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Statistical analysis of word-initial /k/ and /t/ produced by normal and phonologically disordered children

KAREN FORREST, GARY WEISMER and MEGAN HODGE

University of Wisconsin–Madison, Madison, WI 53705, USA

DANIEL A. DINNSEN and MARY ELBERT

Indiana University, Bloomington, IN 47405, USA

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Abstract

The acoustic characteristics of voiceless velar and alveolar stop consonants were investigated for normally articulating and phonologically disordered children using spectral moments. All the disordered children were perceived to produce /t/ for /k/, with /k/ being absent from their phonetic inventories. Approximately 82% of the normally articulating children's consonants were classified correctly by discriminant function analysis, on the basis of the mean (first moment), skewness (third moment) and kurtosis (fourth moment) derived from the first 40 ms of the VOT interval. When the discriminant function developed for the normally articulating children was applied to the speech of the phonologically disordered group of children, no distinction was made between the velar and alveolar stops. Application of the model to the speech of individual children in the disordered group revealed that one child produced distinct markings to the velar–alveolar contrast. Variability measures of target /t/ and /k/ utterances indicated greater variability in this disordered child's productions compared with the normally articulating children. Phonological analysis of this child's speech after treatment, in which the velar–alveolar contrast was not treated, revealed target appropriate productions of both /t/ and /k/. By contrast, the other three phonologically disordered children, for whom no acoustic distinction was found between target /t/ and target /k/, did not evidence any knowledge of the contrast after treatment with other target phonemes.

Key words: Normal articulation, phonological disorders, spectral moments.

Introduction

The remediation of phonological disorders in children has been shown to relate to a child's knowledge of his/her phonological system (Rockman, 1983; Dinnsen and Elbert, 1984; Gierut, 1986). Assessment of this knowledge is based on adult listeners'

Address correspondence to: Karen Forrest, PhD, 565 Waisman Center, 1500 Highland Avenue, University of Wisconsin-Madison, Madison, WI 53705-2280, USA.

judgments about the child's production of phonemes in the target language. Although this may provide a general description of a child's phonological system, a perceptual analysis may not fully credit a speaker with all (s)he knows. For example, if a phonemic contrast is differentiated in a way that is not appropriate to the ambient language, the adult listener may not perceive the distinction. This type of insensitivity to non-native contrasts has been demonstrated repeatedly in perception studies (see, for example, Werker and Tees, 1984) with adults. The inadequacy of the adult listener in perceiving non-native markings to phonemic contrasts points to the need for finer-grained analysis procedures in investigating phonological knowledge of functionally misarticulating children. Towards that end, acoustic phonetic analyses have been employed (Weismer, Dinnsen and Elbert, 1981; Maxwell and Weismer, 1982; Hoffman, Stager and Daniloff, 1983; Catts and Jensen, 1983; Weismer, 1984; Gierut and Dinnsen, 1986; Chaney, 1988; Forrest and Rockman, 1988).

For the most part, acoustic studies of misarticulated speech have investigated temporal parameters that cue phonemic contrasts, for example duration of VOT (Catts and Jensen, 1984; Gierut and Dinnsen, 1986; Forrest and Rockman, 1988, Tyler, Edwards and Saxman, 1990), and vowel duration preceding stop consonants (Weismer *et al.*, 1981; Maxwell and Weismer, 1982; Weismer, 1984). Although temporal parameters may be relevant to some contrasts, spectral variations provide a more ubiquitous cue to phonemic identity in American English. It is the spectral cues that relate to vocal-tract shape and area, thereby signalling place and manner distinctions. For this reason, comparison of spectral characteristics across target phonemes may provide a clearer understanding of a speaker's markings of contrasts and, by inference, of his/her knowledge about the target sound. Unfortunately, the spectral characteristics of normally articulating children's speech, with which the phonologically disordered speaker may be compared, are not well understood. This may relate to the existing analysis procedures (e.g. LPC and spectrography), which were developed from models of the adult, male vocal tract, and do not provide good resolution of children's speech acoustics. These analysis problems are exacerbated when speech of disordered children is investigated. Therefore, much of the critical information needed for evaluating phonological knowledge in misarticulating children has not been addressed.

Studies that have investigated the spectral characteristics of children's consonants, specifically stops, have met with limited success. For example, using Stevens and Blumstein's (1978) templates Chapin, Tseng and Liberman (1982) were able to categorize correctly only 65% of the voiced stops produced by two 1-year-old children. Classification of velar stops was accomplished with only 40% accuracy. Because the children in the Chapin *et al.* study were so young, it is difficult to know whether the poor classification relates to the instability of phonemes produced by these beginning speakers or to the poor fit of templates derived from adults to the speech of children. The work of Hewlett (1988) suggests that, at least in part, the latter explanation may be true. Investigation of the spectral characteristics of velar and alveolar stop consonants for adults, normally articulating children and one phonologically disordered child indicated that templates developed for adult speakers classified only 69% of the productions of the normal children.

In the present study, we applied a technique of spectral analysis that has not been used previously to investigate speech-production disorders, spectral moments (Forrest, Weismer, Milenkovic and Dougall, 1988), to the investigation of phonologically disordered speakers. Forrest *et al.* (1988) demonstrated that word-initial voiceless stops produced by adult male subjects could be classified with a high degree of accuracy on the basis of spectral moments derived from the first 40 ms of the VOT interval. Furthermore, stop consonants produced by female speakers could be classified with greater than 90% accuracy from the discriminant functions derived from the male speakers. The first four spectral moments (mean, variance, skewness and kurtosis), which were used to classify the stops, were based on the fast Fourier transform (FFT). As such, no assumptions were made about the speakers' vocal-tract dimensions or source characteristics, problems that are inherent in the LPC and spectrographic techniques. Spectral moments may provide an analysis procedure that is appropriate for use with children, thereby enabling investigation of spectral markers to both correct and misarticulated phonemes.

In the present study the spectral-moments procedure was applied to word-initial voiceless stops produced by four phonologically disordered children. The phonological analysis of these children suggested an inventory constraint against voiceless, velar stops such that /k/ was realized as /t/. The purpose of the present investigation was multi-faceted. First, interest centred on determining whether the spectral-moment-analysis procedure could be used to distinguish word-initial /t/ from /k/ as produced by normally articulating children. If the procedure discriminates normal children's /k/ from /t/, would spectral moments discriminate these phonemes in disordered children who did not appear to make a phonemic distinction? Last, did acoustic evidence of a distinction between /k/ and /t/, as determined by the spectral-moments analysis, foreshadow the disordered children's learning of this contrast?

Methods

Subjects

The four phonologically disordered (PD) children in this study were between the ages of 3 years 6 months and 6 years 6 months. All PD subjects had at least six errors that occurred in three or more manner categories, as determined by their performance on the Goldman–Fristoe Test of Articulation (Goldman and Fristoe, 1972). A generative phonological analysis, based on spontaneous conversation and a 256-word probe list that elicited productions in response to pictures, revealed that all the PD children had incorrect underlying representations for the production of /k/.† Specifically, perceptual analysis suggested that all children produced /t/ for /k/ in all word-positions; i.e. these phonologically disordered children had an inventory constraint against the occurrence of /k/. All PD children came from the Bloomington, Indiana, area and were monolingual speakers of American English.

The four normally articulating (NA) children in this study were also aged between 3 years 6 months and 6 years 6 months. All children had age-normal speech, as determined by their mothers who were certified speech–language pathologists and by a second speech–language pathologist, one of the authors (M. H.). The NA children were monolingual speakers of American English from the Madison, Wisconsin, area. Although the NA and PD children were from different geographical areas within the

†Only productive underlying representations were assessed in the generative analysis. Although it was assumed that the children had correct perceptual underlying representations, no formal test of this assumption was undertaken.

Midwestern USA, dialect differences were evidenced in vowel quality, not in consonant production.

Acoustic speech sample

The acoustic speech sample was designed to sample errors that are common in phonologically disordered children, rather than errors that are specific to any given child. Several factors motivated this design of the speech sample. First, the PD subjects in this investigation were part of a larger research project that focused on the effects of different treatment strategies on phonological learning (see Dinnsen, Chin, Elbert and Powell, 1990). Therefore, a valid index of the children's phonological systems at the onset of treatment was needed. Previous research (Forrest, Elbert, Balash and Belles, 1984) has shown that repeated stimulation with minimal pair contrasts, such as occurs in the elicitation of a speech sample for acoustic analysis, may teach the child to produce the contrast correctly. If this occurred, it would be difficult to assess the effects of treatment on phonological learning. The second factor that influenced the choice of a broad speech sample was the desire to investigate, at a later date, the acoustic features of perceptually correct phonemes produced by phonologically disordered children. Finally, the words in the speech sample that did not target word-initial /k/–/t/ contrasts served as foils so that children did not focus on a single phonemic distinction.

The speech sample used in the acoustic analysis is presented in Table 1. Only words with initial /k/ or /t/ (marked with asterisks in Table 1) were analysed for the current report.

Procedures

The acoustic speech sample was gathered separately for each child in a sound-treated booth. Each test word was presented by the experimenter and the child was required to respond with 'I can say *test word*, again'. For some of the children, test words were elicited spontaneously with pictures. The child's speech was transduced with a Sony electret microphone, positioned approximately 20 cm from her/his mouth, and recorded on a cassette tape recorder/reproducer (Marantz, model 220). Each stimulus

Table 1. *Word list for speech sample.*

pot	tot*	cot*
key*	tea*	two*
keen*	teen*	fin
thin	fat	that
vat	she	see
pay	paid	bay
queen	clean	cream
got	dot	duke
do	prop	pop
Bob	spade	Dee
cheap	Jeep	

*Words analysed in this paper.

word was presented six times in random order. Administration of the acoustic probe took approximately 40 min with one 5-min break provided midway through the experimental session.

Data analysis

The speech sample was processed on an IBM AT computer using CSpeech, a speech-analysis package. Each tape-recorded sentence was low-pass filtered at 10 kHz using an eight-pole Butterworth filter (model 901F1, Frequency Devices) and digitized at 20 kHz. The target word was extracted from the carrier sentence and high-pass filtered at 70 Hz using a two-pole digital filter (Milenkovic, 1986) to reduce noise in the waveform. Each target word was displayed on a CRT screen and edited to include only the interval from the onset of the stop burst to the third cycle of the following vowel.

The speech signal was pre-emphasized by 6 dB per octave, and a sequence of Fourier spectra (FFTs) was computed from each edited waveform. Calculations of FFTs were performed at 10-ms intervals using a 20-ms Hamming window. The initial window was centred on the stop burst and the final window was centred on the cursor demarcating the third cycle of the vowel. The spectral moments were obtained by treating each FFT as a random probability distribution from which the summary statistics of mean, variance, skewness and kurtosis (first four moments, respectively) were calculated. A previous analysis of the speech of normal adults has indicated that the variance is not useful as a discrete variable in the classification of stop consonants (Forrest *et al.*, 1988) and was, therefore, not used in the present analysis. However, the variance was used to compute coefficients of skewness (skewness/variance$^{3/2}$) and kurtosis (kurtosis/variance^2), which are dimensionless variables that are normalized with respect to the first moment. (See Forrest *et al.* (1988) for complete details of FFT and moments calculations.) These normalized variables were used in all analyses. Figure 1 presents some representative spectra that vary in mean, skewness and kurtosis.

The moments were grouped across all repetitions of each target phoneme (t or k), independent of vowel context. Moments from each 10-ms time interval were then grouped. For example, the first, third and fourth moments from the first 10-ms interval of all /k/ utterances were grouped; a similar grouping was made for the next 10-ms interval, and so forth. The moments from the first 40 ms of the stop (burst to burst + 40 ms) taken in 10-ms steps served as input variables in a stepwise discriminant analysis (BMDP7M). This provided a time-history of the moments over the initial 40 ms of the VOT interval, thereby including dynamic information about the consonant–vowel transitions in the analysis. Kewley-Port (1983) and Forrest *et al.* (1988) have shown the importance of time-varying spectral information in the classification of stop consonants produced by adults.

All assumptions of discriminant analysis, including normally distributed, uncorrelated input variables, were met. Discriminant analysis is a procedure that linearly combines *n* variables to derive a function that minimizes distance between members of the same category and maximizes the distance between members of different categories. In this way, the target stops could be categorized by similarity or difference of the moments from the first 40 ms of the target words. The discriminant function is calculated from the input variables for which statistically significant differences can be found between the different categories. Statistical distinction of

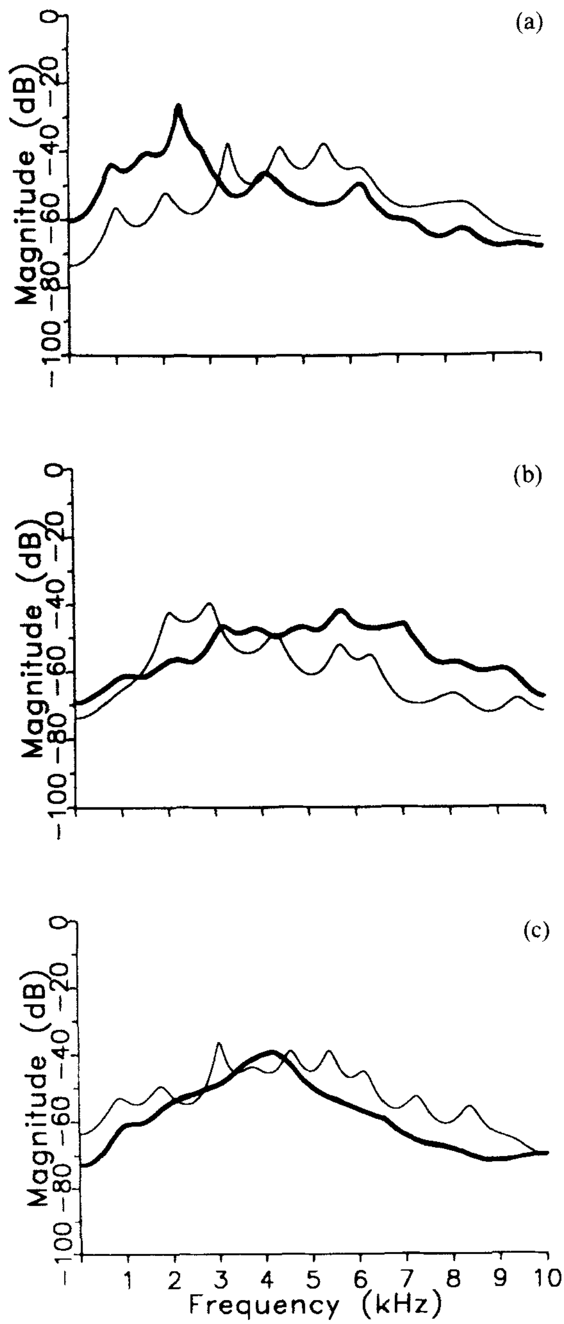

Figure 1. *Comparison of spectra that differ in (a) mean, (b) skewness and (c) kurtosis. Although moments were calculated from the raw FFTs (see text), smoothed LPC spectra (22 coefficients) are presented for ease of viewing. All spectra were derived from one NA child's productions of test utterances. In (a) spectra differ in mean frequency with the heavy-lined spectrum having a lower mean frequency (2·4 kHz) than the thin-lined spectrum (4·7 kHz). In (b) spectra that differ in skewness with a skewness of zero for the heavy-lined spectrum and skewness equal to 2·1 for the thin-lined spectrum are presented. Spectra varying in kurtosis are presented in (c); the heavy-lined spectrum has a kurtosis of 5·0 and the thin-lined spectrum has a kurtosis of 1·1.*

each input variable for the two categories (/k/ and /t/) in the present investigation was determined by one-way ANOVAs.

In addition to categorization of the stops, estimates of stability of repeated productions were obtained by calculating Mahalanobis D^2, a measure of the distance of each repetition (i.e. case) from the centroid of the group. A small value of D^2 indicates that the classification variables associated with that repetition are typical of the group's profiles. Conversely, a large D^2 value suggests a relatively poor match between the individual repetition and the group profile of the classification variables. In the present analysis, the mean D^2 was used as an index of the stability of repeated productions. Although D^2 is used typically as a measure of how well each case fits the discriminant model, it can be inferred that when all cases are fit poorly by the model (i.e. large mean D^2), there is a lot of variability in the data.

Results

Normally articulating children

For the NA group of subjects, /k/ and /t/ were discriminated between with about 82% accuracy on the basis of the spectral moments from the first 40 ms of these stop consonants. A contingency table, showing the classification errors, is given in Table 2. As with other studies (e.g. Chapin *et al.*, 1982), the velar consonant was misclassified more often than was the alveolar stop. In fact, the majority of the classification errors for /t/ (two-thirds) were from a single subject (NA2), whereas the errors in categorizing /k/ were distributed across all of the NA subjects. Although the classification accuracy is similar to that obtained with adults using templates (e.g. Stevens and Blumstein, 1978), it is not as good as the classification of adult stop consonants found with the moments procedure (Forrest *et al.*, 1988). *Post hoc* inspection of the canonical weights indicated that the discrimination of the children's stop consonants was based on variables relating to mean, primarily, and kurtosis, secondarily. This is similar to the results of the analyses performed on the adults' stop consonants in which mean was the dominant discriminator and a combination of skewness and kurtosis served as a secondary variate. However, the precise functions used to discriminate /k/ from /t/ were not the same for the adults and children. Discriminant functions calculated from adult males (Forrest *et al.*, 1988) correctly classified only 64% of the children's /k/ and /t/ utterances. The model calculated from the adult females' /k/ and /t/ utterances classified the children's consonants with only slightly higher accuracy (70%).

Table 2. *Classification of /t/ and /k/ produced by normally articulating subjects.*

		Number of cases	
Phoneme	% correct	t	k
t	83·6	61	12
k	82·1	12	55

There was no difference in the variability of production of target /t/ or target /k/ for the NA children in this study. Using Mahalanobis D^2 as an index of variability, the average D^2 for target /t/ was 11·1 (SD = 7·8) compared with a mean value of 12·1 (SD = 8·95) for target /k/ ($t = 0{\cdot}52$, $p > 0{\cdot}61$).

Phonologically disordered children

Discrimination of /k/ and /t/ could not be made for the PD children on the basis of the moments. In fact, the mean values of each moment were the same for the two consonants produced by the group of PD children. Investigation of the moments for the individual PD children indicated that they could be described by two different patterns. One pattern which was evidenced in three children showed no distinction between any of the moments calculated from the spectra of target /k/ and /t/. The spectra shown in Figure 2 taken from one of these PD children confirms the similarity in the production of the target phonemes. The remaining child (K. R.) showed significant distinctions between the moments calculated from her productions of /t/ and /k/. Specifically, the moments reflecting spectral shape (skewness and kurtosis) were significantly different for the two stop consonants. Spectra for target /k/ and /t/ produced by K. R. are shown in Figure 3. Attempts to classify her productions of target /t/ and /k/ using the model obtained with the NA children were moderately successful. As can be seen in Table 3, 70% of the target /t/ and /k/ utterances were classified correctly from the NA discriminant function. However, only half the target /k/ utterances were classified correctly using this model. That is, classification of K. R.'s /k/ utterances from the NA children's model occurred at chance levels, whereas her /t/ utterances were all classified correctly.

It is clear, then, that only one of the PD children made an acoustic distinction between /k/ and /t/ and that this distinction was not the same one made by normally articulating children. Discriminant analysis was performed on the data from K. R.'s

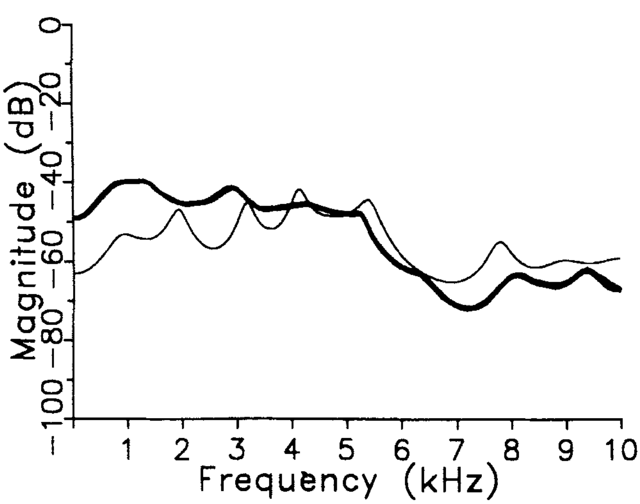

Figure 2. *LPC smoothed spectra from one PD child who did not distinguish /k/ from /t/ as determined from perceptual judgement and acoustic analysis. As indicated by the moments analysis, this child made no productive differentiation between target /k/ (heavy-lined spectrum) and target /t/ (thin-lined spectrum).*

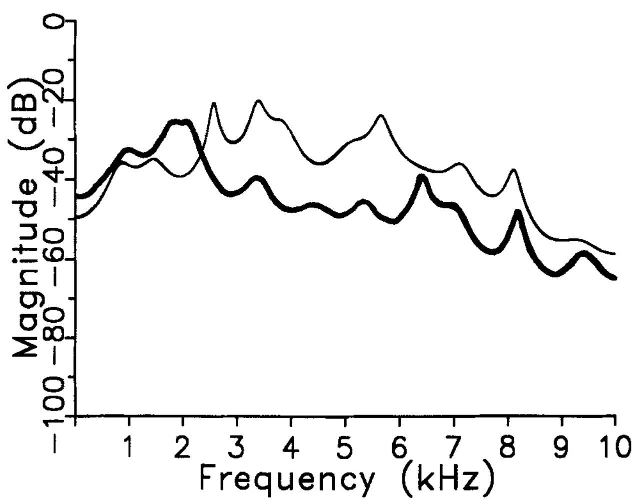

Figure 3. *LPC smoothed spectra from K. R.'s target /k/ (heavy line) and target /t/ (thin line). These spectra are representative of many of the target stops produced by this subject, thereby graphically illustrating the distinction between target /t/ and /k/ revealed by the moments analysis.*

productions of target /t/ and /k/.‡ The outcome of this analysis indicated that K. R.'s /t/ and /k/ could be discriminated with approximately 87% accuracy (100% of /t/ and 76·5% of /k/ utterances) on the basis of kurtosis and skewness, even though there was no perceptible difference between these phonemes in word-initial position. However, K. R.'s repeated productions of target /k/ were more variable than those produced by

Table 3. *Classification of /t/ and /k/ produced by K. R., a phonologically disordered subject.*

		Number of cases	
Phoneme	% correct	t	k
t	100·0	13	0
k	47·1	9	8

‡Because the ratio of observations to parameters was low in this discriminant analysis, several precautions were taken to increase the validity of the analysis. First, a 'jack-knife' procedure (Lachenbruch and Mickey, 1968) in which the discriminant function is calculated by 'leaving one out' (Lachenbruch, 1975; Fletcher, Rice and Ray, 1978) was used as a cross-check of the results. This procedure calculates the discriminant function with one observation omitted and then classifies that observation on the basis of the calculated model. The number of correct classifications are then tallied. In general, this procedure gives a more accurate classification, especially for small samples. In the present analyses, there was a 2% difference in the classification, on average, using the 'jack-knife' versus the standard stepwise procedure. Additionally, tests of the distribution of the input variables were undertaken to assure that they were normally distributed. Although these precautions were undertaken there may be some spurious misclassification because of the low observation to input variable ratio (Lachenbruch, 1968), so interpretation of these results should be considered accordingly. However, because no further predictions were attempted from these data and because the ensuing discriminant function was consistent with the pattern of statistically significant contrasts, as determined by one-way ANOVAs, the outcome of the discriminant analysis from a single subject seemed interesting.

the NA children as well as more variable than her own productions of target /t/. There was no difference between K. R. and the normally articulating children in the mean Mahalanobis D^2 for target /t/ (12·7; SD = 8·21) but the mean value for target /k/ produced by K. R. was 29·3 (SD = 24·2), which was significantly different from the value for NA children ($t = 2{\cdot}56$, $p < 0{\cdot}025$). If variability can be used as a metric of reduced skill as suggested by Kent (1976, 1983, 1984), then K. R.'s production of /k/ may be viewed as a less-skilled realization of this phoneme.

Phonological analyses conducted after the completion of treatment indicated that only K. R. had ambient productions of /k/. Two of the other PD children were credited with some correct productions of /k/, but these productions were inconsistent. The last PD child still had an inventory constraint against velar consonants. The differences in the children's phonologies could not be attributed directly§ to clinical intervention since none of these children, including K. R. was treated on voiceless velar consonants.

Acoustic comparisons using the moments procedure were made between K. R.'s post-treatment /k/ and /t/ and the productions of the normal children. Even though K. R. produced /k/ phonemes that were perceptually acceptable, the acoustic correlates of that phoneme were distinct from those of the normally articulating children. Using the discriminant function calculated from the NA children, 82% of K. R.'s /t/ utterances were classified correctly but only 27% of her /k/ utterances fit the acoustic model of that phoneme produced by the normally articulating children. K. R.'s pre-treatment model classified about 65% of her post-treatment /k/ and /t/ utterances, suggesting that indices of spectral shape (i.e. skewness and kurtosis) still characterized her productions of these phonemes.

Variability of K. R.'s post-treatment productions of target /k/ was reduced, though not significantly, compared with that obtained pre-treatment. However, variability for target /t/ increased ($t = 2{\cdot}64$; $p < 0{\cdot}015$). Mahalanobis D^2 was 16·6 for target /k/ (compared with 29·3 before treatment) and 24·3 for target /t/ (compared with 12·7 prior to treatment). This suggests that the discriminant function calculated for /k/ post-treatment represented all repetitions better than the function calculated from the pre-treatment tokens of target /k/. Unfortunately, the improvement in the model for target /k/ was accompanied by a less-stable model for the target /t/ phonemes produced by K. R. after treatment.

Discussion

The present study substantiates earlier findings that acoustic analysis of misarticulated speech may provide greater insight into the phonological knowledge possessed by certain speech-disordered children (Maxwell and Weismer, 1982; Catts and Jensen, 1983; Geirut and Dinnsen, 1986; Forrest and Weismer, 1988). The spectral

§Because /k/ versus /t/ was not a training target for any child, the emergence of the contrastive use of these phonemes cannot be ascribed *directly* to clinical intervention. However, the contribution of training on other phonemes to the acquisition of /k/ cannot be dismissed completely. Elbert and Dinnsen (1987) have shown that phonemes targeted in treatment may have broad, though generally predictable, effects on phonological reorganization in disordered speakers. Additionally, the knowledge of other phonemes may impact the acquisition of a missing sound in a child's phonological system. In the present study, the effect of these variables was not assessed.

moments calculated from the first 40 ms of the voiceless stops revealed two distinct patterns within the group of PD children. One pattern, which included three of the four PD subjects, showed no difference between the productions of /k/ and /t/. The remaining PD subject, however, appeared to contrast /k/ and /t/ acoustically, such that 88% of her productions of these phonemes were classified correctly. This information is valuable in that it can explain, and perhaps in future work predict, a child's acquisition of phonemes that are untreated. For example, in the present work the child with some knowledge of the velar–alveolar contrast as measured acoustically, acquired /k/ without intervention, whereas those children with no acoustic markers for the contrast did not evidence any knowledge of /k/ after treatment on other phonemes. Of course, it is possible that other unknown factors influenced K. R.'s acquisition of the /k/–/t/ contrast.

It is particularly interesting to note that even though subject K. R. produced target-appropriate /k/ after treatment, the acoustic cues to that phoneme were not consistent with those produced by normally articulating children. This is similar to Hewlett's (1988) findings with a phonologically disordered speaker. In his study, the PD child's treatment was directed toward correcting a 'velar-fronting' problem. Even after treatment, when the child was perceived to produce the /k/–/t/ contrast correctly, she was using a different pattern than the normally articulating children. Like Hewlett's findings, the present results suggest that a perceptually correct production by a phonologically disordered speaker may be different from the productions of a child who never demonstrated misarticulations. The consequences of this suggestion are unclear. Because the listener of a given language is able to understand a wide range of acoustic signals as falling into a discrete phonemic category, differences in the acoustic cues to that category, within certain limits, may be inconsequential to the listener. The source of these differences between normal and phonologically disordered children remains in question. For example, the acoustic characteristics of a phonologically disordered child's /k/ phonemes may resemble those of a younger normal speaker who is acquiring this phoneme. This would suggest a normal, though delayed, development for the disordered speaker.

This idea of delayed development of phonemic mastery is further substantiated by the greater variability in K. R.'s productions of target /k/, as compared with the NA children. One metric of skill acquisition is the reduction of variability across repeated productions of the same gesture (Bruner, 1973; Kent and Forner, 1979, 1980; Magill, 1983). In the present study, K. R. showed a reduction in the spectral variability of target /k/ in her post-treatment production compared with her pre-treatment productions. This would suggest an increase in mastery of the articulatory manoeuvres involved in distinguishing velar from alveolar consonants. However, the separation of velar and alveolar consonants into two distinct productive classes may have had an effect on the stability of known articulations. Post-treatment target /t/ exhibited somewhat greater variability than was noted prior to therapy when /k/ and /t/ were indistinguishable perceptually. This would imply that the divergence of a phoneme into two target appropriate classes may impact on both the known and novel elements.

It would be interesting to know if the phonologically disordered child would ever produce speech like that produced by a child who has developed speech normally. For example, does the PD speaker continue to modify his/her phonemes to approach those produced by NA children? If so, how long does this modification take? Alternatively, do PD children produce any phonemes, even those that are perceived to be produced correctly, like a NA child? That is, does a phonological disorder pervade the entire system? These questions are ripe for investigation.

Consistent with the results of Hewlett (1988) and Chapin *et al.* (1982), the stop consonants of the children in the present study did not appear to fit the same acoustic 'template' used for adults. Only 70% of the stop consonants produced by the NA subjects in this study were classified correctly using the discriminant function calculated from female adult speakers. This is similar to the rate of classification found by Hewlett. Although the general cues used to discriminate /k/ from /t/ were the same for the children and adults, namely indices of mean frequency and spectral shape, the precise values of these parameters were different.

The moments procedure may provide a useful tool in investigating spectral characteristics of normal and misarticulated speech. However, the success of classification may improve with spectral information from a longer interval of the phonemes produced by children. As Hewlett (1988) has shown with misarticulating children, and Nittrouer, Studdert-Kennedy and McGowan (1989) have shown with normally articulating, young children, transitional information may be more important in children's speech. If information in the transition and/or vowel carry more weight in the speech of children than in adults, as Hodge (1989) has suggested, it may be useful to investigate the time-varying spectral cues to phonemes over a longer interval in the young speakers.

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