The Acquisition of Fricatives and Affricates: Evidence From a Disordered Phonological System

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This study describes the acquisition of the entire fricative and affricate sound classes by a child with a disordered phonological system and other co-occurring conditions. Pretreatment, the participant, age 5;3 (years; months), produced homorganic stops for all fricatives and affricates. Two fricatives, /v/ and /z/, were taught one at a time in the word-initial position, first by imitation and then in minimally paired words to test hypotheses regarding the generalization of the features [continuant] and [strident] across word positions and sound classes. The 26-week treatment followed cognitive-linguistic principles and resulted in reorganization of the sound system to include the fricative and affricate sound classes.

Key Words: phonological acquisition, phonological intervention, fricatives, affricates, phonological disorders

Fricatives and affricates represent two of the later-developing sound classes and are often produced incorrectly by both normally developing children (Farwell, 1976; Smit, 1993) and those with disorders (cf. Ingram, Christensen, Veach, & Webster, 1980; Shriberg, 1993). Findings from cross-sectional and longitudinal studies of groups of children provide general information on the development of these sound classes. Because fricatives are acquired over a lengthy time period, however, little information is available on the development of these phonemes in individual children. A notable exception is Smith's (1973) study of the acquisition of phonology by his son, Amahl. Data on the acquisition of the entire fricative and affricate sound classes by an older child with a phonological disorder have not been reported.

Although previous studies report treatment of fricatives in children with disordered phonologies (e.g., Bedore, Leonard, & Gandour, 1994; Miccio & Elbert, 1996; Powell, 1991; Saben & Ingham, 1991), no study has reported a systematic gap in phonological acquisition where the entire fricative and affricate classes were missing as late as 5 years of age but sounds such as /r/ and /l/, typically later developing sounds, were produced correctly. Further, acquisition of these classes in children with concomitant problems in other developmental domains have not been reported. In this study, we describe the acquisition of the fricative and affricate sound classes in response to treatment in a child with disordered phonology and other co-occurring conditions.

Fricatives and Affricates in Normal Development

In normally developing children, fricatives and affricates are acquired after stops, nasals, and glides (Ferguson, 1978; Smit, Hand, Freilinger, Bernthal, & Bird, 1990; Stoel-Gammon, 1985). Ferguson suggested fricatives pose articulatory and possibly perceptual problems for young children that inhibit their production and account for their relatively late development. He summarized the order of acquisition of the English fricatives in three groups: first acquired are /f s ʃ/ followed by /v z/ and finally /θ ð ʒ/. Ingram (1978) noted the affricates /ʧ/ and /ʤ/ appear about the same time as /ʃ/.

Because fricatives and affricates are acquired over a relatively long period of time (Dinnsen, 1996; Farwell, 1976; Ferguson, 1978; Moskowitz, 1975), observation of the acquisition of these classes in individual children is difficult. Cross-sectional studies (Poole, 1934; Prather, Hedrick, & Kern, 1975; Smit et al., 1990; Templin, 1957;

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Wellman, Case, Mengert, & Bradbury, 1931) provide age norms for the acquisition of particular consonants, but not the order of acquisition in individual children. Methodological differences result in different reported ages and orders of acquisition across these investigations. Children have minimal opportunities to produce each sound and only successful production of target-appropriate speech sounds is reported. A child producing [θ] for /s/ but [f] for /θ/, for example, would not receive credit for producing /θ/. In addition, an arbitrary level of mastery such as correct production by 75 or 90% of the children in the sample, results in the appearance of a lengthy acquisition process from 2 to 4 years or more.

Some fricatives are acquired early. Stoel-Gammon (1985) reported that over 50% of her 2-year-old subjects produced /f/ and /s/ in the word-initial position and [s] in the word-final position during conversational samples. Dyson (1988) reported word-initial /f/ and /s/ were in the inventories of 10 subjects from ages 2;0 to 3;3. The palatal /ʃ/ was used by 4 subjects but appeared to be emerging along with the affricate /tʃ/. In the final position, /f s ʃ/ were observed across intervals.

Discrete stages for the acquisition of correct fricative production are not supported by longitudinal data. Smith's (1973) diary study of the phonological development of 26-month-old Amahl revealed he did not produce fricatives. Word-initial labiodental fricatives were realized as [w], final voiced fricatives were omitted, and all other fricatives were realized as homorganic stops. By age 3;9, Amahl produced /f/ correctly, and realized /θ s ʃ/ as [s]. His acquisition of the fricative class did not progress smoothly from one substitution to another or to correct production. Edwards' (1979) investigation of the acquisition of fricatives by 6 children from ages 1;6 to 2;6 confirmed there was no universal order of acquisition of the fricative class.

Fricatives and affricates are the sound classes most often mispronounced by children learning English (Bricker, 1967; Olmsted, 1971; Snow, 1963), and these classes have a larger proportion and a greater range of substitutions than other consonants (Snow, 1963). Smit (1993) found that stops were used primarily as substitutions for word-initial fricatives and affricates. Substitutions among fricatives were relatively common, and lateral fricatives and palatal and alveolar affricates were observed. Rare errors included use of glides or velar stops for fricatives and affricates, labials for palatals, or bilabial fricatives for labiodentals.

Fricatives and Affricates in Disordered Development

Studies of children with disordered phonologies have, for the most part, shown the same patterns of emergence as typically developing children but at later ages (Dinnsen, Chin, Elbert, & Powell, 1990; Ingram, 1978). Ingram (1978) reported that fricatives were the phonemes most commonly in error in 15 children he studied with disorders. The rate of acquisition of the children with disorders was slower, but substitution patterns were similar to those of 15 normally developing children at earlier ages. Shriberg and Kwiatkowski (1994) divided consonant phonemes into developmental sound classes based on the average percentage of consonants used correctly: the "early-8" did not include fricatives or affricates, the "mid-8" included /f v ʧ ʤ/ and the "late-8" included /ʃ θ s z ð ʒ/. Children with normally developing and disordered phonologies had similar percentages correct on the sounds /ʧ ʤ ʃ s z/. Normally developing children for the most part dentalized these sounds, but the primary errors of children with disorders were omissions and unusual substitutions. Other fricatives were more often incorrect in disordered children.

Investigators have reported unusual substitutions for fricatives and affricates including a dental click for sibilants (Bedore et al., 1994), an ingressive alveolar fricative for final /f s z/ (Ingram & Terselic; 1983), a voiceless nasal snort for all sibilant fricatives and the affricates (Edwards & Bernhardt, 1973), and a voiceless lateral fricative for the sibilant fricatives and affricates (Grunwell, 1981). When error types are taken into consideration, atypical errors of disordered phonologies are distinguished from typical errors that are most likely to self-correct (Smit, 1993).

Treatment of Functionally Disordered Phonology

A common method of treating errors is to teach each fricative, beginning with the one presumed to occur first in normal development. Descriptions of disordered phonologies show, however, that not all children's error patterns are similar to those of younger, normally developing children, and a number of studies have found no advantage to choosing targets based on a developmental continuum (i.e., Elbert & McReynolds, 1985; Gierut, Morrisette, Hughes, & Rowland, 1996; Powell & Elbert, 1984).

An alternative approach is to choose targets based on linguistic principles (e.g., Gierut, Elbert, & Dinnsen, 1987; Leonard & McGregor, 1991). In these approaches, a target is chosen for its representativeness of an error pattern. Treatment targets are chosen in a variety of ways, including distinctive feature errors (McReynolds & Bennett, 1972), phonological knowledge (Gierut et al., 1987), or phonetic universals (Tyler & Figurski, 1994). Treatments concentrate on repeated practice of one sound or a small number of sounds in contrast to others as vehicles for triggering system-wide generalization (Gierut, 1989; Weiner, 1981).

Treatment of Disordered Phonology With Concomitant Developmental Difficulties

For methodological reasons, treatment studies primarily examine children with functional phonological disorders or children whose speech production is related to a specific etiology (e.g., hearing impairment, cleft palate). Much of a clinician's caseload, however, consists of children who present combinations of problems or risk factors, including delays in language, cognition, gross and fine motor skills, or some degree of hearing loss. The associated problems may or may not have precipitated the phonological

disorder but may, nonetheless, be causally correlated (Shriberg & Kwiatkowski, 1982a).

It is difficult for a clinician to determine whether a treatment shown to be successful with functional phonological disorders is applicable to a child who shares some, but not all, characteristics of the subjects studied. Consequently, traditional sound-by-sound treatments that follow a developmental hierarchy (e.g., Van Riper & Emerick, 1984) or broad, multiple-phoneme treatments (e.g., Hodson & Paden, 1991) are presumed to be the most likely to succeed.

In a child with multiple errors, however, an approach that maximizes the treatment effect by planning for generalization may be more efficient (Elbert & Gierut, 1986; Powell, 1991). As a preliminary step to advancing our understanding of the applicability of linguistic treatments to other populations, this study of a child with multiple delays examines the introduction of two distinctive features using two target sounds.

Purposes of the Study

The purposes of this study are twofold: (a) to observe the path of acquisition of the entire fricative and affricate sound classes and (b) to test the appropriateness of applying linguistic principles of intervention to a child with concomitant developmental difficulties in other domains. Two sounds were chosen for treatment, each intended to introduce a new, distinctive feature to the child's phonological system and to trigger generalization across word positions, sound classes, and linguistic units.

Method

Participant

K, age 5;3, was referred by her special education teacher, who described her speech as "unintelligible." According to her mother, K did not start talking until about 3 years of age. She "always had a hard time with speech," and was very frustrated with her inability to communicate. She had one older sister, age 7;2, with no history of speech difficulties.

Health and Educational History. K was born without complications and weighed 7 lbs, 14 oz at birth. She started to walk shortly before her first birthday. She had numerous episodes of bilateral recurrent otitis media documented from age 2 years to the time of the study. In the year preceding the study, K twice underwent bilateral myringotomies with insertion of pressure equalization (PE) tubes. At the beginning of this study, tubes were in place bilaterally. Results of a pure-tone audiological evaluation indicated K heard pure tones in the right ear at 20 decibels hearing level (dB HL) at 500 Hz, 30 dB at 1000 Hz, 30 dB at 2000 Hz, and 20 dB at 4000 Hz. In the left ear K responded to pure tones at 30 dB at 500 Hz, 25 dB at 1000 Hz, 25 dB at 2000 Hz and 20 dB at 4000 Hz. Previous audiograms provided by K's otolaryngologist showed that for the 2 years previous to this study, K's hearing thresholds fluctuated between 10 and 30 dB across the speech frequencies, and speech recognition thresholds ranged from 10 to 25 dB. An adaptive behavior profile compiled by the school social worker (Brigance Diagnostic Inventory of Early Development; Brigance, 1978) indicated K was 16 months below age level in psychomotor development including some problems with gross and fine motor skills, 20 months below age level in academic skills, and 18 months below age level in speech and language. K was within normal limits in self-help and social skills.

Before attending public school, K was enrolled in an early childhood preschool program 4 afternoons a week, where she received occupational therapy in a group 3 times weekly. Although the program included general language stimulation for all participants, no direct speech or language treatment was provided. Testing administered by an occupational therapist revealed a 16-month gross motor delay and a 12-month fine motor delay according to the Peabody Developmental Motor Scales (Folio & Fewell, 1983). K had difficulty cutting, reproducing shapes, and buttoning clothing. When K began kindergarten, she was placed in a special education classroom and was mainstreamed into a kindergarten class one and one-half hours per day. According to K's teacher, she worked best in a one-to-one situation. Classroom goals included preacademic skills such as counting, shapes, and numbers. K received small-group occupational therapy services twice weekly.

Psychoeducational and Linguistic Evaluation. The school psychologist reported K's scores on the Weschler Preschool and Primary Scale of Intelligence (Weschler, 1967) fell in the 3rd percentile with a standard score of 72. Results of the Peabody Picture Vocabulary Test–Revised, Form L (Dunn & Dunn, 1981), were in the 1st percentile. Mean length of utterance (MLU) for a 50-utterance sample was 3.3, indicating a delay of about 20 months (Miller, 1981).

K made 42 errors on the Sounds-in-Words Subtest of the Goldman-Fristoe Test of Articulation (Goldman & Fristoe, 1986), placing her score below the first percentile. The Percent Consonants Correct (Shriberg & Kwiatkowski, 1982b) was determined from a continuous speech sample of 100 words. Results indicated a score of 33 or a severe phonological disorder. K was not stimulable for production of any sounds missing from the phonetic inventory (Powell & Miccio, 1996).

To obtain an adequate sample for a comprehensive phonological analysis, a 300-item picture-naming task (Gierut, 1985) was administered to provide multiple opportunities to sample each English consonant in each word position. The sample was analyzed within a standard linguistic framework as applied to disordered systems (Dinnsen, 1984; Elbert & Gierut, 1986) and included independent and relational analyses (Stoel-Gammon, 1996). To be included in the inventory, a sound had to be produced at least twice in two different words.

Independent analysis revealed K's phonetic inventory included nasals and voiced and voiceless stops at three places of articulation. K also produced glides (including /h/), liquids, and a glottal stop:

		m		n				ŋ
p	b		t	d			k	g	ʔ
				l		r		
		w			j			h

K produced words of one to three syllables using alternating stress patterns. She produced open and closed syllables and two-member consonant clusters in onset and coda positions. All English singleton consonants in the phonetic inventory were produced across word positions in accordance with English phonotactic constraints. Glottal stops occurred word-initially.

Relative to the adult phonology, all nasals and liquids were used correctly all of the time. Voiced and voiceless stops contrasted in the word-initial position. In the word-final position, alveolar stops were often voiceless. Velar stops matched the adult form unless the presence of alveolar stops triggered consonant harmony, for example:

cup	[kʌp]	gum	[gʌm]	rock	[rɑk]	pig	[pɪg]
cut	[tʌt]	gate	[deɪt]	sock	[tɑt]	dog	[dɑd]

Production of the glide [j] varied with a glottal stop or [h] in the word-initial position. Target /h/ also varied with [/], for example:

yes	[jɛt]	hide	[hɑɪd]
yellow	[ʔɛlo]	hat	[hæt]
yard	[hɑrd]	house	[ʔaʊt]

K's phonological system was restricted by an inventory constraint that limited obstruent consonants to stops; that is, no fricatives or affricates occurred in any context (see Table 1). Voiced and voiceless stops contrasted in the initial position but not always in the final position.

Inflected forms were elicited to determine if K changed any productions as a consequence of placing a consonant in a new phonetic environment with the same base morpheme, for example, "brush" and "brushing." No alternations were observed for any sounds.

No vowel errors were noted and vowel production reflected features of the local dialect. K produced alternating English stress patterns in words of up to three syllables. The majority of K's productions reflected the adult syllable structure. Exceptions occurred where the target clusters contained /s/. In these cases, CCV syllable structure was realized as CV:

	frog	[prɑg]	throw	[troʊ]	blow	[bloʊ]	glove	[glʌb]
but:	swim	[wɪm]	sleep	[lip]	stove	[toʊb]	snow	[noʊ]

Research Design

A single-case multiple-baseline-across-behaviors design was used in this investigation. In this design, two target behaviors are modified using the same treatment paradigm (McReynolds & Kearns, 1983). The second target behavior remains in baseline until the first target behavior has changed. Control is demonstrated when the second target behavior responds to the same treatment used for the first behavior. In this study, two sounds were taught, each one chosen to enhance the child's phonetic inventory by addition of a new distinctive feature. All other fricatives and the affricates remained in baseline to illustrate the effects of treatment on the acquisition of the other sounds absent from the phonetic inventory.

TABLE 1. Examples of K's pretreatment productions of words with target fricatives and affricates.

Labiodental		Intervocalic		Alveolar		Palatal	
face	[peɪt]	thumb	[tʌm]	soup	[tup]	shoe	[tu]
leaf	[lip]	mouth	[maʊt]	bus	[bʌt]	shave	[teɪb]
van	[bæn]	them	[dɛm]	zebra	[dibrə]	chip	[tɪp]
wave	[weɪb]	mother	[mʌdə‡]	nose	[noʊt]	peach	[pit]
						jeep	[tip]
						page	[peɪt]

Choosing the Treatment Targets

The goal of treatment was to induce acquisition of the fricative and affricate sound classes by teaching one sound as a vehicle for learning the features of the absent sound classes. This decision was based on the finding that treating sounds from this group results in the most system-wide change (Gierut et al., 1987). This eliminated treating any of the glides or velar stops because K used them correctly some of the time.

Because English has a larger set of fricatives than affricates, a fricative was chosen to heighten awareness of other members of this manner class. Learning the manner distinction between stops and fricatives involves acquisition of the distinctive feature [continuant] (cf. Elbert & McReynolds, 1978; Miccio, 1995a, 1995b; Powell, Miccio, Elbert, Brasseur, & Strike-Roussos, 1999).

Marked aspects of the phonological system were also considered. Because previous findings reported that voiced obstruents predict the occurrence of voiceless ones (McReynolds & Jetzke, 1986), targets were narrowed to the voiced fricatives: /v ð z ʒ/. Of this group, /ð/ was eliminated because it does not occur across word positions in words used frequently by young children. The palatal /ʒ/ was eliminated because it does not occur across word positions in English, is often pronounced [ʤ] by adults in K's dialect region, and does not occur frequently in words used by young children. Although both /v/ and /z/ were suitable candidates, /v/ was chosen because it is more visible and, thus, an appropriate first target for introducing a new manner of articulation. Because fricatives in word-initial position result in more accurate production of fricatives in final position (Elbert & McReynolds, 1978), /v/ was treated in the word-initial position.

To summarize, the purpose of treatment was to reorganize the sound system by teaching the later-developing phoneme /v/ in the initial position of words. Treatment was predicted to result in production of the earlier-developing voiceless cognate /f/ and the introduction of the feature [continuant] to the obstruent class. Teaching in the initial position was predicted to generalize across positions and teaching an unknown sound was predicted to result in more accurate production of known sounds /k g h j/.

The voiced alveolar fricative /z/ was chosen as the next treatment target to introduce a stridency distinction among the coronal fricatives, i.e., the contrast between /z/ and /ð/. Treatment was predicted to result in production of the voiceless cognate /s/ and the introduction of the contrasting feature [strident] to the obstruent class. The remainder of the fricatives and affricates were monitored in baseline.

Treatment Approach

The training strategy incorporated the philosophy of training "deep" (Elbert & Gierut, 1986) or "vertically" (Fey, 1986). The child's underlying pattern of error is disrupted by teaching a representative aspect of the sound system in a limited set of treatment items. Repeated practice to a preestablished performance level stabilizes accurate sound production and provides the opportunity to discover a new underlying pattern from a limited set of items (Elbert & McReynolds, 1978; Powell, 1991; Powell & Elbert, 1984).

Treatment incorporated two main principles: acquisition and conceptualization (Bernhardt, 1992; Elbert & Gierut, 1986; Gierut, 1998). During the acquisition phase, the child is taught the phonetic aspects of sound production and automatic production of the correct form is emphasized. During the conceptualization phase, the target sound is used contrastively in minimally paired words. In this study, intervention aimed at acquisition of the target sound will be referred to as imitation treatment and intervention targeting conceptualization of the phonemic contrast will be referred to as minimal pairs treatment.

K was taught to produce /v/ in imitative drills involving five words with /v/ in the word-initial position. Immediate feedback for incorrect productions included instruction in the correct articulatory gestures. Tangible reinforcement (stickers) was provided for correct productions. Imitation training continued until K produced the stimulus items correctly 90% of the time over three consecutive treatment sessions.

The five stimulus words were then paired with five minimally contrastive words beginning with the child's previous production of [b]. In this phase, picture stimuli were presented without a verbal model and correct productions were rewarded with verbal praise. Incorrect productions were followed by verbal feedback regarding the minimal pair contrast and included modeling of the contrast. Activities included sorting and matching items according to their initial sounds and role reversal activities in which K requested cards from the clinician. Treatment continued until K produced the items correctly 90 percent of the time over three consecutive sessions.

At the termination of /v/ treatment, K was taught to produce /z/ following the same procedures. Treatment was administered 4 days a week for 20–30 minutes each day by the first author in the speech-language room in K's school. The first three sessions were devoted to treatment; the fourth session of each week was used to probe for generalization to untrained items. All sessions were audiorecorded using a Marantz PMD201 cassette recorder and Shure lavalier microphone.

When K reached criterion for termination of /z/ treatment, her phonetic inventory was complete and the study was terminated. K received no other direct speech-language treatment during the course of the study; however, her special education classroom provided a rich language environment. Following termination of the experiment, a classroom generalization program that emphasized calling attention to K's "new sounds" in storybooks and toy names was implemented.

Generalization Probes

Before treatment, a 126-item subset of the 300-item probe used in the initial phonological analysis was administered three times over a 2-week period to confirm that no fricatives or affricates were emerging in K's language. This smaller probe consisted of items containing fricatives and affricates across word positions. Each fricative except /ð/ and /ʒ/ was elicited in 15 words containing the target sound. Five words were elicited in each of three word positions: initial, intervocalic, final. The voiced interdental fricative /ð/ was elicited in nine words, five containing /ð/ in word-initial position and four containing /ð/ in the intervocalic position. The voiced palatal /ʒ/ was not probed because it is usually produced as [ʤ] in K's dialect. Once treatment began, the 126-item probe was elicited once a week (after every three sessions). The remainder of the probe session elicited a language sample through play.

Reliability

All treatment sessions and generalization probes were audiorecorded and transcribed by the first author according to conventions of the International Phonetic Alphabet (International Phonetic Association, 1999). A second judge independently transcribed 20% of the data. Both judges were certified speech-language pathologists. With regard to connected speech samples, the first 100 utterances for which the adult target was known were used in reliability calculations. Point-by-point interjudge agreement for consonants was 86% for the treatment data, 82% for the generalization probes, and 80% for the connected speech samples. Intrajudge agreement was calculated for 20% of the data transcribed by the first author. Agreement was 95% for the treatment data, 90% for the generalization probes, and 87% for the connected speech samples.

Results

Quantitative Changes Relative to the Target Phonemes

Correct Production During Treatment

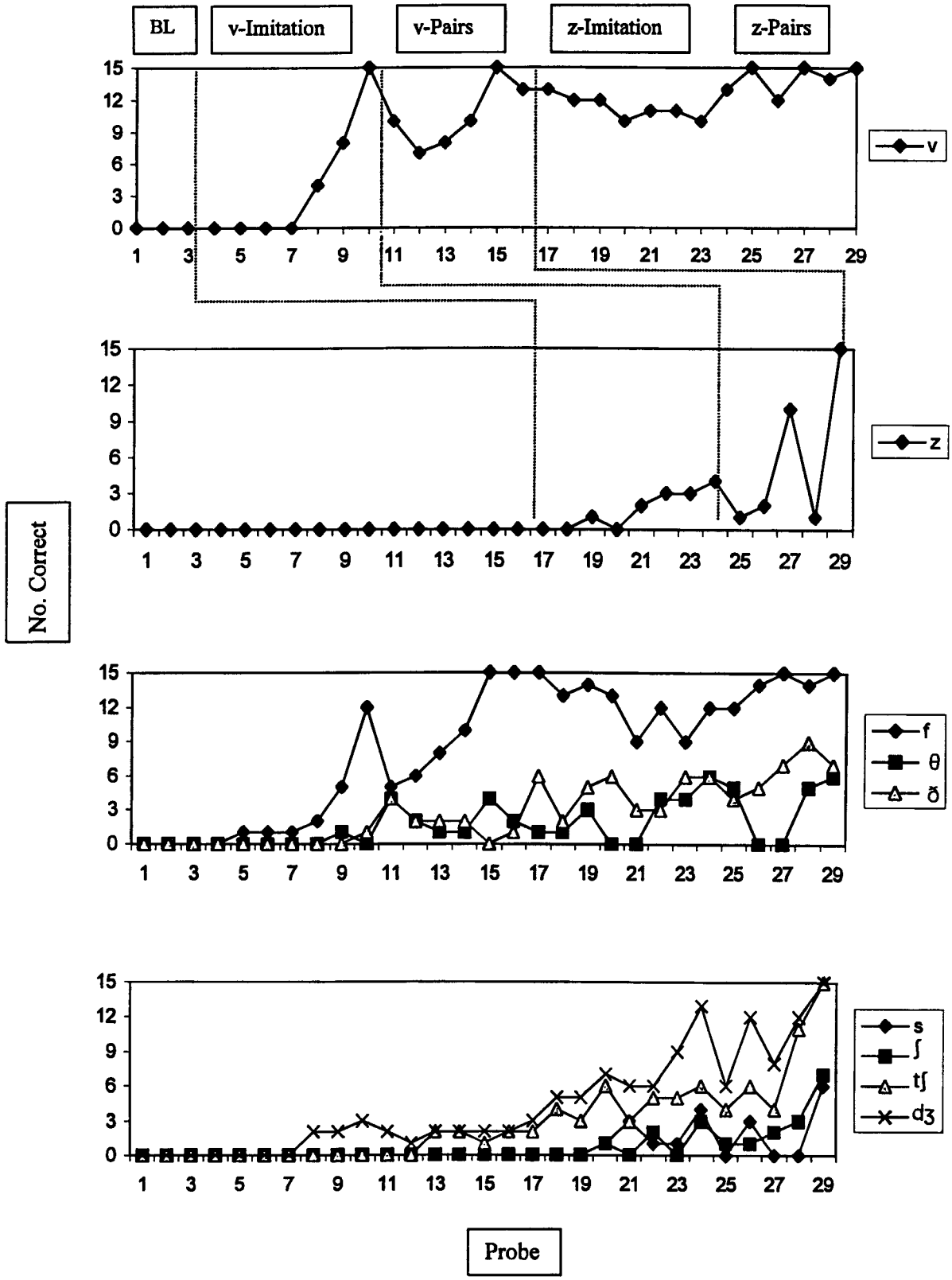
Treatment of /v/. K produced /v/ early in treatment and advanced to minimal pairs treatment in the 7th week. When minimal pairs treatment began, correct productions dropped to 60% correct but climbed steadily back to criteria within 6 weeks.

Treatment of /z/. Correct /z/ productions appeared by the end of the first week of treatment on this sound. K advanced to naming minimal pairs during the 8th week of "z" treatment (Probe 24). When minimal pairs training began, /z/ productions returned to baseline but corrected rapidly. K met the termination criteria following 5 weeks of minimal pairs training.

Generalization to Untrained Words

Words Containing /v/. K's performance on the generalization probe (see Figure 1, Panel 1) reflects production of /v/ in untrained words. Generalization remained at zero until Probe 8. From that point, /v/ production improved

FIGURE 1. Generalization of correct production of each fricative or affricate across 15 untreated probe words plotted as a function of probe number.



steadily to 100% correct during Probe 10. When minimal pairs were introduced, correct production dropped to as low as 7 of 15 items. With further conceptualization training, production gradually returned to 100% by Probe 15.

Words Containing /z/. Target /z/ did not generalize rapidly to untreated words. At the end of imitation training, only 4 of 15 probe items were produced correctly despite 90% correct production during treatment. During minimal pairs treatment, correct production increased to a maximum of 10 correct on probe items during Probe 27, returned to 1 correct on Probe 28, and increased to all 15 items by the final probe (see Figure 1, Panel 2).

Generalization Across Word Positions

Words Containing /v/. Treatment of /v/ in the word-initial position resulted in generalization across word positions during imitation treatment (see Figure 2). Target /v/ was produced correctly in all three word positions by Probe 10. During minimal pairs, production of /v/ remained at a high level for the treated initial position but not for final and intervocalic positions. Correct productions across word positions recurred by Probe 15.

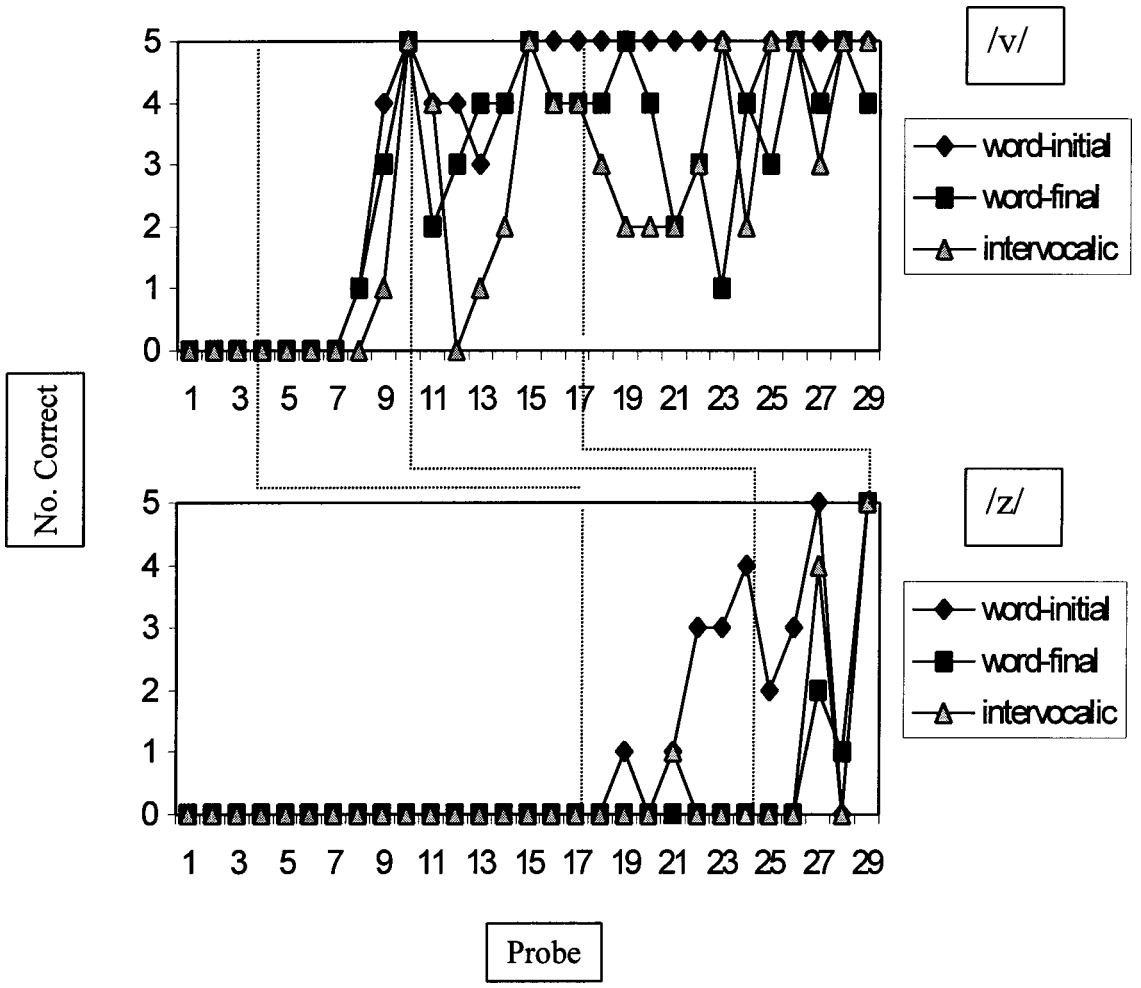
Words Containing /z/. Correct productions of /z/ occurred only in the targeted position on the generalization probe during imitation training. Unlike /v/, generalization across word positions did not occur until minimal pairs training (see Figure 2).

Generalization Across Linguistic Units

Target /v/ in Connected Speech. Correct productions of /v/ were not observed in a connected speech sample until Probe 11. During minimal pairs training, spontaneous productions during conversation and play increased in frequency and were unaffected by changes in treatment phase. At the end of /v/ treatment, the sound was produced correctly in 30% of words with target /v/ in connected speech.

Target /z/ in Connected Speech. Correct productions of /z/ were not observed in a connected speech sample until minimal pairs were targeted, but production increased gradually across time. At the end of minimal pairs training, /z/ was produced correctly in 25% of words with target /z/ during conversation and play.

FIGURE 2. Generalization of the treated sounds /v/ and /z/ across word-positions (5 opportunities each position) plotted as a function of probe number.



Generalization Within and Across Sound Classes

Generalization During /v/ Treatment. During imitative drill on the fricative /v/, correct productions of the voiceless cognate /f/ roughly paralleled emergence of /v/ in generalization probes (see Figure 1, Panel 3). Inconsistently correct productions of /θ/, /ð/, and the voiced affricate /ʤ/ were also observed. The first target-appropriate productions of the voiceless affricate /ʧ/ coincided with the beginning of minimal pair treatment of /v/ vs. /b/.

Generalization During /z/ Treatment. During treatment of /z/, target-appropriate productions of /s/ and /ʃ/ emerged and the interdental fricatives occurred some of the time. Unlike the cognates /v/ and /f/, which were acquired simultaneously, /s/ lagged behind /z/. During /z/ imitation training, /s/ and /ʃ/ occurred in a maximum of 3 probe items each. During minimal pairs training, /s/ and /ʃ/ occurred only in a few probe items. At the end of the study, /s/ and /ʃ/ were produced correctly in 6 and 7 probe items, respectively (see Figure 1).

Generalization of Known Sounds

Production of /k g j h/ During /v/ Treatment. During baseline, sounds known by the child but sometimes affected by harmony (/k g/) or substitution (/j h/) were produced correctly an average of 65% of the time. Productions increased to an average of 80% correct simultaneously with the emergence of /v/ in untrained words. By Probe 11, / k g j h/ were correctly produced 100% of the time during probes. During connected speech samples, these sounds were produced correctly an average of 90% of the time.

Production of /f v θ ð ʧ ʤ/ During /z/ Treatment. At the end of /v/ treatment, K produced /f v θ ð ʧ ʤ/ target-appropriately some of the time. When treatment targeted /z/ in imitation, correct productions of /f/ and /v/ decreased to 10 of 15 items for /f/ and 11 of 15 items for /v/. During minimal pairs treatment of /z/ in contrast to /d/, correct productions of the labiodentals returned to 100%. The voiced interdental /ð/ showed a gradually increasing learning curve but correct productions of /θ/ were inconsistent. Correct productions of both affricates reached 100% at the final probe. Because all fricatives and affricates were produced in some untrained words, the study was terminated.

Qualitative Changes in Production

Throughout treatment, changes in production were monitored across time (diachronic changes) in probe words containing fricatives and affricates in the adult form. The labiodentals /f/ and /v/ were acquired quickly and words containing them underwent little variation. Word histories of the other fricatives revealed a general pattern where K departed from consistent use of stops to variable productions of fricatives, affricates, and stops. Variable productions gradually decreased and consistent productions of the target fricative increased. Examples of diachronic and synchronic change in individual lexical items are shown in Appendices A–D.

Acquisition of a Manner Distinction Among Obstruents. Qualitative changes in probe items revealed increased knowledge of the target sound system that was not evident from the quantitative data. During /v/ training, target-correct labiodental and interdental fricatives and affricates emerged. Labiodentals also emerged as substitutions for interdentals, but alveolar and palatal fricatives and affricates were unaffected. During production of /v/ in minimal pairs, interdental fricatives also substituted for alveolar fricatives. Words with palatal fricatives, however, patterned

TABLE 2. Patterns of acquisition of word-initial fricatives and affricates.

Phase	/f/	/v/	/θ/	/ð/	/s/	/z/	/ʃ/	/ʧ/	/ʤ/
Baseline	p	b	t	d	t	d	t	t	d
/v/-imitation	f	b~v	f~t~p	d~v	t	d~t	t	t	t~d
/v/-minimal pairs	f	b~v	ft~t~p	d~v~ð	t~θ	d~ð~θ	t~ʧ	t~ʧ	d
/z/-imitation	f	v	θ~f	d~v~ð	t~θ~s	d~ð~s~z~ts~dz	t~ʧ~ʃ~s	t~ʧ	d~ʤ
/z/-minimal pairs	f	v	θ~s~t	v~ð	t~θ~s	d~ð~z	t~ʧ~ʃ	t~ʧ~ts	d~ʤ
Final probe	f	v	θ~t	ð	θ~s	ð~z	t~ʧ~ʃ	tʃ	ʤ

Note. Variations that occurred at least twice during a phase are included.

TABLE 3. Patterns of acquisition of word-final fricatives and affricates.

Phase	/f/	/v/	/θ/	/s/	/z/	/ʃ/	/ʧ/	/ʤ/
Baseline	p	b	t	t	d	t	t	d
/v/-imitation	p~f	b~v	t~t^{h}~xt	t~xt	d~t	t	t~t^{h}~xt	d~t
/v/-minimal pairs	p~f~pf	b~v	t~t^{h}~xt~f~θ	t~xt~θt	d	t~xt	t~t^{h}	d~ʤ
/z/-imitation	p~f	b~v	t~f~θ~p	t~xt~θ~s	d~ʤ	t~xt~ʧ	t~ts~ʧ	d~ʤ
/z/-minimal pairs	f	v	f~θ~ts	t~xt~θ	d~z	t-ʧ	t~ʧ	d~ʤ~ts
Final probe	f	v	θ~f	θ~s	d~z	ʧ	tʃ	ʤ

Note. Variations that occurred at least twice during a phase are included. The phoneme /ð/ was not probed in the word-final position.

with target affricates. By the end of /v/ treatment, K's phonological system contained a manner distinction among the obstruents; that is, production of contrasting stops, fricatives, and affricates (see Tables 2 and 3).

Acquisition of a Nonredundant Stridency Distinction Among Fricatives. Although sibilants continued to be excluded from the phonetic inventory until intervention directly targeted /z/, positive change occurred during /v/ treatment. Words with target sibilants were produced with dental fricatives instead of stops. This change illustrates acquisition of the feature [continuant]. In words with target sibilants, correct voicing emerged first, followed by substitution of /ð/ or an affricate during the minimal pairs treatment, and finally correct production. Words with one target sibilant followed the pattern of the word "zoo" during /v/ treatment: [tu] > [du] > [ðu] > [duθ] > [ðu] > [du] > [ðu]. During "z" treatment the pattern changed to [θu] > [su] > [ðu] > [tsu] > [ðu] > [zu] > [tsu] > [zu] > [ðu] > /zu/.

When treatment targeted /z/ in imitation, all coronal fricatives had multiple variations including alveolar fricatives and affricates. Labiodental fricatives were unaffected by treatment of /z/. A stridency distinction emerged with the acquisition of /s z/ in contrast to /θ ð/. Target-appropriate productions of /ʃ/ also emerged. Early in the /z/-imitation phase, [s] substituted for target /ʃ/; however, no palatals substituted for target alveolars in the word-initial position. These qualitative changes enhanced intelligibility and signaled system-wide learning (see Table 2).

Production of Clusters and Affricates as Substitutions. In a few cases, clusters or labial affricates occurred temporarily for fricatives. The word "laughing," for example, changed from [læpɪŋ] to [flæpɪŋ] before correct production occurred. The word "roof" followed the pattern: [rʊp] > [frʊpf] > [rʊpf] > /rʊf/. Palatal affricates emerged target-appropriately and as substitutions for sibilant fricatives. Both stops and alveolar affricates sometimes substituted for target affricates (see Appendix A). In the word-final position, changes from the stop substitution pattern included clusters containing voiceless lateral [ɬ] or velar [x] fricatives (see Appendix B). Coronal affricates never substituted for nonsibilant fricatives.

Before treatment, K produced two-member consonant clusters in both onset and coda positions. Except for omission of /s/ in onset clusters, substitutions for fricatives were the homorganic stop. Correct production of fricatives in two consonant clusters emerged in connected speech after they emerged as singletons. No attempts to produce words with three consonant onset clusters (e.g., spr-) were observed in any speech samples.

Overgeneralization. Cases of overgeneralization of a newly learned fricative or affricate to other fricatives, affricates, or stops were observed. With the emergence of some target-correct productions of /v/, some target-appropriate /b/ productions also changed to [v]. The word "buzzing," for example, was produced [vʌdɪŋ] until /z/ was targeted directly. At that time, "buzzing" was produced [bʌdɪŋ], [dʌdɪŋ], or [vʌdɪŋ] until target /z/ was produced as [ð] in Probe 28: [bʌðɪŋ]. Correct production of /bʌzɪŋ/ did not occur until the final probe. Other examples of overgeneralization of fricatives to target stops include productions of "page" [feɪd] and "badge" [væd]. Words in which targeted fricatives mapped to the incorrect word position followed a longer course of acquisition to the correct production than other generalization probe items.

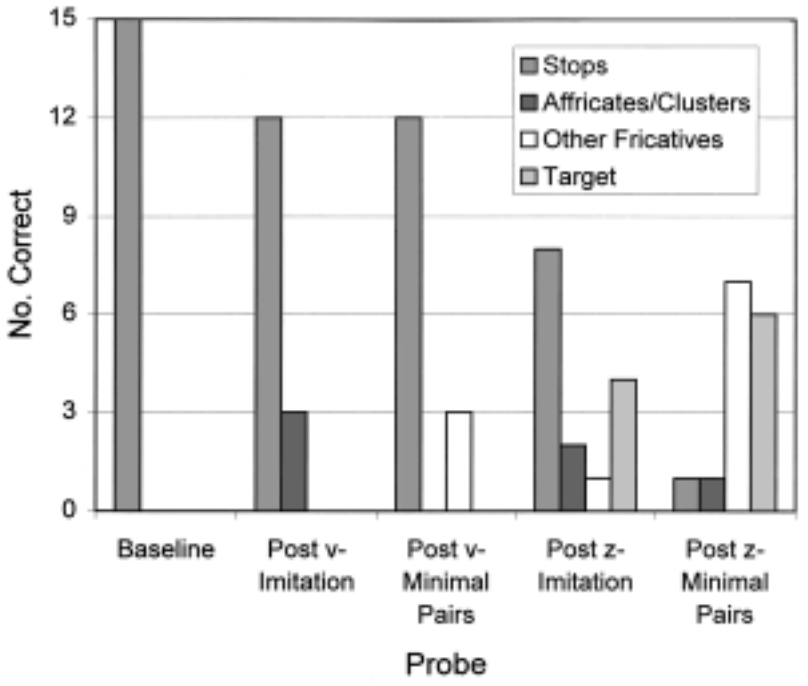
Acquisition of Lexical Items Containing Two Different Fricatives or Affricates. Words with one fricative or affricate were produced correctly before words with two phonemes from these classes. The word "fat," for example, was initially produced [pæt] but was produced correctly by the end of /v/ treatment and throughout the remainder of the study. The word "face," initially produced as [peɪt], followed the following pattern of acquisition while /v/ was taught: [peɪt] > [beɪt] > [peɪt] > [feɪxt] > [peɪt] > [feɪt] > [feɪθ]. During /z/ treatment, "face" returned to [feɪt] until the target-correct production /feɪs/ emerged in Probe 25. Words with more than one fricative required more systematic changes to achieve correct production.

Trade-off relationships were also observed. The word "fish," for example, was produced [pɪt]. During the imitation phase of /v/ treatment, production changed to [fɪt]. During minimal pairs training, a voiceless velar fricative [x] was produced in a postvocalic cluster [fɪxt]. During imitation of /z/, "fish" changed to [fɪts] then [fɪʧ] and back to [fɪt]. When /ʃ/ finally emerged, /f/ reverted to [p], (i.e., [pɪʃ]). During minimal pairs treatment, /f/ reemerged in the initial position. The previously correct production of /ʃ/, however, changed to /ʧ/. The probe word "fish" was not produced correctly until the end of /z/ treatment (see Appendix B).

Sounds With Least Knowledge Posttreatment. Although correct productions were inconsistent at the end of the study, the features [continuant] and [strident] were established in the phonetic inventory. The fricatives, /θ s ʃ/ showed the least target-correct productions on the final generalization probe (see Figure 1). Because of the nature of changes in the probed lexical items over time, correct production was predicted to gradually extend to new lexical items. The rationale for this prediction is illustrated in the characterization of substitutions for target /s/ (see Figure 3). Although /s/ was produced correctly in only 6 of 15 probe items on the final generalization probe, examination of substitution types reveals /s/ was emerging. During baseline, all /s/ items were produced as [t]. As treatment progressed, the number of fricative substitutions and correct productions increased.

Generalization to Connected Speech. In connected speech samples, treated sounds were consistently produced correctly. Although some correct productions of all untrained fricatives and affricates were observed, untrained fricatives did not occur at high levels except for /f/. Predominant substitutions, however, were members of the fricative or affricate sound classes. Although generalization outside of the treatment setting was not measured directly, K's teacher remarked that K used the treated sounds /v/ and /z/ in the classroom. Informal classroom observation indicated that /f/ also occurred frequently in conversation and fricative errors were mostly within class substitutions.

FIGURE 3. The nature of substitutions for target /s/ produced on the generalization probe at the end of each treatment phase.



Discussion

In this study, a child with a phonological disorder and other developmental concerns was taught to produce two fricatives in the word-initial position to determine the effects of limited exposure to the missing sound class on acquisition of the English fricative and affricate systems. For this child, instruction in the production of two fricatives in the word-initial position resulted in acquisition of the other word positions and the remaining fricatives and affricates in single-word probes. Correct productions also emerged in connected speech. Sounds produced correctly some of the time before treatment progressed to 100% correct without direct intervention.

At the beginning of the study, all fricatives and affricates were excluded from the phonetic inventory. During /v/ treatment, K acquired the feature [continuant] for obstruents with the addition of /f θ ð/ to the phonetic inventory. Although /s z ʃ/ continued to be excluded from the inventory, substitutions for these sounds were often affricates or other fricatives instead of stops. During /z/ treatment, K acquired a stridency distinction with addition of /s z ʃ/. Focus on the features [continuant] and [strident] resulted in acquisition of the fricative and affricate classes.

Comparison to Normal Development

K did not follow the most generally reported order of acquisition, that is, /s/ or /f/ followed by /ʃ/ and finally, /z v/ and /θ ð/. Treatment of /v/, generally considered a later-developing fricative, triggered its acquisition and that of its earlier-developing cognate /f/. Productions of the typically later-developing interdental fricatives also occurred before any sibilant fricatives. K produced the affricate /ʤ/ during /v/ treatment, but its emergence did not trigger fricatives at the same place of articulation. Acquisition of the feature [continuant] appeared to enable K to begin producing a branching [-continuant] [+continuant] segment (Bernhardt & Stoel-Gammon, 1994). Acquisition of /s/ did not occur until treatment of its cognate /z/. Treatment of one sibilant triggered acquisition of the other sibilants.

Patterns of Change

In K's phonology, interdental fricatives were produced for target alveolars at the same time as labiodentals were produced for interdentals; that is, /s z/ > [θ ð] but /θ ð/ > [f v]. Dinnsen and Barlow (1998) reported this chain shift occurs among the voiceless fricatives of children with both normally developing and disordered phonologies. Studies of change as a function of treatment have found new sounds appear in one word position, disappear, and reappear in another word position, before generalizing across the system (Powell et al., 1999). This same behavior was observed in K's phonology.

In her study of the emergence of fricatives in normally developing children, Edwards (1979) found stop substitutions predominated in the word-initial position and fricatives in the final position. This finding was not replicated in K. This may be because fricatives were directly taught in the word-initial position or because K had a more complex syllable structure with an established coda position before treatment. K did not substitute approximants for fricatives (e.g., [w] for /v/), as observed by Ferguson (1978).

Substitutions progressed from stops to other obstruents.

Differences in generalization as a function of the pretreatment substitution pattern have been reported. Forrest, Dinnsen, and Elbert (1997) found that with a consistent substitution across word positions, the sound targeted in treatment generalized to other word positions. Children with variable substitutions across word positions learned the treated sound only in the treated position. K's pretreatment substitution pattern was the same across contexts and disruption of the pattern generalized across contexts; however, those fricatives that were directly taught were the most firmly established in the phonetic inventory and across positions. New sounds were added with some contextual restrictions that gave way to eventual widespread use of the new sound (Dinnsen, 1996). In K's phonology, this was especially true for sibilants.

K's generalization patterns indicated that manner of articulation was more difficult than place of articulation. The manner classes in K's pretreatment phonetic inventory were correctly produced with regard to place. Following treatment on /v/, K learned other nonsibilant fricatives and the affricates, but no sibilant fricatives. The sibilant fricatives, with their high frequency energy concentration, were not learned until a sibilant fricative, /z/, was directly targeted.

Directly targeting the anterior coronal /z/ resulted in acquisition of its cognate /s/ and the nonanterior coronal /ʃ/. Although /ʃ/ is commonly referred to as palatal in American phonetics, the glide /j/ is the only true English palatal (International Phonetic Association, 1999; Ladefoged & Maddieson, 1996). Use of the term palatal for /ʃ/ is an abbreviation of palatoalveolar (sometimes referred to as postalveolar). Because the homorganic coronal stop of both /s/ and /ʃ/ is /t/, it was difficult to determine if K already knew the [anterior] distinction or if it was acquired without direct treatment. Acoustic analysis may have revealed formant trajectories for /s/ produced as [t] were different from /ʃ/ produced as [t], but differences were too subtle to be observed in this study.

Acquisition of the affricates relatively early in treatment is difficult to explain. Attention to the feature [continuant] appeared to be all K needed to produce a stop-fricative combination as a single unit. K's affricate substitutions for fricatives showed little confusion with regard to place. Alveolar affricates tended to substitute for alveolar fricatives and palatal affricates were either target-appropriate or substituted for palatal fricatives.

Stoel-Gammon and Dunn (1985) suggest a continuum of variability: (a) little or no variability, (b) variability without improved accuracy, (c) variability that includes correct production, and (d) correct production. They noted that the specific type of variability a child exhibits seems to depend on the child's underlying knowledge. Although variability did not play a role in choosing the fricatives targeted for treatment in this study, the different types of variability discussed by Stoel-Gammon and Dunn occurred once treatment began. Powell and Miccio (1996) viewed production accuracy along a continuum from "never correct" to "always correct." Accurate productions that are limited to certain contexts represent intermediate points on the continuum of the adult phonological system.

A Deviant Phonological System

A number of studies have reported cases of children who at an early stage of development produced obstruent stops in a variety of contexts but excluded fricatives and affricates in all contexts. Those children, however, had other later-developing sounds (i.e., liquids) missing from their phonetic inventories as well (Smith, 1973; Stoel-Gammon, 1985). In this case, K had adult-like use of the English liquids in the absence of any obstruents other than stops. Her phonology contained a systematic gap and did not conform to implicational hierarchies described in the literature (Dinnsen et al., 1990; Stoel-Gammon, 1985). Dinnsen, Chin, and Elbert (1992) noted that all children in their study conformed to the hierarchy following treatment although one child, described as having a truly deviant system, did not conform before intervention. Treatment appears to alert a child to the feature distinctions needed to conform to the adult system.

In the case of K, other developmental concerns such as fine motor problems and a history of otitis media may have contributed to the difficulty with acquisition of fricatives and affricates. Fricative production requires ability to configure the tongue and the fine force control to generate turbulence but not completely stop the airflow (Kent, 1992; Olive, Greenwood, & Coleman, 1993). K, aged 5;3 at the beginning of treatment, learned 9 sounds involving two new manner classes in 26 weeks. Her ability to imitate the clinician early in treatment does not support fine motor control problems as the sole explanation for the phonological disorder.

The intermittent hearing losses K experienced in association with chronic otitis media at key moments in acquisition may have resulted in lack of attention to the high frequency, low intensity fricatives. Atypical speech production has been reported in children with early chronic otitis media (Miccio, Yont, Davie, & Vernon-Feagans, 1999; Petinou, Schwartz, Mody, & Gravel, 1999; Shriberg, 1994) and fricatives may be the sound class most affected by the disease (Miccio et al., 1999).

Choosing Targets Based on Developmental Norms

Directly targeting /v/, a presumably later-developing sound, may appear counter to developmental principles. It should be noted, however, that K was 5;3 when treatment began. At this age, most children have acquired all fricatives or are producing within class substitutions. Ingram (1988) noted that the late acquisition of /v/ cannot be explained by articulatory constraints because it appears early in acquisition in other languages.

Limitations of the Study

Although much information was gained from phonological analysis based on impressionistic phonetic transcriptions, more fine-grained acoustic analysis may have revealed differences in productions among fricatives, affricates, and stops that were not readily observed in this study. Phonetic transcriptions of productions during K's

treatment revealed instances of excessive aspiration of voiceless stops substituted for fricatives (see Appendices). These productions suggested to the investigators that K was attending to the target contrasts. Acoustic analysis may have revealed other differences between stops substituted for target fricatives vs. stops produced target-correctly.

This study used a single-case multiple-baseline-across-behaviors design in which a second target behavior /z/ remained in baseline until the first target behavior /v/ changed. Control was demonstrated when /z/ responded to the same treatment used for /v/. An underlying assumption of this design is that the two treated behaviors are functionally independent to the extent that treatment of the first does not directly enhance the other. Because all sounds absent from K's pretreatment phonetic inventory were obstruents, it was impossible to choose a control sound for which the investigators could be certain treatment on any other sound would not enhance learning of the control sound. In addition, the unavailability of any child with a similar profile prevented direct replication of the study. Although internal validity was demonstrated (see Figure 1), external validity was compromised, and it cannot be assumed that other children with fricatives and affricates missing from their phonetic inventories will respond to treatment in the same way.

Results of this study show that, in this case, a linguistic treatment approach was applied successfully to the treatment of a phonological disorder in a child with concomitant problems in other domains. The question of relative effectiveness in comparison to other treatments was not explored in this study. It is possible that more traditional treatments such as teaching one sound at a time in a developmental continuum may have resulted in acquisition of the fricative and affricate classes. To measure the question of relative effectiveness, multiple participants with similar pretreatment phonologies and concomitant developmental delays would be required. In this study, treating a representative part of the problem resulted in system-wide change despite other concomitant factors that may affect learning.

Generalization across environments and maintenance of newly learned material is a concern for all children and especially those with cognitive delays. Although K demonstrated generalization across linguistic units as a result of treatment, continued generalization in the absence of direct treatment 4 days a week was a primary concern. Following completion of the study, K's special education teacher and mother were taught to reinforce generalization in the classroom and home by calling attention to K's "new sounds" in her environment. Although anecdotal reports from the mother and teacher stated K used fricatives in her daily activities, experimental probes to directly measure retention during maintenance were not obtained.

Conclusion

Analyzing data with attention to feature distinctions and time-based analysis of change increased our understanding of the effectiveness of the treatment strategies used in this study. Careful observation of the path of acquisition during remediation of disordered speech production provides a window through which the relationships among sounds and the consequences of introduction of a new sound into a phonological system can be observed. By testing hypotheses proposed in the literature, speech-language pathologists contribute to the refinement of models that influence our assessment and treatment methods and improve services to children with phonological disorders.

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Appendix A (part 1 of 2)

Examples of Acquisition of /f v θ ð/

Probe	fire	roof	roofie	vanilla	wave	waving	thumb	bath	bathy	them	mother
1–4	paɪ.ə±	rʊp	rʊpi	bənɪlə	weɪb	weɪbɪŋ	tʌm	bæt	bæpi	dɛm	mʌdə±
5	paɪ.ə±	rʊp	rʊpi	bənɪlə	weɪb	weɪbɪŋ	tʌm	bæt	bæpi	dɛm	mʌdə±
6	paɪ.ə±	rʊp	rʊpi	bənɪlə	weɪb	weɪbɪŋ	tʌm	bæt	bæpi	bɛm	mʌdə±
7	paɪ.ə±	rʊp	rʊpi	bənɪlə	weɪb	weɪbɪŋ	tʌm	bæp	bæti	dɛm	mʌdə±
8	paɪ.ə±	rʊp	rʊpi	vənɪlə	weɪv	weɪbɪŋ	tʌm	bæt^{h}	bæpi	vɛm	mʌdə±
9	faɪ.ə±	rʊp	rʊfi	vənɪlə	weɪv	weɪbɪŋ	fʌm	bæt^{h}	bæfi	vɛm	mʌdə±
10	faɪ.ə±	frʊpf	rʊpfi	vənɪlə	veɪv	weɪvɪŋ	tʌm	bæt	bæti	vɛm	mʌdə±
11	vaɪ.ə±	rʊpf	rʊfi	vənɪlə	weɪb	weɪvɪŋ	ftʌm	bæθ	bæfi	vɛm	mʌðə±
12	faɪ.ə±	rʊpf	rʊpi	vənɪlə	weɪv	weɪbɪŋ	pʌm	bæt	bæθi	vɛm	mʌdə±
13	faɪ.ə±	rʊpf	rʊpi	vənɪlə	weɪv	weɪvɪŋ	tʌm	bæt	bæti	vɛm	mʌnə±
14	faɪ.ə±	rʊf	rʊpi	vənɪlə	weɪv	weɪvɪŋ	ftʌm	bæt	bæxti	vɛm	mʌðə±
15	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪv	weɪvɪŋ	tʌm	bæθ	fæti	vɛm	mʌdə±
16	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪv	weɪvɪŋ	tʌm	bæt	bæθi	vɛm	mʌdə±
17	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪv	weɪvɪŋ	ðʌm	væt	bæti	vɛm	mʌðə±
18	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪv	weɪvɪŋ	ðʌm	væt	væfi	vɛm	mʌdə±
19	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪv	weɪbɪŋ	θʌm	væt	væfi	vɛm	mʌðə±
20	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪb	weɪbɪŋ	fʌm	bæf	bæpi	vɛm	mʌðə±
21	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪv	weɪvɪŋ	tʌm	bæf	væfi	ðɛm	mʌdə±
22	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪb	weɪvɪŋ	θʌm	væf	væfi	vɛm	mʌdə±
23	faɪ.ə±	rʊf	rʊpi	vənɪlə	weɪv	weɪvɪŋ	θʌm	bæf	bæfi	vɛm	mʌðə±
24	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪb	weɪvɪŋ	θʌm	bæθ	bæfi	vɛm	mʌðə±

Appendix A (part 2 of 2)

Examples of Acquisition of /f v θ ð/

Probe	fire	roof	roofie	vanilla	wave	waving	thumb	bath	bathy	them	mother
25	faɪ.ə±	rʊf	rʊpi	vənɪlə	weɪv	weɪvɪŋ	θʌm	bæf	bæfi	vɛm	mʌdə±
26	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪv	weɪvɪŋ	tʌm	bæf	bæfi	vɛm	mʌðə±
27	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪv	weɪvɪŋ	sʌm	væf	væfi	ðɛm	mʌðə±
28	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪv	weɪvɪŋ	θʌm	væf	bæfi	ðɛm	mʌðə±
29	faɪ.ə±	rʊf	rʊfi	vənɪlə	weɪv	weɪvɪŋ	θʌm	bæf	bæfi	ðɛm	mʌðə±

Note. Shading denotes changes in treatment phase from baselines to /v/ in imitation followed by minimal pair training, to /z/ in imitation followed by minimal pair training. The phoneme /ð/ was not probed in the word-final position. Voiceless stops transcribed with [ʰ] were excessively aspirated.

Appendix B

Examples of Acquisition of /s z ʃ/

Probe	soup	ice	icy	zebra	buzz	buzzing	shirt	push	pushing
1–6	tup	aɪt	aɪti	dibrə	bʌt	bʌdɪŋ	tʃt͡	pʊt	pʊtɪŋ
7	tup	aɪt	aɪti	dibrə	bʌt	bʌtɪŋ	tʃt͡	pʊt	pʊθɪŋ
8	tup	aɪxt	aɪti	dibrə	bʌd	bʌdɪŋ	tʃt͡	pʊt	pʊθɪŋ
9	tup	aɪxt	aɪti	dibrə	vʌd	bʌdɪŋ	tʃt͡	pʊt	pʊθɪŋ
10	tup	aɪxt	aɪti	dibrə	bʌd	bʌdɪŋ	tʃt͡	pʊt	pʊθɪŋ
11–12	tup	aɪθt	aɪti	dibrə	bʌd	bʌdɪŋ	tʃt͡	pʊt	pʊθɪŋ
13	tup	aɪt	aɪti	ðibrə	bʌd	vʌdɪŋ	ʧʃt͡	pʊt	pʊxtɪŋ
14	tup	aɪt	aɪxti	dibrə	bʌd	bʌdɪŋ	ʧʃt͡	pʊt	pʊtɪŋ
15	fup	aɪt	aɪti	dibrə	vʌd	bʌdɪŋ	ʧʃt͡	pʊt	pʊtɪŋ
16	tup	aɪt	aɪti	dibrə	vʌd	bʌdɪŋ	ʧʃt͡	pʊt	pʊtɪŋ
17	θup	aɪθ	aɪti	sibrə	vʌd	bʌdɪŋ	ʧʃt͡	pʊxt	pʊtɪŋ
18	θup	aɪt	aɪti	sibrə	vʌd	vʌdɪŋ	ʧʃt͡	pʊxt	pʊtɪŋ
19	tup	aɪt	aɪti	zibrə	vʌd	bʌdɪŋ	ʧʃt͡	pʊxt	pʊxtɪŋ
20	sup	aɪts	aɪti	dribrə	vʌd	vʌdɪŋ	ʧʃt͡	pʊxt	pʊʧɪŋ
21	sup	aɪt	aɪsi	tsibrə	vʌd	bʌdɪŋ	ʧʃt͡	pʊθt	pʊʧɪŋ
22	ðup	aɪt	aɪti	zibrə	vʌd	vʌdɪŋ	ʧʃt͡	pʊt	pʊʧɪŋ
23	tup	aɪt	aɪti	sibrə	vʌd	bʌdɪŋ	ʧʃt͡	pʊt	pʊtɪŋ
24	sup	aɪt	aɪti	zibrə	vʌd	dʌdɪŋ	ʃʃt͡	fʊt	pʊʧɪŋ
25	tup	aɪxt	aɪti	tibrə	bʌd	bʌdɪŋ	ʧʃt͡	pʊt	pʊtɪŋ
26	sup	aɪt	aɪti	zibrə	bʌd	bʌdɪŋ	tʃt͡	pʊt	pʊtɪŋ
27	θup	aɪts	aɪθi	zibrə	vʌz	bʌdɪŋ	ʃʃt͡	pʊt	pʊtɪŋ
28	θup	aɪθ	aɪθi	dibrə	vʌz	bʌðɪŋ	ʃʃt͡	pʊts	pʊtsɪŋ
29	sup	aɪθ	aɪsi	zibrə	vʌz	bʌzɪŋ	ʃʃt͡	pʊts	putsɪŋ

Note. Shading denotes changes in treatment phase from baselines to /v/ in imitation followed by minimal pair training, to /z/ in imitation followed by minimal pair training.

Appendix C

Examples of Acquisition of /ʧ/ and /ʤ/

Probe	chip	punch	punching	jeep	orange	orangey
1–6	tɪp	pʌnt	pʌntɪŋ	tip	ɔrɪnt	ɔrɪnti
7	tɪp	pʌnt	pʌntɪŋ	tip	ɔrɪnt	ɔrɪnti
8–10	tɪp	pʌnt	pʌntɪŋ	dip	ɔrɪnʤ	ɔrɪnʤi
11	tɪp	pʌnt	pʌntɪŋ	dip	ɔrɪnʤ	ɔrɪndi
12	tɪp	pʌnt	pʌnʧɪŋ	dip	ɔrɪnʤ	ɔrɪndi
13	tɪp	pʌnt	pʌntɪŋ	dip	ɔrɪnt	ɔrɪnʤi
14–15	tɪp	pʌnt	pʌntɪŋ	dip	ɔrɪnʤ	ɔrɪnʤi
16	tɪp	fʌnt	fʌntɪŋ	dip	ɔrɪnʤ	ɔrɪnʤi
17	tɪp	pʌnt	fʌntɪŋ	dip	ɔrɪnʤ	ɔrɪnʤi
18	tɪp	pʌnt	pʌntɪŋ	dip	ɔrɪnʤ	ɔrɪnʤi

Probe	chip	punch	punching	jeep	orange	orangey
19	ʧɪp	pʌnt	pʌnʧɪŋ	dip	ɔrɪnd	ɔrɪndi
20	tɪp	pʌnt	pʌnʧɪŋ	ʤip	ɔrɪnʤ	ɔrɪnʤi
21	ʧɪp	pʌnt	pʌntɪŋ	dip	ɔrɪnʤ	ɔrɪnʤi
22	ʧɪp	pʌnt	pʌntɪŋ	ʤip	ɔrɪnt	ɔrɪnʤi
23	ʧɪp	pʌnt	pʌnʧɪŋ	dip	ɔrɪnʤ	ɔrɪnʤi
24	ʧɪp	pʌnʧ	pʌnʧɪŋ	dip	ɔrɪnʤ	ɔrɪnʤi
25	tsɪp	pʌnt	pʌnʧɪŋ	dip	ɔrɪnʤ	ɔrɪnʤi
26	ʧɪp	pʌnt	pʌntɪŋ	ʤip	ɔrɪnʤ	ɔrɪnʤi
27	ʧɪp	pʌnʧ	pʌnʧɪŋ	dip	ɔrɪnʤ	ɔrɪnʤi
28–29	ʧɪp	pʌnʧ	pʌnʧɪŋ	ʤip	ɔrɪnʤ	ɔrɪnʤi

Note. Shading denotes changes in treatment phase from baselines to /v/ in imitation followed by minimal pair training, to /z/ in imitation followed by minimal pair training.

Appendix D

Examples of Acquisition of Words Containing Two Different Fricatives

Probe	face	vase	shave	shaving	thief	theirs	father	juice	juicy	cheese	cheesy	fish	fishing
1–6	peɪt	beɪt	beɪb	teɪbɪŋ	pib	dɛrd	pɑdə±	tut	duti	tid	titi	pɪt	pɪtɪŋ
7	peɪt	beɪt	beɪb	teɪbɪŋ	pip	dərt	pɑdə±	tut	dzuti	dit	titi	pɪt	pɪtɪŋ
8	peɪt	veɪt	teɪb	teɪbɪŋ	pipf	dɛrd	pɑdə±	tuxt	ʤuti	ʧit	tidi	fɪt	pɪʧɪŋ
9	pʰeɪt	veɪt	veɪb	teɪbɪŋ	fipf	dɛrd	fɑdə±	ʤut	ʤuti	ʧit	tidi	fɪt	pɪʧɪŋ
10	feɪxt	veɪθ	feɪv	fteɪvɪŋ	ptif	dɛrt	pɑðə±	dut	duti	tid	ʧidi	fɪt	pɪʧɪŋ
11	feɪxt	veɪxt	teɪv	teɪvɪŋ	fif	dɛrt	pɑðə±	ʤut	ʤuti	tid	tidi	fɪt	pɪʧɪŋ
12	peɪt	veɪt	teɪv	teɪbɪŋ	fif	dɛrd	pɑðə±	ʤut	ʤuti	ʧid	ʧidi	fɪt	pɪʧɪŋ
13	feɪt	veɪt	teɪv	teɪbɪŋ	fif	dɛrd	fɑðə±	ʤuxt	duti	ʧid	ʧidi	fɪt	fɪtɪŋ
14	feɪt	veɪxt	teɪv	teɪvɪŋ	vif	dɛrd	pɑdə±	dut	duti	ʧid	ʧidi	pɪt	fɪtɪŋ
15	feɪt	veɪt	θeɪv	teɪvɪŋ	fif	dɛrd	fɑdə±	dut	ʤuti	ʧid	ʧidi	fɪt	fɪtɪŋ
16	feɪt	veɪt	θeɪv	teɪvɪŋ	fif	θɛrd	pɑdə±	dut	duti	ʧid	ʧiði	fɪt	fɪtɪŋ
17	feɪt	veɪt	θeɪv	teɪvɪŋ	fif	dɛrd	fɑðə±	dut	ʤuti	ʧid	ʧidi	fɪxt	fɪtɪŋ
18	feɪt	veɪt	θeɪv	teɪvɪŋ	tif	dɛrd	fɑdə±	ʤut	ʤuti	ʧid	ʧiði	fɪxt	pɪtɪŋ
19	feɪt	veɪt	ʧeɪv	teɪvɪŋ	fif	dɛrd	fɑdə±	dut	duti	ʧid	ʧidi	fɪxt	fɪʧɪŋ
20	feɪt	veɪt	ʃeɪv	ðeɪvɪŋ	fif	vɛrd	fɑðə±	ʤut	ʤuti	ʧid	ʧidi	fɪt	fɪtɪŋ
21	feɪt	veɪt	ʧeɪv	ðeɪvɪŋ	vif	dɛrd	fɑdə±	ʤut	ʤuti	ʧid	ʧizi	fɪts	fɪtɪŋ
22	feɪθ	veɪt	ʃeɪv	seɪvɪŋ	fif	ðɛrd	fɑdə±	ʤut	ʤuti	ʧid	ʧidi	fɪt	fɪtɪŋ
23	feɪt	beɪθ	teɪv	ʃeɪvɪŋ	fif	ðɛrd	fɑdə±	ʤut	ʤuti	ʧid	ʧidi	fɪt	fɪtɪŋ
24	feɪt	veɪt	teɪv	ʃeɪvɪŋ	fif	ðɛrd	fɑdə±	ʤut	ʤuti	ʧid	ʧidi	fɪʧ	fɪʧɪŋ
25	feɪt	veɪt	seɪv	seɪvɪŋ	θif	ðɛrd	fɑdə±	ʤut	ʤuθi	ʧid	ʧidi	fɪt	fɪtɪŋ
26	feɪt	veɪθ	ʃeɪv	teɪvɪŋ	fif	ðɛrd	fɑdə±	ʤuts	ʤusi	ʧid	ʧizi	fɪʧ	fɪsɪŋ
27	feɪs	veɪt	seɪv	θeɪvɪŋ	fif	sɛrd	fɑðə±	ʤut	ʤutsi	ʧid	ʧizi	fɪʧ	fɪtɪŋ
28	feɪs	veɪθ	ʃeɪv	teɪvɪŋ	θif	ðərz	fɑðə±	ʤuθ	ʤutsi	ʧid	ʧiði	pɪʃ	pɪʃɪŋ
29	feɪs	veɪs	ʃeɪv	ʃeɪvɪŋ	θif	ðərz	fɑðə±	ʤuθ	ʤutsi	ʧiz	ʧizi	fɪʃ	pɪʃɪŋ

Note. Shading denotes changes in treatment phase from baselines to /v/ in imitation followed by minimal pair training, to /z/ in imitation followed by minimal pair training. Voiceless stops transcribed with [ʰ] were excessively aspirated.