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Journal
Proceedings of the Annual Meeting of the Berkeley Linguistics Society, 37(37)

ISSN
2377-1666

Author
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Publication Date
2013

Peer reviewed

Pharyngealization in Chechen is Gutturalization

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Introduction

Knowing the phonetic and phonological properties of rare types of consonants, such as clicks, implosives, and pharyngeals, is essential for understanding how they affect the phonological systems of the languages in which they occur.[1] This study focuses on consonants with a primary or secondary pharyngeal articulation, which occur in only 21 of UPSID's 451 languages (5.32%; Maddieson 1984). However, these segments are found in over 12 different language stocks spread across North America, Eurasia, and Africa (Nichols and Bickel 2009). Pharyngeal or pharyngealized consonants, then, are rare enough token-wise that they are understudied in many respects, but are phylogenetically common enough that they are important to phonological theory and historical linguistics.

This study focuses on pharyngeal consonants and "pharyngealization" in Chechen, a Nakh-Daghestanian language of the northeast Caucasus region of the Russian Federation with approximately 1.3 million speakers (All-Russia Population Census 2002).[2,3] Previous accounts of pharyngeal consonants and "pharyngealization" in Chechen have, with one important exception, not included instrumental

[1] *Acknowledgements*: Many thanks to Johanna Nichols for inspiration, financial support, gathering field data, and being very patient. Thank you also to Sharon Inkelas, Keith Johnson, Andrew Garrett, and the audiences of the 2011 Berkeley QP Fest and BLS 37 for very helpful suggestions throughout this research. Thank you to UC Berkeley, the Beinecke Foundation, and the Survey of California and Other Indian Languages for additional financial support. Thank you, finally, to the Chechen speakers who contributed recordings. All remaining errors are solely my fault.

[2] This study seeks to explain data only from standard literary Plains Chechen, spoken in the lowlands surrounding Grozny. However, Chechen dialects offer pertinent material for a study on pharyngealization since it can be demonstrated that Plains Chechen has historically simplified $C^{ʕ}$ to C in some words (Magomedov 2005:125).

[3] I put the word *pharyngealization* in quotes when it is used as a cover term for what I will argue is both phonetic pharyngealization and epiglottalization. I do not use quotes when I mean purely phonetic pharyngealization as I define it in the discussion of acoustic tube modeling in §2.

data to support their claims, and moreover they do not agree on the basic phonemic inventory of Chechen. In trying to resolve that confusion, I have found evidence that what has been called "pharyngealization" in Chechen involves both phonetic pharyngealization and epiglottalization, and may be the acoustic result of a specific complex of muscle action that results in a flattened, backward protruding tongue configuration similar to that found in related neighboring languages such as Dargi (Gaprindašvili 1966), Tsakhur, and Udi (Ladefoged and Maddieson 1996:308; Catford 1983).

I first review the literature to highlight the diversity of opinions on how "pharyngealization" is to be analyzed and which pharyngeal consonants are present in the phonemic inventory of Chechen. Next, I explain the acoustic tube models that are used to generate predictions about the acoustic characteristics of phonetic uvularization, pharyngealization, and epiglottalization. I then compare these predictions to the output of linear regression models of acoustic data provided by 5 native speakers of Chechen. I bolster the conclusions drawn from those comparisons with evidence from Chechen phonology. I conclude by examining the broader implications of my findings for the idea of a GUTTURAL natural class and for understanding post-velar, supraglottal articulations.

1 Previous Accounts

Out of the literature that discusses "pharyngealization" in Chechen, only Kingston and Nichols (1987) provide instrumental phonetic data. Other works present a variety of opinions on which kinds of post-velar consonants should be considered part of Chechen's phonemic inventory, but no instrumental data to support their claims. To try to resolve this basic disagreement in the literature, this study attempts to determine the precise place(s) of articulation associated with what has been called "pharyngealization" in Chechen. After reviewing Kingston and Nichols (1987) in some detail, I present a short summary of the claims presented in the literature.

Kingston and Nichols (1987:15-18) examined "pharyngealization" in Chechen using recordings of wordlists provided by two native speakers (1 M, 1 F). The wordlists were composed of monosyllabic or disyllabic words which contained all the language's consonants and all the possible "pharyngealized" variants. All but two of the words contained /a/ or /aː/ in the first syllable, which always bears primary stress in Chechen. In most cases, the consonant of interest was word-initial. Kingston and Nichols (1987) extracted the frequencies of F1-F3 using an LPC technique, and found that "pharyngealization" involves a rise in F1 and a fall in F2 and/or F3, producing general compaction of the spectrum (Kingston and Nichols 1987:21). They also found that "pharyngealized" stops have a longer VOT than their plain or ejective counterparts (Kingston and Nichols 1987:18-19).

Nichols (1997:943,962-3) describes Chechen as having a pharyngeal stop (symbolized as /ʕ/) and fricative (/ħ/), and describes "pharyngealization" as "a morphophonemic prosody" associated with the preceding consonant. She argues that a cluster analysis (in which "pharyngealization" is analyzed as a consonant plus a following pharyngeal consonant) is disfavored because of "severe constraints on clusters, especially initial." She also argues against "pharyngealization" being associated with the vowel because its manifestation is centered between the consonant and vowel "in an almost segment-like acoustically compacted delay in voice onset of the vowel and in distortion of the formant transitions in the following vowel."

Aliroev (1999:42-44) analyzes Chechen as having two pharyngeal phonemes. One is a voiced pharyngeal stop with a voiced fricative allophone [ʕ] and the other is a voiceless fricative /ħ/. "Pharyngealization" is analyzed as a cluster of a consonant followed by an identically voiced pharyngeal phoneme.

Nichols and Vagapov (2004:21,35) present a phoneme inventory in which Chechen possesses an epiglottal stop and fricative. They describe "pharyngealization" as being phonetically epiglottalization.

Finally, Magomedov (2005:125) describes Chechen as having a single pharyngeal phoneme that varies between [ʕ] and [ħ]. He adopts a cluster analysis for pharyngealization.

2 Predictions from Acoustic Tube Modeling

Acoustic tube models can be used to make predictions about the formant values that will result from particular articulations (Stevens and House 1955; Fant 1960; Stevens 1998; Johnson 2003). One can simulate the effects of articulations at various places, including the uvula, middle pharyngeal wall, and epiglottis. The formant values generated by acoustic tube modeling can then be used as predictions of the properties that a sound made at a particular place of articulation will have. If the values from a given sound sample match the predicted values for a particular articulation, one has evidence that the articulation is being used. However, because the mapping from acoustics to articulation is 1:*many* (e.g. English /ɹ/ can be produced with two distinct articulations), a match between the predictions of acoustic tube modeling and the results of acoustic analysis can only be taken as evidence for, not proof of, the presence of the articulation coded into the model. This type of comparison is used by Shahin (2002) to analyze uvularization in Arabic and pharyngealization in St'át'imcets Salish and by Yeou (2001) and Yeou and Maeda (1995) to study pharyngeal consonants and "emphasis" in Arabic.

The acoustic tube models that are mathematically implemented here involve modeling the vocal tract as a combination of three tubes: one for the cavity formed behind the constriction, one for the constriction itself, and one for the cavity formed in front of the constriction. Three equations are used to describe the resonant frequencies (formants) that result as sound passes through these tubes. The equations describe general types of tubes, namely tubes closed at one or both ends or two tubes joined together as a resonant system (here, a Helmholtz resonator). The equation in (1) describes formants produced in the back cavity, which is modeled as a tube closed at both ends (Johnson 2003:106). The glottis forms one closed end since air flows only out of it (and into the tube). Because the constriction opening is small, little air escapes through it, and this opening can be considered to be effectively closed.

(1)

$$F_{bn} = \frac{nc}{2l_b}$$

n stands for the order of formant whose frequency is being calculated (first, second, third, etc.) and c stands for the speed of sound in the cavity, which is taken to be the speed of sound in warm, dry air (∼35,000 cm/sec). l_b stands for the length of the back cavity, which is determined by subtracting half the length of the constriction ($l_c/2$) from the point of constriction (measured as cm from the glottis).

The back cavity and the cavity formed by the constriction create a "resonant system called a Helmholtz resonator in which the volume of air in the constriction oscillates like a piston in and out of the constriction" (Johnson 2003:106). The single resonance produced by the Helmholtz resonator can be characterized by the equation in (2).

(2)

$$f = \frac{c}{2\pi}\sqrt{\frac{A_c}{A_b l_b l_c}}$$

A_c is the cross-sectional area of the constriction and l_c is the length of the constriction. A_b is the cross-sectional area of the back cavity while l_b is the length of that cavity.

The front cavity can be considered to be closed at one end and open at the other. The end of the cavity adjacent to the constriction can be considered closed because little air passes through. The other end is the opening formed by the lips. The resonances produced in the front cavity are described by the equation in (3), where l_f is the cavity's length (Johnson 2003:102).

(3)

$$F_{fn} = \frac{(2n-1)c}{4l_f}$$

l_f is calculated by subtracting the point of constriction and half the length of the constriction ($l_c/2$) from the total vocal tract length.

Vocal tract length was determined based on values measured from this study's data, but other parameters of the acoustic tube models were based on values reported in the literature on Arabic. Vocal tract measurements were made from recordings of the speakers by identifying (for each speaker) 5 points in time at which the first three formants were equally spaced. At these points, the vocal tract takes on a neutral shape, and the equation for a tube open at one end in (3) can be used to model the entire vocal tract (Johnson 2003:103). Because the formant frequencies are known in this instance, one can solve for the length variable of the equation. Doing so results in giving the equation the following form:

(4)

$$L = \frac{(2n-1)c}{4F_n}$$

I calculated a length for the vocal tract based on the F3 measurement at each of these 5 times. Those lengths were then averaged to provide a vocal tract length for each speaker. Finally, the lengths obtained for each speaker were averaged and the average vocal tract length for the speakers in the data was found to be 18.18 cm.

Using X-ray tracings from Ghazeli (1977) that were redrawn in Shahin (2002:31), the length of constriction was estimated for uvularized and pharyngealized articulations and was then scaled based on the average vocal tract length of 18.18 cm. The uvularized articulation was modeled with a length of constriction of 2.138 cm and the pharyngeal articulation with a length of constriction of 1.069 cm. The length of constriction for epiglottalized articulations was assumed to be 0.535 cm based on the size of the epiglottis in Ghazeli's (1977) X-ray tracings and how it makes contact with the pharyngeal wall.

The cross-sectional area of the various constrictions models the degree of constriction, and was determined with reference to the values used by Yeou and Maeda (1995), who obtained accurate predictions using certain values for voiced and voiceless uvular and pharyngeal consonants. For the uvular place of articulation, the value for the voiced uvular fricative and the value for the voiceless uvular fricative were averaged to obtain a cross-sectional area of 0.275 cm^2 because this study does not distinguish between voiced and voiceless consonants for the purpose of acoustic tube modeling or analysis. For the pharyngeal articulation, the voiced and voiceless fricatives were averaged to obtain the value 0.325 cm^2. The value for an epiglottal articulation was assumed to be 0.300 cm^2, which is the average of the values for the uvular and pharyngeal articulations as well as "the minimum cross-sectional area of the constriction for vowels which was measured by Fant (1960)" (Alwan 1986:28).

The cross-sectional area of the back cavity was assumed to be 2 cm^2 for a uvular secondary articulation. For a pharyngeal articulation, it was assumed to be 1.75 cm^2 since some sphincteric closure has been found to occur with pharyngeal and epiglottal articulations by Esling (1996:73-4). I assumed that such sphincteric closure would be greater with epiglottal articulations than with pharyngeal articulations, so the value 1.5 cm^2 was assumed for epiglottal articulations.

The points of constriction for uvular and epiglottal articulations were determined using X-ray tracings from Ghazeli (1977) in consultation with the parameters listed by Alwan (1986:28). When the points of constriction were scaled to the average 18.18 cm vocal tract used in these models, they were 8.019 cm from the glottis for uvular articulations and 3.742 cm from the glottis for epiglottal articulations. The point of constriction for a purely pharyngeal articulation was assumed to lie halfway between these two, and was assumed (after scaling) to be 5.881 cm from the glottis.

To account for raising of the larynx in pharyngeal and epiglottal articulations, which is reported by Esling (2005:21) and measured quantitatively by Alwan (1986:28), a small amount was subtracted from the back cavities associated with those two places. For the pharyngeal articulation, 0.3743 cm was subtracted, while for the epiglottal articulation, 0.7486 cm was subtracted. The subtraction for the epiglottal place of articulation is based on Alwan's (1986:28) measurement of 0.7 cm of larynx raising during Arabic pharyngeal consonants, which she notes are associated with backward and downward movement of the epiglottis. The subtraction for what this study calls the pharyngeal place of articulation is assumed to be 0.35 cm, half of the measured 0.7 cm, in Alwan's model. After scaling 0.35 cm and 0.7 cm to the vocal tract length used in this model (18.18 cm), the subtractions are 0.3743 cm and 0.7486 cm for the pharyngeal and epiglottal places of articulation.

The following table summarizes the parameters used in the acoustic tube models to derive the formant frequencies for the three possible secondary articulations. All the values for these parameters are in centimeters unless otherwise noted.

(5) Parameters Used in Acoustic Tube Models

	Uvularization	Pharyngealization	Epiglottalization
Vocal Tract Length	18.18	18.18	18.18
Point of Constriction	8.019	5.881	3.742
l_c	2.138	1.069	0.535
A_c (in cm^2)	0.275	0.325	0.300
A_b (in cm^2)	2.00	1.75	1.50
Adjustment to Back Cavity	—	-0.3743	-0.7486
Back Cavity Length[4]	6.950	4.972	2.726
Front Cavity Length	9.088	11.761	14.167

Using these parameters, nomograms were produced to derive formant frequencies from the acoustic tube models. These are not shown for reasons of space but are available upon request and can be seen in Sylak (2011). The nomograms varied the point of constriction but held all other values constant. The table below shows the predictions that are compared to the results of acoustic analysis in the next section.

[4] The adjustment for larynx raising is incorporated into these values.

(6) Summary of Predictions

All values in Hz	F1	F2	F3	F2−F1	F3−F1
Uvularization	536	963	2518	427	1982
Pharyngealization	744	1041	2232	297	1488
Epiglottalization	618	1853	2063	1235	1445

3 Acoustic Analysis

3.1 Data

The data for acoustic analysis come from recordings of readings of a wordlist by 5 male native speakers of Chechen originally from the Republic of Chechnya. The wordlist elicited all the "pharyngealized" versus plain consonant contrasts and elicited many of the possible vowels after a glottal stop (a plain consonant) and after an epiglottal stop (which can be thought of as a "pharyngealized" glottal stop; Kingston and Nichols 1987). Praat transcription (Boersma and Weenink 2001) was used to delineate the vowel after a pharyngealized consonant or its plain counterpart since the vowel, especially the first half, is where the effects of "pharyngealization" from a preceding consonant are greatest (Kingston and Nichols 1987; Yeou 2001). These delineated vowels, which were always /aː/ or /a/, were sorted based on the place of articulation of the consonant preceding them (labial, dental, alveolar, or post-alveolar). When the effects of "pharyngealization" on different vowel qualities was being examined, vowels were sorted into the groups front non-low, back non-low, and low because these seem to correspond to three main types of tongue configurations (Ladefoged and Maddieson 1996:284, fig. 9.3). For reference, the following table shows the phonemic inventory of Chechen, following Nichols and Vagapov (2004:21). The segments that were examined in this study are indicated in bold. Where I depart from the phonetic transcription of vowels below in the rest of the study, I indicate the variant that I use in parentheses introduced with an equal sign. This variant conforms to Nichols' and Vagapov's (2004) working romanization.

(7) Phonemic Inventory of Chechen (Nichols and Vagapov 2004:21)

CONS	Labial	Dental	Alveolar	Postalv	Velar	Uvular	Ep/Ph	Glot
Stop	**p** p' **b**	**t** t' **d**	**t͡s** t͡s'	**t͡ʃ** t͡ʃ'	k k' g	q q'	**ʡ**	**ʔ**
Fricative	v		**s** **z**	ʃ **ʒ**	x	ɣ	**ħ**	**h**
Nasal	**m**		**n**					
Liquid		l	r̥ r					
Glide				j (= pal.)				

VOWELS	Front	Front Round	Central/ Back	Back
High	**i iː** ɛ eː	**y** yː		**u uː** **o oː**
Mid	^{i}**ɛ/**^{i}**æ iːe̯** (= **ia ie**)	y̯œ yːo	ʌ/ə(= a)	u̯ɔ uːo̯/uːə̯
Low	**æ**		**a aː(= aa)**	o̯a/ɔ ɔː

3.2 Methods

Praat was used to separate and transcribe C, C_P, and V in contrasting C_PV and CV sequences (C_P = "pharyngealized" consonant). Out of C, C_P, and V, it was V that most often showed a statistically significant difference in its formants between its realizations in a CV and a C_PV sequence. Thus, V was chosen as the object of analysis. Praat's formant tracking and scripting capabilities were used to obtain 10 equally temporally separated measurements for F1-F3 in each V that was transcribed in the relevant C_PV and CV sequences. These measurements were taken in order to gather more accurate data on formant trajectories and were hand-corrected where necessary.

3.3 Analysis

To see how the formant trajectories differed between segments with respect to time, pharyngealization status, speaker, and vowel, linear regression modeling was used.[5] Because the formant measurements were taken over brief time periods (from approximately 55 to 300 milliseconds) for monophthongs, the data for each formant was assumed to be roughly linear. The statistical program R (R Development Core Team 2011) was used to computationally implement the linear regression models. Linear regression models were used to analyze the 10 equally temporally separated values of F1, F2, and F2−F1 according to the consonantal or vocalic subgroup assigned to the data being analyzed. The results of applying linear regression to the F3 data are not reported since the difference between a plain and pharyngealized consonant was almost never found to be significant. F1 and F2 have both been reported to be salient to the perception of "pharyngealized" consonants, as has the value of F2−F1 since it models compaction of the spectrum (Kingston and Nichols 1987). Compaction of the spectrum was identified as an analytically (and probably perceptually) noticeable effect of pharyngealization in Chechen (ibid.).

Because /aː/ or /a/ was the vowel most frequently encountered in data on the consonantal subgroups, vowel quality was not assumed to have a main effect in the

[5] Many thanks to Melinda Woodley for suggesting this method, for helping to implement it, and for advice on how to interpret the results.

models. However, speaker identity was assumed to have an effect since as few as 3 speakers may have provided data for a given "pharyngealized" vs. plain contrast. This could skew the data, and so the effect had to be taken into account. The linear regression model used to analyze the property of interest (F1, F2, F2−F1; abbreviated hereafter as 'PI') for consonantal subgroups was:

(8) PI∼Time*Pharyngealization+Speaker

It was assumed that F1, for example, would start out higher in pharyngealized segments and fall as time passed. Thus, it was assumed that time and pharyngealization would both be main effects and that they would interact, with a given formant measurement (e.g. F1) increasing or decreasing through time in pharyngealized variants but staying constant in plain variants.

For analyzing properties of interest according to vocalic subgroups, the linear regression model that was used is that in (9).

(9) PI∼Time*Pharyngealization+Speaker+Vowel

Because the starting values of the properties of interest were highly dependent on the quality of the vowel being examined, vowel quality was assumed to be a main effect.

3.4 Results

At this point, it is possible to compare the results of acoustic analysis to the predictions made via acoustic tube modeling. In the following discussion, I will proceed from anterior to posterior by place of articulation through the consonantal subgroups and then through the vocalic subgroups in the order front non-low, back non-low, low. For reasons of space, I do not report full results for the linear regression models.[6] Instead, I report the sum of each linear regression model's intercept plus the main effect of "pharyngealization" in order to obtain a value for each formant in each consonantal and vocalic subgroup. The intercept can be thought of as a baseline value that one might expect to occur after a plain consonant. The main effect of "pharyngealization" provides an estimate of how much one can expect the actual formant measurement to deviate from the intercept when the token is after a "pharyngealized" consonant.

Each table in (10)-(16) shows the value (intercept+pharyngealization) from the linear regression model under the label 'Measured,' followed by a reminder of the predictions made by acoustic tube modeling (shown originally in (6)) of the formant values each secondary articulation should yield. Finally, the table shows my judgment of which secondary articulation there is evidence for. Above each table, I show the place of articulation that was analyzed, the segments at that place that

[6] For full results and a longer version of this paper, see Sylak (2011).

were analyzed, and my overall judgement of which secondary articulation is occurring at that place. The table in (17) gives an overall summary of which secondary articulations may be occurring at each place of articulation.

(10) Labial (p, b, m): *Pharyngealization*

	Measured	Uv.	Ph.	Ep.	Secondary Articulation Matched
F1	772.652	536	744	618	Pharyngealization
F2	998.687	963	1041	1853	Uvularization/Pharyngealization
F2−F1	226.035	427	297	1235	Pharyngealization

(11) Dental (t, d): *Pharyngealization*

	Measured	Uv.	Ph.	Ep.	Secondary Articulation Matched
F1	746.493	536	744	618	Pharyngealization
F2	1103.455	963	1041	1853	Pharyngealization
F2−F1	356.961	427	297	1235	Pharyngealization

(12) Alveolar (ʦ, s, z, n): *Pharyngealization*

	Measured	Uv.	Ph.	Ep.	Secondary Articulation Matched
F1	775.962	536	744	618	Pharyngealization
F2	1182.646	963	1041	1853	Pharyngealization
F2−F1	406.684	427	297	1235	Uvularization

(13) Post-Alveolar (ʧ, ʒ): *Epiglottalization* or *Pharyngealization*

	Measured	Uv.	Ph.	Ep.	Secondary Articulation Matched
F1	638.777	536	744	618	Epiglottalization
F2	1144.726	963	1041	1853	Pharyngealization
F2−F1	505.948	427	297	1235	Uvularization

(14) Front, Non-Low vowels (i, iː, y, yː, ia, ie): *Epiglottalization*

	Measured	Uv.	Ph.	Ep.	Secondary Articulation Matched
F1	432.4	536	744	618	Uvularization
F2	1903.353	963	1041	1853	Epiglottalization
F2−F1	1470.953	427	297	1235	Epiglottalization

(15) Back, Non-Low vowels (u, uː, o, oː): *Epiglottalization* or *Pharyngealization*

	Measured	Uv.	Ph.	Ep.	Secondary Articulation Matched
F1	584.099	536	744	618	Epiglottalization
F2	1010.73	963	1041	1853	Pharyngealization
F2−F1	426.631	427	297	1235	Uvularization

(16) Low vowels (a, aː, æ): *Pharyngealization*

	Measured	Uv.	Ph.	Ep.	Secondary Articulation Matched
F1	810.327	536	744	618	Pharyngealization
F2	1144.648	963	1041	1853	Pharyngealization
F2−F1	334.321	427	297	1235	Pharyngealization

(17) Summary of Results of Acoustic Analysis

LABIAL	DENTAL	ALVEOLAR
Pharyngealization	Pharyngealization	Pharyngealization
POST-ALVEOLAR		
Epiglottalization *or* Pharyngealization		

FRONT NON-LOW	BACK NON-LOW	LOW
Epiglottalization	Epiglottalization *or* Pharyngealization	Pharyngealization

3.5 Discussion

What is called “pharyngealization” in Chechen seems actually to be *two* phonetic types of secondary articulation: pharyngealization and epiglottalization. A possible explanation for why these articulations are grouped into one effect (“pharyngealization”) is that they are the results of a single complex of muscle action in and around the tongue. This complex of muscle action produces a tongue configuration that is affected by other muscle actions necessary for achieving the primary articulation of the segment in question. This is what causes “pharyngealization” to be realized variously as both pharyngealization and epiglottalization. Moreover, the complex of muscle action seems to produce consistent acoustic effects (such as elevated F1 and lowered F2; Kingston and Nichols 1987) that are perceived as belonging to a single phonological modification.[7]

One complex of muscle action that could produce what has been called “pharyngealization” in Chechen is the constriction of the inferior pharyngeal constrictor

[7] An alternative explanation may be that pharyngealization and epiglottalization produce similar enough acoustic effects that listeners perceive them as the same articulation.

bringing the tongue back and the vertical muscle flattening the tongue (Abd-El-Malek 1939; Ladefoged et al. 2002). This gives the tongue a flattened, plateau-like shape and causes it to protrude posteriorly toward the pharyngeal wall. A similar tongue configuration is directly attested by Gaprindašvili (1966:14) for Dargi and by Catford (1983) for Udi and Tsakhur, which are all related to Chechen.

Specifically, the complex of muscle action may operate in the following way. When the tongue tip must be brought forward for dental and alveolar articulations, the protrusion of the tongue backward may be hampered. This causes pharyngealization because the tongue protrudes backward, but at a higher point. In addition, because the tongue is flattened to some degree, the back protrusion does not produce uvularization, which would require raising and arching of the tongue. When the tip of the tongue must be raised significantly, as with a post-alveolar consonant, the tongue is still flattened and protruded backward, but epiglottalization is produced because the raising of the tongue tip causes the back protrusion to lower, like a seesaw. With vowels, the tongue cannot be as significantly flattened as it can be with anterior consonants. However, since the tongue's mass is shifted backward, the action of the inferior pharyngeal constrictor is more pronounced. This may be the explanation for why front and back non-low vowels are associated with epiglottalization. With low vowels, the constriction point for the vowel is so near the middle pharynx wall that the inferior pharyngeal constrictor is already constricting to that position, making it unavailable for constriction at another point.

4 Evidence from Chechen Phonology

While the mapping from articulation to acoustics is 1:1 (the same articulation will always yield the same acoustic result), the reverse mapping from acoustics to articulation is 1:*many*. This means that when the results of acoustic analysis match the predictions from acoustic tube models, there is *evidence* for the articulation embodied in the prediction from the acoustic tube model, but not definitive *proof* since another articulation might be able to produce the same acoustic effects. This means that additional evidence must be sought in the absence of articulatory data, and Chechen phonology provides that evidence.

One fact about Chechen phonology that can be explained by the proposed complex of muscle action is the fact that velar and uvular consonants cannot be "pharyngealized" (Nichols 1997:963). With a velar or uvular consonant, the tongue dorsum is forced up to the velum or uvula, but such an upward forcing of the tongue is antithetical to the flattening action that is part of the proposed complex of muscle action. Thus, "pharyngealization" cannot occur with these consonants.

Another fact about Chechen phonology that can be explained with this complex of muscle action is that "pharyngealization" is a free variant of a syllable-initial post-consonantal uvular ejective (Magomedov 2005:125) as in the words *t͡ʃq'or* [t͡ʃˤor] "bark, skin" and *tq'a* [tˤʌ] "twenty" (Nichols and Vagapov 2004:270,405). A possible explanation is that the first consonant positions the tongue for the primary articulation while the uvular stop positions the tongue dorsum in its uppermost and backmost position (at the uvula). If a speaker relaxes the uvular articulation, the tongue dorsum falls and is susceptible to being flattened by the relaxation of the transversal muscles, yet the tongue is still far back. In addition, the larynx raises in preparation for the ejective release of /q'/, which creates an acoustic effect similar to pharyngealization or epiglottalization, since these are accompanied by larynx raising (Esling 1996; Alwan 1986). This creates an effect similar enough to that created by the proposed complex of muscle action that speakers hear "pharyngealization," although in fact the tongue may not be actively flattened by the vertical muscle or pulled posteriorly by the constriction of the inferior pharyngeal constrictor. The proposal of a specific complex of muscle action seems to be supported both by predictions from acoustic tube modeling and by evidence from Chechen phonology.

5 Conclusion

By examining "pharyngealization" in detail, this study has shown that the pharyngeal and epiglottal places of articulation are not phonologically contrastive in Chechen, as opposed to what has been claimed for Agul (Ladefoged and Maddieson 1996:37-8). In addition, it has been shown that "pharyngealization" varies freely with a uvular articulation, /q'/, in the post-consonantal position of a syllabic onset. From these facts, one can infer that the phonetically uvular, pharyngeal, and epiglottal places of articulation are phonetically and phonologically grouped together, at least by the phenomena shown. I interpret this as evidence supporting the existence of a GUTTURAL natural class in Chechen (McCarthy 1994). If one chooses to interpret the evidence this way, as I do, then "pharyngealization" is better viewed as *gutturalization*, since "pharyngealization" has been shown here to involve both phonetic pharyngealization and epiglottalization.

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