Acoustic Features of Pharyngeal /s/ Fricatives Produced by Speakers with Cleft Palate

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The production of pharyngeal fricatives represents one type of compensatory speech maneuver exhibited by speakers with palatal clefts. Several investigators have observed that some speakers with cleft palate substitute pharyngeal fricatives for consonants normally produced in the front of the mouth (1, 8). Although pharyngeal consonants have long been known to be present in the speech of certain cleft palate speakers, their acoustic correlates are not well understood.

As their label implies, pharyngeal fricatives are produced by approximating the tongue to the pharyngeal wall (7). Subtelny (10) has recently provided radiographic evidence that pharyngeal consonant gestures used by speakers with cleft palate are accomplished by retracting the tongue dorsum to the pharyngeal wall, thereby producing a primary constriction in the lower pharynx.

It is of considerable importance to note that pharyngeal fricatives are normally not produced by speakers of English. Rather, fricatives are normally produced by forming a primary constriction in the mouth—that is, at loci between the velum and the lips. There are, however, several languages that employ pharyngealized consonant gestures. Klatt (6) and Stevens (9) have recently examined the acoustic properties of pharyngeal consonants produced by Arabic speakers. Their data indicate that pharyngeal consonants are characterized by a set of distinctive acoustic features and that these features differ markedly from those associated with consonants produced in the front of the mouth. Specifically, Klatt (6) and Stevens (9) have shown that the pharyngeal consonant productions of Arabic speakers exhibit "the distinctive property that F_1 is high and relatively close to F_2 . This property distinguishes pharyngeal consonants from those produced with a more anterior constriction position, all of which are characterized by a low-frequency first formant." In addition, Klatt and

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This study was supported, in part, by a grant from the Riley Memorial Association, Indianapolis, Indiana. We appreciate the assistance of Dr. James C. Shanks, Indiana University Medical Center, Indianapolis.

Stevens have shown that the Arabic voiceless fricative $/\hbar/$ shows intense, lower frequency F_3 excitation.

These recent observations, coupled with our clinical impressions, suggest that pharyngeal consonants produced by speakers with cleft palate should also be characterized by a set of distinctive acoustic features. We hypothesize that the latter is true for specific pharyngeal compensatory speech maneuvers used by speakers with cleft palate. For example, pharyngeal articulations of the voiceless fricative /s/ are identical to gestures used by Arabic speakers to utter the voiceless fricative /ħ/ (6, 9, 10). In both cases, the consonants are produced with a constriction well back in the vocal tract —that is, 1 to 3 cm. from the glottis.

To obtain information about the acoustic properties of pharyngeal consonants spoken by speakers with cleft palate, recordings of a number of pharyngealized /s/ utterances were obtained and subjected to acoustic analysis. It was expected that these analyses would enlarge our current understanding of compensatory speech mechanisms employed by speakers with cleft palate.

Method

SUBJECTS AND RECORDINGS. The subjects participating in this study were four speakers with cleft palate—two adults (one man and one woman) in their mid-thirties, and two male children (a 9-year old, and a 10-year old). These four subjects were heterogeneous with respect to their type of palatal clefts, surgical background, etc. Despite their heterogeneity, all four speakers evidenced one important common behavior—they all exhibited consistent pharyngeal /s/ substitutions in place of /s/ productions normally produced in the front of the mouth.

The pharyngeal /s/ productions were initially identified on a perceptual basis by the senior author and a speech pathology colleague. Sound-synchronous cinefluorographic studies were completed for each speaker with cleft palate to verify that these subjects did produce the pharyngeal substitutions by forming a primary constriction in the lower pharynx. To date, these radiographic materials have been used only to verify that constriction locations were always in the region appropriate (i.e., between 1 to 3 cm from the glottis) for the generation of pharyngeal consonants (6, 9).

High-quality tape recordings were obtained of each speaker producing a set of CV syllables. The syllables consisted of the voiceless pharyngeal /s/ followed by the vowels /i/, /u/, /a/, /ə/, and /e/. The CV syllables were spoken within the sentence frame: Say ______ again.

For comparative purposes, recordings were made of a female and a male adult normal talker producing the monosyllables within the same sentence frame.

Acoustic ANALYSIS. The acoustic properties of pharyngeal /s/ sounds produced by all speakers were measured using digital computer processing and analysis techniques (3, 5). Each speaker's recordings were played into a set of 35 bandpass filters whose center frequencies ranged from 270 Hz to 9.5 KHz. Following rectification and smoothing, the filter outputs were scanned by a multiplexer at 10 msec intervals, linearly quantized, and stored on computer magnetic tape. Thus, spectral information for each 10 msec of speech was represented by a set of 35 values, each value representing the amplitude (in 1024 levels on a linear scale) of the energy passed through one of the 35 filters. Finally, the short-time spectral characteristics of the pharyngeal /s/ utterances were determined by a series of computer programs operating on the digital data.

Initially, digital spectrograms were made of the five sentences produced by each speaker:

The spectrograms were studied and the time samples for segments associated with the readily discernible pharyngeal /s/ utterances were identified. Short-time spectra for pharyngeal /s/ were obtained by averaging the digital data across time intervals defined by the durations of these fricative productions. Eleven average short-time spectra were obtained for each speaker: five spectra for /s/'s in Say words; five spectra for /s/'s in Sue, see, saw, sah and say monosyllables, and one average spectra obtained by integrating the digital data across all ten /s/ occurrences (hereafter referred to as short-time average spectra). For comparative purposes, the recordings of the two normal speakers were processed and analyzed in an identical manner.

Results and Discussion

Average short-time spectra of pharyngeal /s/ sounds produced by the four speakers with cleft palate are compared with /s/ consonants produced by the two normal speakers in Figure 1. The output spectral characteristics for /s/'s produced by the normal speakers conform with those reported in the literature. For example, normal /s/ spectra were characterized by broad band noise with a prominent energy maxima above 3500 Hz (2, 4, 9).

By contrast, the output spectral characteristics for pharyngeal /s/'s produced by speakers with cleft palate were always characterized by a set of distinctive acoustic properties that differed markedly from /s/ sounds gestured in the front of the mouth. One consistent feature of the output spectra of pharyngeal /s/'s produced by speakers with cleft palate was the presence of characteristic resonance patterns earmarked by multiple spectral maxima. Pharyngealization of /s/ consonants gave rise to spectral outputs with energy maxima appropriate to a high F_1 (600–800 Hz), which



FIGURE 1. Short-time average spectra of normal and pharyngeal /s/ sounds. Amplitudes in dB relative to the maximum components are plotted as a function of frequency. S_1 and S_2 are short-time average spectra for the two normal speakers. S_{1P} , S_{2P} , S_{3P} , and S_{4P} are short-time average spectra for speakers with cleft palate.

were relatively close to F_2 (1000–1200 Hz). As Klatt (6) and Stevens (9) have observed, these properties distinguish pharyngeal consonants from fricatives employing a more anterior constriction location, all of which are characterized by a low frequency first formant. The results of our spectral analyses also support the observations of Klatt and Stevens in that they show that pharyngealization of /s/ is associated with a relatively strong, low frequency (~2000 Hz) excitation of F_3 . Taken together, our observations show that the output spectral properties of pharyngeal /s/ consonants spoken by speakers with cleft palate were, in general, comparable to those of /h/ fricative spoken by speakers of Arabic (6, 9).

It is important to recognize that the present observations of articulatory substitutions used by speakers with cleft palate have been restricted to a single consonant element /s/. It is expected that further observations involving additional consonant elements and other types of compensatory maneuvers (namely, uvular or velar gestures) would be fruitful and essential to the development of a more complete understanding of articulatory and acoustic features of speech produced by speakers with cleft palate.

Summary

Acoustic features of pharyngeal /s/ substitutions spoken by persons with cleft palate were measured using digital computer processing and analysis techniques. Average short-time spectral characteristics of pharyngeal /s/ sounds produced by four speakers with cleft palate were compared with spectral features of normally gestured /s/ sounds spoken by two normal speakers. The output spectral characteristics of pharyngeal /s/'s were always characterized by a set of distinctive acoustic properties that differed markedly from normal /s/ sounds gestured in the front of the mouth. One consistent feature of pharyngeal /s/'s was the presence of multiple spectral maxima. Pharyngealization of /s/ consonants gave rise to spectral outputs with energy maxima appropriate to high F_1 values which were relatively close to F_2 , as well as to relatively strong, low frequency excitation of F_3 . The output spectral properties of pharyngeal /s/ consonants spoken by speakers with cleft palate were, in general, comparable to those of /ħ/ fricatives spoken by speakers of Arabic.

> reprints: Dr. B. Weinberg Department of Audiology & Speech Sciences Purdue University West Lafayette, Indiana

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