QUANTIFICATION OF PHARYNGEAL ARTICULATIONS USING MEASUREMENTS FROM LARYNGOSCOPIC IMAGES

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ABSTRACT

One difficulty in the physical observation of articulatory structures in the pharynx is the reliability of measurements for comparative purposes. The objective of the present approach is to review and explore techniques of identifying and measuring degrees of adjustment of the pharyngeal articulatory mechanism in the production of auditorily controlled settings.

Anatomical landmarks are identified on computer images transferred from laryngoscopic videotapes, and measurements are taken of dimensions defined by the configuration of the pharyngeal articulators. Comparisons are taken across linguistically contrastive consonants and vowels, where the activity of the laryngeal sphincter accompanies tongue retraction and larynx raising, and implications are drawn for the measurement of voice quality settings. Measurements of the “tense,” raised-larynx series of Yi (Nosu) are illustrated.

1. PHARYNGEAL ARTICULATIONS

Many kinds of measurements have been made of the shape and size of the vocal tract under different phonetic conditions. This report is intended to point out an area of the vocal tract where measurement continues to be a challenge, and to present some videolaryngoscopic data which illustrate the kinds of articulations that should be considered when evaluating vocal tract volume or articulator configuration quantitatively. The aspect of speech production which we are interested in is the behaviour of the articulators in the pharynx, as observed with a fibreoptic laryngoscope.

Catford [1,2,3], Gauffin [4], Kodzasov [5], Painter [6], and Esling [7] describe the auditory phonetic distinctions and articulatory parameters which define the sounds the pharynx is capable of producing. These analyses isolate stop, fricative, approximant and trill manners of pharyngeal (often called epiglottal) articulation. Traill’s research identifies “sphincteric phonation” (trilling of the aryepiglottic "laryngeal sphincter" mechanism) as a phonatory phenomenon, demonstrating the importance of considering the effects of the laryngeal sphincter on glottal phonation type [8].

2. PRIOR RESEARCH

Anthony [9] and Ladefoged, Anthony and Riley [10] developed a model for specifying vocal tract area based on vocalic articulations and direct measurements of material impressions. Larynx height is undetermined in these studies, and any degree of pharyngeal constriction is unspecified, although the data reported suggest that the vowels were probably produced with a more lowered larynx and therefore expanded pharynx. The Swedish study by Gauffin and Sundberg [11], using laryngoscopic sweeping and corresponding x-ray pictures of various vowels, offers similar results as far as the contrasts in vocalic quality are concerned but suggests that pharyngeal size (and larynx height) might have been different than in the UCLA studies. The difference could be accounted for by considering the pharyngeal and laryngeal parameters employed by the different subjects when articulating the vowels. That is, a vowel articulated with a raised-larynx setting will generate lower volume values than the "same" vowel articulated with a lowered-larynx setting, just as their auditory quality will differ. It is these considerations that guide research into voice quality settings, where habitual postures of the vocal tract articulators affect both articulatory measurements and acoustic realizations of vowels, transitions and consonants.

The ultrasound study by Minifie, Hixon, Kelsey and Woodhouse [12] establishes that pharyngeal wall movement is greater during low (open) vowels than during high (close) vowels. They report that "pharyngeal wall movement during consonant production appeared to be dependent on the adjacent vowels." The finding relating open vowels to pharyngeal activity has a direct bearing on the articulations being examined in the present report. The Minifie et al. study considered American English vowels, where vowel tokens such as [ɑ] demonstrate the strongest pharyngeal characteristics, relating to the initiation of the laryngeal sphincter. In many other languages with pharyngeal consonants or with series of sounds with features of larynx raising (often called "laryngealized," "glottalized" or "tense" or even "creaky"), the effect of the laryngeal sphincter and of concomitant tongue backing and larynx raising will be even greater. It is these pharyngeal phenomena, as consonantal segments, in conjunction with vowel production, or as secondary articulations in conjunction with consonant production in the front of the mouth, that can be viewed and analyzed as a primary impedance factor with a feedback effect on the glottal source.

Direct laryngoscopic measurement of laryngeal structures has been approached stereoscopically. Despite Niimi and Baer’s [13] and Fujimura, Baer and Niimi’s [14] design of a double-bundle fibrescope which would capture two images and allow triangulation of distances in the deepest parts of the oral cavity, calculating meaningful distance measurements of structures around the glottis remains elusive. MRI has been

used to evaluate vocal tract volume during phonological contrasts between [+ATR] and [-ATR] vowels in West African languages (Tiede [15]). These measurements are very close to the kind of articulation that characterizes the engagement of the laryngeal sphincter, as in pharyngeals. The point of similarity is the elevation of the larynx that normally accompanies pharyngealization, and which is found in the retracted tongue position of [-ATR] vowels.

Two major constraints in all measurements of pharynx shape are individual anatomy and voice quality setting, whether inherent in the subject's long-term accent or a feature of a phonological series. The anatomical shapes in Figure 1 are quite different from the structures in Figures 2–5, although the phonetic target is virtually identical.

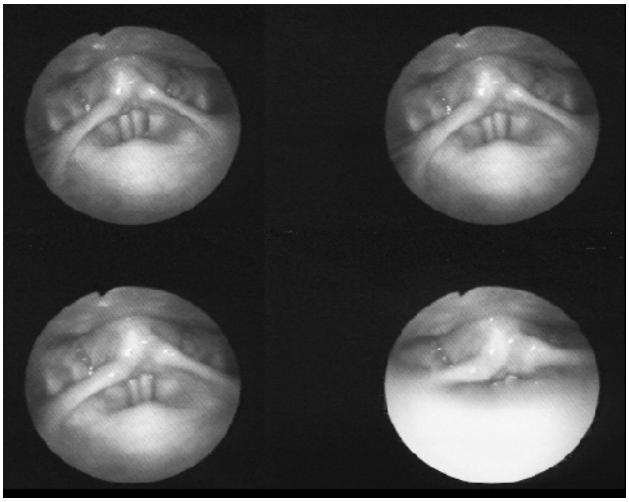

Figure 1: A 4/30sec sequence of the first author producing a voiced pharyngeal approximant [iʕ]. The laryngoscopic view of the pharynx in the last frame shows a retracted tongue root (bottom of circle), elevated larynx, and closely sphinctered aryepiglottic mechanism obscuring the vocal folds (centre), with a narrow channel remaining between the aryepiglottic folds and the base of the epiglottis. The pharynx is reduced in volume by the raised larynx and by the antero-posterior action of the sphincter. See [16] for orientation.

3. PROCEDURE

In our research, varying articulatory settings, either long-term or phonologically conditioned, are posited to alter what would otherwise be described as the same speech sound. In preliminary tests, cardinal pharyngeal consonants and the vowels [i,ɑ,u] were examined in five voice quality environments: raised larynx voice, pharyngealized voice, neutral voice, lowered larynx voice and faucalized voice. Anatomical landmarks were identified on computer images transferred from laryngoscopic videotapes, and measurements were taken of three angles defined by the configuration of the pharyngeal articulators: the aryepiglottic fold angle, the pyriform sinus angle defined by the posterior borders of the laryngeal lumen, and the angle from the epiglottic tubercle to the cuneiform cartilages.

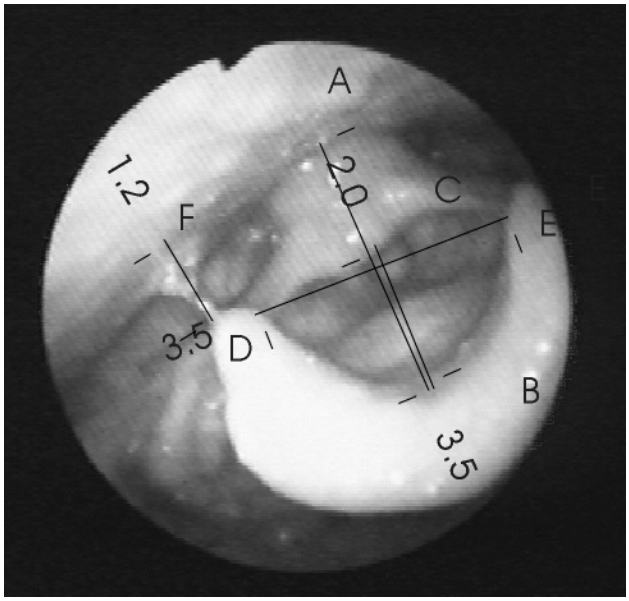

Figure 2: A 1/30sec laryngoscopic frame of the pharynx of the fourth author producing the "lax" [m] phoneme of Yi (Nosu), a Tibeto-Burman language of western Sichuan, China.

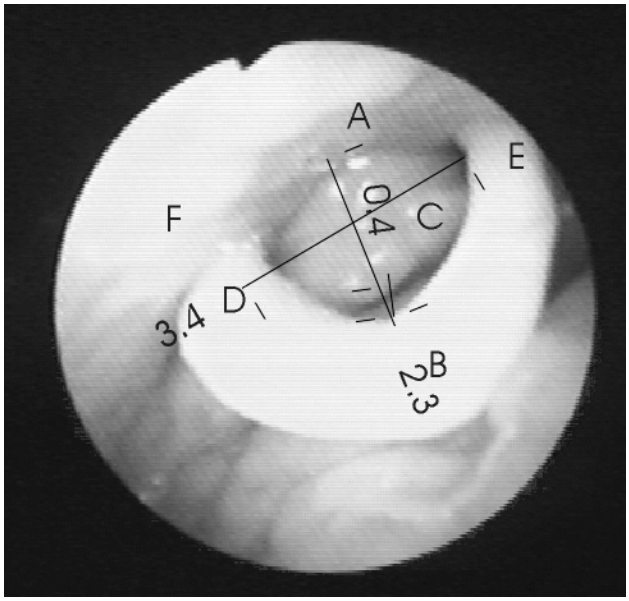

Figure 3: A 1/30sec laryngoscopic frame of the pharynx of the fourth author producing the "tense" [m̰] of Yi (Nosu).

Consistent with earlier findings [17], the postures for raised larynx voice and for pharyngealized voice were found to be identical, and the postures for lowered larynx voice and faucalized voice were found to be identical, although the robustness of the angle measurement algorithm was found to have limitations [18]. Initial results suggest that raised larynx voice and pharyngealized voice are produced by a similar setting of the pharyngeal articulators, with the aryepiglottic folds in sphincted mode. Lowered larynx

voice and faucalized voice also share common articulatory features based on the measurements of the three angles, in contrast to the two raised larynx settings. In all settings, the open [ɑ] vowel can be demonstrated to exhibit the characteristics of a pharyngeal, with angles resembling raised-larynx tokens of [i] or [u]. The proposed explanation is that a high degree of articulatory adjustment is required where a vowel is maximally susceptible to a given setting (as in the case of [i] in raised-larynx mode), and that a smaller degree of adjustment is required where a vowel is minimally susceptible to a given setting (as in the case of [ɑ] in raised-larynx mode). Further measurements between articulatory landmarks in the pharynx are being investigated.

The technique adopted here is to identify landmark articulators and to describe their configurations in general articulatory terms in order to provide relative comparisons of the pharyngeal space. Comparisons of configurations are based on known phonological contrasts between pharyngeal and non-pharyngeal items. The first challenge is to identify all landmarks in subjects with differing anatomies, and to be able to follow their movements relative to one another. The second procedure followed here is to observe the most salient differences that occur between postures, and to state differences of lengths between landmarks as ratios. The reason that global statements of configuration are permissible in this context is that maximal differences in possible phonetic production have been isolated for examination, where landmark identification and ratios can be expected to differ significantly in relative terms. Another reason for relative description of differences in configuration is that voice quality settings are habitual and long-term, allowing an average posture to be calculated over time. Although examining such differences is only implied in the present research, the segmental contrasts illustrated here give a good indication of the effect that superimposing a pharyngeal setting has on the "colour" of an oral or nasal continuant. It is implied in this procedure that the choice of language and the evaluation of its voice quality are critical elements in the likelihood of finding stable configurations to measure.

Video images obtained laryngoscopically [7] are transferred to Corel Draw for measurement. Four figures are presented here to illustrate the technique that is being adopted. Figure 3 [m̰] is the "tense" counterpart of Figure 2 [m] in Nosu. It bears a relationship to Figure 1 in that the larynx is raised, the tongue retracted, and the aryepiglottic sphincter tightly engaged. First, several anatomical landmarks are identified:

A, the mid-sagittal point on the posterior pharyngeal wall;
B, the mid-point on the semi-circular inner epiglottal rim;
C, the anterior mid-point where the aryepiglottic folds join;
D, the right-most end (image-left) of the arc of the epiglottis;
E, the left-most end (image-right) of the arc of the epiglottis;
F, the posterior pharyngeal wall opposite point D.

Length ratios are then calculated to relate these distances.

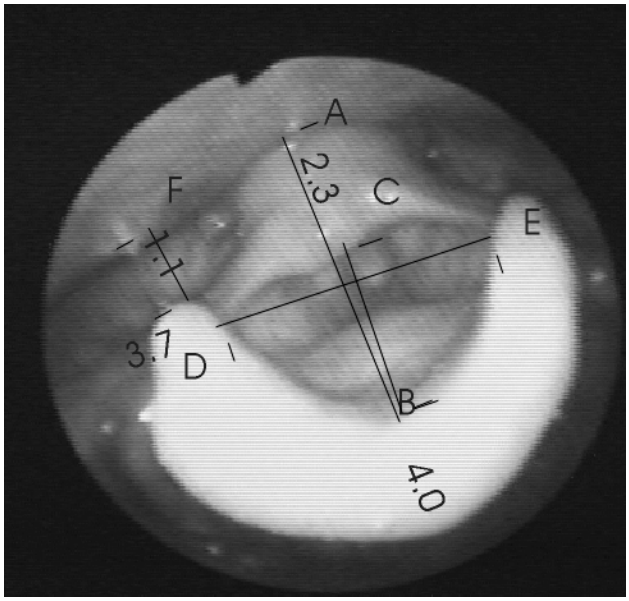

Figure 4: A 1/30sec laryngoscopic frame of the pharynx of the fourth author producing the "lax" [i] of Yi (Nosu). The pharyngeal articulators are in the same position as for [m].

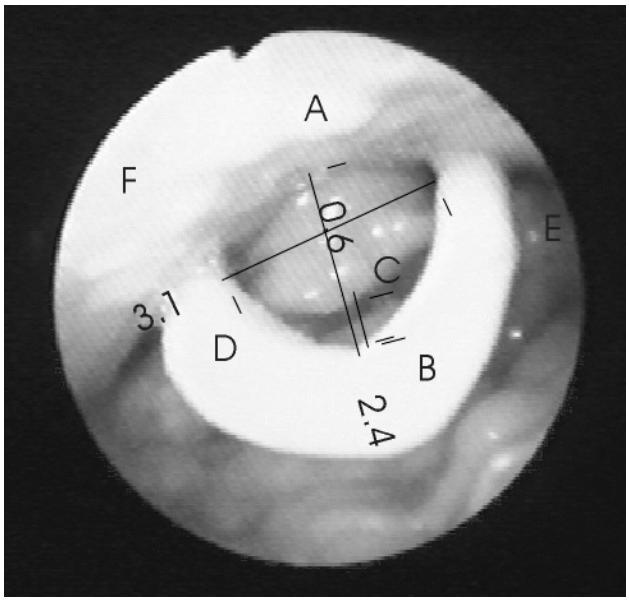

Figure 5: A 1/30sec laryngoscopic frame of the pharynx of the fourth author producing the "tense" [ḛ] of Yi (Nosu). The pharyngeal articulators are in the same position as for [m̰].

4. FINDINGS AND IMPLICATIONS

The relationship of the relative distances in the epilaryngeal space, in arbitrary units, can be illustrated as follows:

Distance/Ratio	[m]	[m̪]	[i]	[e̞]
A→B	3.5	2.3	4.0	2.4
B→C	2.0	0.4	2.3	0.6
D→E	3.5	3.4	3.7	3.1
D→F	1.2	0.0	1.1	0.0
BC/AB	0.57	0.17	0.57	0.25
AB/DE	1.00	0.67	1.08	0.77
DF/AB	0.34	0.0	0.27	0.0

The three principal relationships are that [m] and [i] share a large epilaryngeal tube (the opening between the aryepiglottic folds and the curve of the epiglottis), while [m̪] and [e̞] share a significantly narrowed transverse opening. The "cartilaginous ring" for [m] and [i] is virtually circular (1.00) while the pursed shape for e [m̪] and [e̞] is oblong. The space between the epiglottal arc and the posterior pharyngeal wall for [m] and [i] is 1/3 to 1/4 the total antero-posterior distance. The space between the epiglottal arc and the posterior pharyngeal wall for [m̪] and [e̞] is nil (fully compressed). These measurements help define phonetically what is meant by the general terms "tense" and "lax."

Previous descriptions and measurements of the shape of the pharyngeal space and epilaryngeal space have not considered the effect of variable long-term larynx-height adjustments on individual vowels. Examples of cardinal pharyngeals and of pharyngealized consonants and vowels show major changes in the configuration of the articulators which can be tentatively measured and compared using distance ratios and articulator identification protocols. Ratios of videolaryngoscopic dimensions in the epilaryngeal space are considerably smaller in the antero-posterior as well as the transverse dimension under raised-larynx/ pharyngealized conditions. In instrumental research, even only of vowel quality, it is relevant to take these relationships into account.

5. ACKNOWLEDGEMENTS

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