22	26.59	10.28
	–voice	29	144.66	31.05	29	25.69	9.33
Alveolars	+voice	25	114.80	15.84	25	28.60	15.91
	–voice	29	111.38	25.14	29	28.45	14.09
Velars	+voice	25	131.60	24.53	25	34.60	11.98
	–voice	22	140.68	33.64	22	45.45	20.52

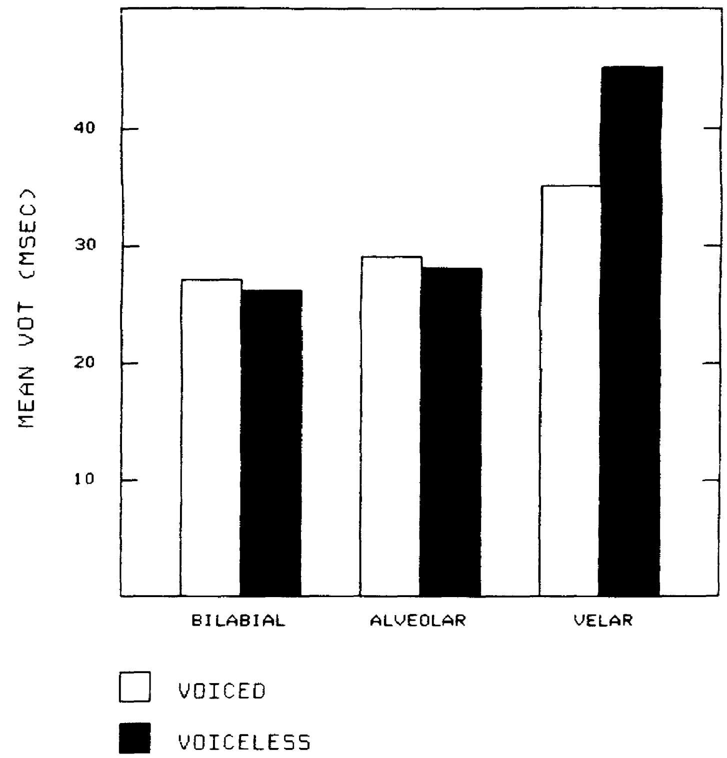

Fig. 2. Mean VOT values (msec) for voiced and voiceless stops in each place of articulation for Aaron.

logically, of course, it would have been impossible to rule out all potentially relevant parameters. Thus, these findings, while specific to the acoustic parameters measured, do support the phonological description indicating the absence of a word-initial voice contrast in stops.

Becca's acoustic analysis. Mean values for closure duration and VOT for voiced and voiceless stops in each place of articulation are displayed in Figures 3 and 4; means and standard deviations are also reported in Table 2.

For closure duration, results of the analysis of variance indicated that there was a significant voice distinction for stops [$F(1, 108) = 58.39$, $p < 0.025$], with voiceless stops of greater duration than voiced stops. This finding is generally consistent with closure duration data reported for adults (Flege and Port, 1980; Malécot, 1968; Stathopoulos and Weismer, 1983). There was no significant main effect for place of articulation [$F(2, 108) = 2.58$]; the relative place sequence (bilabial > alveolar or velar) was maintained, but only for voiced stops. A significant voice-by-place interaction [$F(2, 108) = 4.23$, $p < 0.025$] was noted; that is, mean voiced-voiceless distinctions were greater for alveolar and velar stops than bilabial stops.

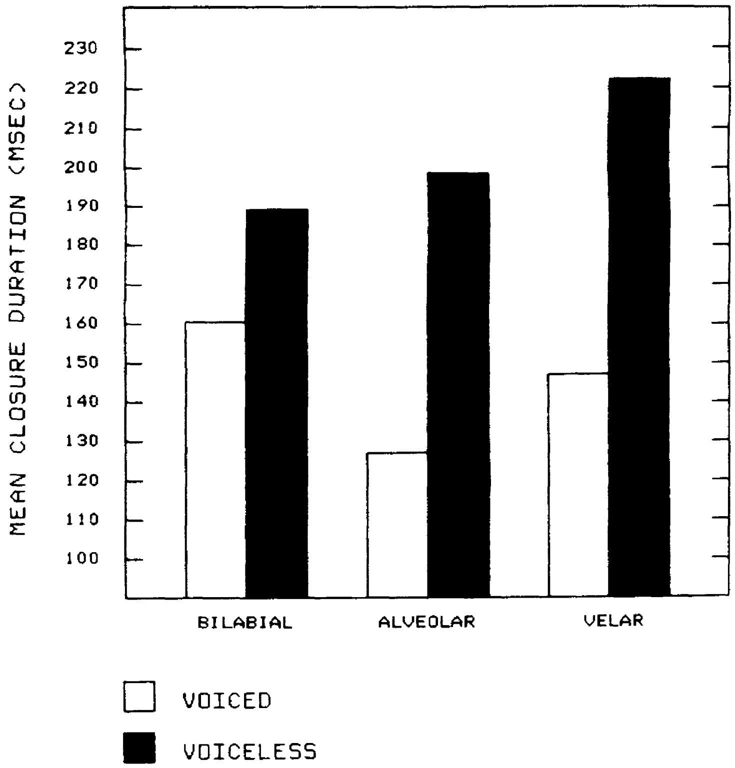

Fig. 3. Mean closure duration values (msec) for voiced and voiceless stops in each place of articulation for Becca.

TABLE 2

Means and standard deviations for closure duration and VOT in msec for each place of articulation for Becca

Place of Articulation		Closure Duration			VOT		
		n	$\bar{x}$	σ	n	$\bar{x}$	σ
Bilabials	+voice	25	160.00	44.21	25	18.40	10.77
	–voice	18	188.61	37.57	18	37.78	24.69
Alveolars	+voice	23	126.74	44.05	23	19.13	9.73
	–voice	15	198.00	35.24	15	33.33	18.19
Velars	+voice	24	146.67	31.23	24	32.29	17.38
	–voice	9	222.22	25.99	9	34.44	13.10

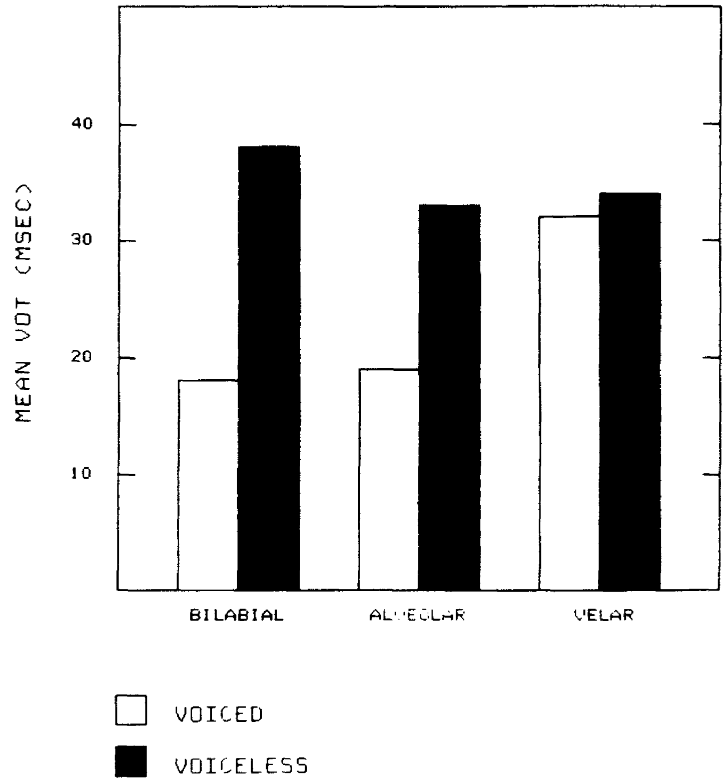

Fig. 4. Mean VOT values (msec) for voiced and voiceless stops in each place of articulation for Becca.

For VOT, the results of the analysis of variance indicated a significant main effect for voice [$F(1, 108) = 13.65$, $p < 0.025$] ; VOT values for voiceless stops were of greater duration than for voiced stops. There was no significant main effect for place of articulation [$F(2, 108) = 1.55$] ; however, relative place trends (velar > alveolar > bilabial) were maintained, but only for voiced stops. There was no significant interaction between voice and place [$F(2, 108) = 2.31$] .

The results of the acoustic analysis for Becca indicated that both timing intervals, closure duration and VOT, were used to effect a voice contrast among word-initial stops. These results, while specific to the test items and acoustic parameters measured, were not consistent with those of the phonological analysis which failed to identify a distinction in voice for word-initial stops. Becca demonstrated more productive knowledge of the voice contrast in word-initial stops than was originally determined by the phonological analysis.

DISCUSSION

These two children displayed superficially similar patterns of error, but their productive knowledge of the voice contrast in stops was different. For Aaron, phonological and acoustic phonetic data were converging. Given all the available data, this child did not produce or acoustically mark the voice distinction word-initially. For Becca, on the other hand, phonological and acoustic data were non-converging. Taken together, related sources of data indicated that Becca was, in fact, producing a voice contrast for stops in all positions; word-initially, however, this contrast was not perceptible to adult listeners. Moreover, acoustic phonetic data were necessary to accurately characterize Becca's productive knowledge of the voice contrast.

Differences in productive knowledge of the word-initial voice contrast may also have implications foı treatment goals. For Becca, the voice contrast may not need to be taught since she was already consistently producing the relevant distinction. Her problem would appear to be a matter of phonetic implementation, and her error would be viewed as phonetic in nature. For Aaron, it is clear that his error is phonological in nature and requires learning the voice contrast in initial position. It is less clear, however, what the goals of treatment should be in this case. The most obvious recommendation is that the voice contrast should be directly taught since it was not systematically produced in word-initial position. Here, treatment might take the form of minimal-pair contrast training (cf. Ferrier and Davis, 1973) between word-initial voiced and voiceless stops. In light of some recent research findings (Dinnsen and Elbert, 1984), however, it may not be necessary to teach this contrast. Specifically, Dinnsen and Elbert demonstrated that if a child is taught to produce more marked aspects of phonology, the acquisition of unmarked aspects of phonology will occur without direct treatment. For Aaron, there is some likelihood that voicing in the unmarked word-initial position would be spontaneously acquired, since he already produced this contrast in more marked post-vocalic positions.[7] In this case, production of the word-initial voice contrast might only need to be monitored or minimally treated in the course of clinical intervention. Thus far, there are no available data to suggest which of these two treatment goals is to be preferred, but these considerations are suggestive of future research.

The results of the acoustic and phonological analyses also bear upon the accuracy of the voice contrast hierarchy. By examining related sources of data, it is possible to establish whether the sound systems of these children violate the voice contrast hierarchy. In the case of Becca, even though the phonological analysis did not converge with the acoustic evidence, the acoustic evidence did indicate that the voice contrast hierarchy was maintained. This child produced a voice distinction in both marked and unmarked word positions; however, the strength of the contrast varied by position. That is, in post-vocalic positions, the contrast was perceptible to listeners, whereas, word-initially, it was not.

[7] Of course, this does not explain why the child does not already produce the voice contrast in initial position, given that he produces it in more marked contexts. Claims about markedness do not in all cases correspond with claims about order of acquisition (Locke, 1983).

In the case of Aaron, the voice contrast hierarchy was not obviously maintained. This child's sound system violated the linguistic universal and, therefore, was not like any other known phonological system. Evidence of this type can be brought to bear on the formulation of the voice contrast hierarchy. It may be necessary to revise this universal to accommodate this child's unusual phonological system. While it is not uncommon to find well-defined exceptions to language universals (cf. Gamkrelidze, 1975), qualifications of this particular universal are not readily apparent. More likely, this type of evidence also may bear on the characterization of Aaron's sound system. It has been suggested (Connell, 1982) that violations of language universals may serve as a means of systematically determining the severity of a child's speech sound disorder. Aaron's violation of the voice contrast hierarchy could be taken as evidence that his sound system (or at least part of the system) was structurally unlike that of other languages, indicative of a "severe" phonological disorder.[8]

In conclusion, the results of this study demonstrated that (1) phonological and acoustic phonetic sources of data were necessary to accurately describe the faulty sound systems of two children; (2) despite superficially similar phonological patterns, the children had very different productive knowledge of the relevant voice contrast; and (3) differences in productive knowledge may be reflected in subsequent treatment goals. These findings were consistent with those of previous research (Maxwell, 1981a, 1981b; Maxwell and Weismer, 1982; Weismer *et al.*, 1981), which underscored the importance of bringing phonological and acoustic phonetic data to bear upon the clinical assessment and treatment of children with phonological disorders. What was unique about this study, however, was that related sources of evidence were also used to empirically validate a substantive universal, the voice contrast hierarchy. It was only possible to establish "true" violations of the voice contrast hierarchy when converging sources of data, phonological and acoustic phonetic, were examined. Counterexamples to linguistic universals, when based on both phonological and acoustic phonetic evidence, may aid in defining the full range and nature of language types, in both normal and phonologically disordered speakers.

[8] Aaron was enrolled in a clinical research program subsequent to his participation in this study. In this intervention program, other faulty aspects of his sound system were targeted for treatment. After approximately nine months of intervention, Aaron produced targeted sounds with only 50% accuracy. Both the level of performance following treatment and the length of time enrolled in treatment suggest that Aaron's sound system may, in fact, have been "severely" disordered.

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