

# Chapter 15

## Segmental Phonetics and Phonology in Caucasian languages

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### Abstract

This chapter surveys the major topics of Caucasian segmental phonetics and phonology, focusing on topics with broader implications for general phonetic and phonological theory. The author first presents an acoustic phonetic analysis of phonemic inventories in the three Caucasian families, including both a review of recent instrumental data on the topic as well as a new analysis of new and existing experimental acoustic data. This analysis focuses on four primary topics: obstruents with different laryngeal features, typologically unusual segments, small vocalic inventories, and pharyngealization. The new acoustic data from a nonce-word experiment in Georgian and Megrelian offer evidence that aspiration in voiceless stops gradually, yet significantly shortens if another voiceless stop precedes the relevant one in a given word. The second part reviews analyses of Caucasian phonotactics, primarily of South Caucasian consonant clusters that play a crucial role in discussions on production versus perception in phonology. The chapter concludes with a collection of phonological alternations that have potential for future research on phonology. Keywords: acoustic phonetics, naturalness in phonology, laryngeal features, consonant clusters, ejective obstruents, double articulation, aspiration dissimilation, pharyngeals, epiglottals, final voicing

### 1 Introduction

Prominent characteristic features of Caucasian phonetics and phonology include large consonantal versus small vocalic inventories in Northwest Caucasian, extensive consonant clusters in Kartvelian, and a large number of phonemes with place of articulation in the postvelar parts of the vocal tract in Nakh-Dagestanian languages. Common to all three families is a three-way distinction in the laryngeal features of obstruents, with ejectives. It is safe to say that beyond these focal topics, segmental phonetics and phonology of Caucasian languages are severely

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<sup>1</sup> Note: some references might be missing in the preprint version. Check the published version.

understudied. This chapter outlines the main characteristics of Caucasian phonetics and phonology, focusing on processes that bear broader implications for general phonetics and phonological theory. Many questions remain open even for the well-studied aspects of Caucasian phonology. For some of these questions, I have tried to offer new insights using experimental data or relying on the reanalysis of existing data. I also discuss areas of Caucasian phonology that went largely unnoticed but have a potential to provide insightful and broadly relevant results with future research.

Many treatments of Caucasian phonology include detailed qualitative phonetic descriptions, but quantitative acoustic analyses are still lacking with few notable exceptions. Section 15.2 is an attempt to fill this gap; for each language family, I discuss aspects of consonantal and vocalic inventories that are most relevant for phonetic typology. I present new experimental data for Kartvelian: for the purpose of examining various aspects of Kartvelian phonetics, I conducted an experiment involving 12 speakers of Georgian and one speaker of Megrelian (Beguš, 2017). For Northwest Caucasian, I present new analyses of already existing data, primarily from Ubykh. Section 15.3 describes the phonotactics and focuses on Kartvelian consonant clusters, which have played a major role in the development of articulatory approaches to phonology and are relevant for the discussion on the role of production versus perception in phonology. The final section discusses active phonological alternations in Caucasian languages, including those that received due attention as well as those that went largely unnoticed but are directly relevant to the focal topics of current phonological theories.

## 2 Phonemic Inventories

This section discusses the main characteristics of phonemic inventories across the three Caucasian families.

### 2.1 Kartvelian

Phonemic inventories are relatively similar across the Kartvelian family. The main characteristics are the symmetrical five-vowel system, a three-way opposition in laryngeal features of stops and affricates (voiced, voiceless aspirated, ejective), and a two-way opposition of laryngeal features in fricatives (voiced and voiceless). The common places of articulation are bilabial, labio-dental, dental or alveolar, post-alveolar, velar, uvular, and glottal. Table 15.1 illustrates the Kartvelian languages' consonantal inventories; Table 15.2 presents their vocalic inventories.

/χ, ʁ/ are usually analyzed as velar /x, ɣ/ in Georgian and Megrelian. /q/ is limited to Svan, /j/ is absent from Georgian, /ʔ/ is a phoneme only in Megrelian. Svan has /w/ instead of /v/; in Laz and Megrelian, [v] and [w] are allophonic.

Table 1: Combined consonantal inventories of Kartvelian languages.

	bilab.	l.-d.	dent.	alveo.	post-al.	pal.	vel.	uvul.	glot.
stop	p <sup>h</sup> , b, p'		t <sup>h</sup> , d, t'				k <sup>h</sup> , g, k'	q, q'	ʔ
affricate				ts, dz, ts'	tʃ, dʒ, tʃ'				

nasal	m		n			
tap/trill			r/r			
fricative		v	s, z	ʃ, ʒ		χ, ʁ h
approx.					j	
lat. appr.			l			

Note: Harris (1991c); Lacroix (2009); Shosted and Chikovani (2006); and Tuite (1998a).

		front		central		back
	high	i (y)				u
	open-mid		ɛ (œ)	ə		ɔ
	low		(æ)	ɑ		

Table 2: Kartvelian vowel inventories

Note: Holisky (1991), Shosted and Chikovani (2006).

Georgian and Laz have five-vowel systems: /a, ɛ, ɔ, i, u/. Schwa is limited to Svan and Megrelian; in the latter, it is a back vowel (Harris, 1991c). Svan also has fronted /æ, oe, y/ (by umlaut; Tuite, 1998a). Upper Bal and Lashx dialects of Svan additionally feature length opposition (Tuite, 1998a).

Laryngeal features are among the better-studied aspects of Kartvelian phonetics. This is not surprising, as Georgian is one of the more accessible languages with ejective stops. This section focuses on laryngeal features and discusses crucial information that these languages bring for phonetic typology of ejective obstruents. I survey previous acoustic data on laryngeal features in Kartvelian and provide new information on phonetics of ejective, aspirated, and voiced stops in Georgian.

### 2.1.1 Phonation

The exact phonetic realization of the three laryngeal features is subject to extensive debate. The first point of dispute is the phonetic realization of Georgian voiced series of stops (Butskhrikidze, 2002; Grawunder, Simpson, & Khalilov, 2010; Shosted & Chikovani, 2006; Vicenik, 2010; Wysocki, 2004). While most studies analyze the voiced series as phonetically voiced (Shosted & Chikovani, 2006; Vicenik, 2010), recurring proposals have claimed that voiced stops are phonetically voiceless and characterize the Georgian voiced/voiceless-aspirated opposition in terms of presence or absence of aspiration (Robins & Waterson, 1952; Wysocki, 2004).

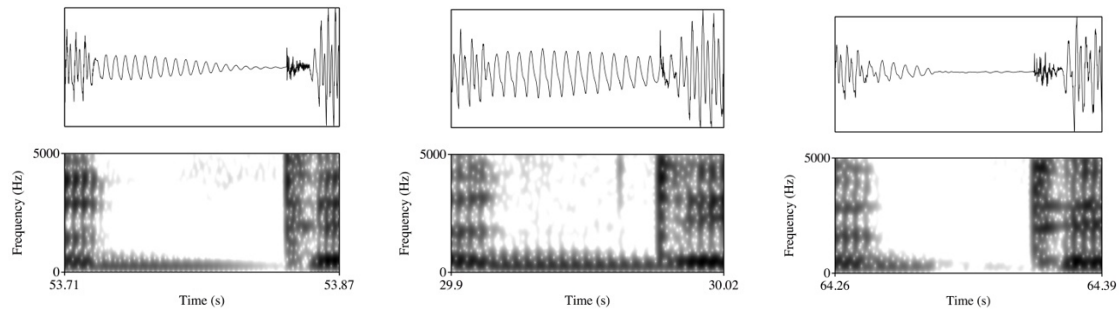
Wysocki (2004) argues in favor of the latter approach and bases their claims on the fact that the phonetic realization of most absolute initial voiced stops features no phonation during closure. However, it is not clear that absolute word-initial position should be representative; phonation is dispreferred in absolute initial position for articulatory reasons (Davidson, 2016; Solé, 2011). Vicenik (2010) measured the rate of phonation into closure in Georgian post-vocalic stops, word-initially and wordfinally. On average, 75% of closure is voiced in voiced stops,

compared to 17% in voiceless aspirated and 27% in ejectives. The difference in voicing into closure between voiced versus voiceless stops/ejectives is significant, the difference among the latter two is not, for most places of articulation. Vicens (2010) measures voicing into closure as a function of prosodic position: voicing into closure does not differ significantly in word-initial position after a vowel-final carrier phrase versus word-medial intervocalic position; the rates of voicing during closure do not significantly differ between the two conditions, except for velar stops. For velars, a significantly greater proportion of closure is voiced intervocalically, but the absolute duration of voicing during closure remains the same (Vicens, 2010).

Our experimental data align well with these results. Twelve speakers of Georgian were instructed to read 675 nonce words of the structure CVCVCV. Voicing into closure was not quantified in the study, but acoustic inspection aligns well with the conclusion that the “voiced” series of stops in Georgian is in fact phonetically voiced in intervocalic position. Impressionistically, most speakers have at least half of the closure or more voiced (Figure 15.1). Based on these observations and backed by the study in Vicens (2010), we can maintain the analysis that the unaspirated series of Georgian stops is phonetically and phonologically voiced: the amount of phonation into closure is substantial enough and significantly different for voiced stops compared to ejectives and voiceless aspirated that it likely does not result from automatic phonetic voicing in postvocalic position (cf. Wysocki, 2004).

Our recordings also reveal an aspect of voiced-stop realization that received less attention so far but has the potential to shed further light on the system of laryngeal features in Georgian. There exists a good amount of variation in the realization of voiced stops among speakers, but relatively little within-speaker variation (although this observation is not quantified in our study). Speakers vary in the production of the intervocalic voiced stops to the degree that for some speakers, closure is consistently fully voiced, whereas for others, almost no phonation into the closure is present. Spectrograms and waveforms in Figure 15.1 illustrate this variation. Inter-speaker variation in the production of voiced stops warrants further study. Variation in stop production is attested not only for the voiced series but also for ejectives and aspirated stops. A study that would test potential correlations between inter-speaker variability in closure voicing with other phonetic parameters, such as VOT and burst intensity of the other two series of stops is lacking and would shed light on the otherwise unclear distributions.

A related issue has to do with what perceptual cues speakers employ in distinguishing stops with different laryngeal features (Vicens, 2010). It is possible that VOT duration (or presence/absence of aspiration noise) is a more prominent cue than voicing into closure. Such a hypothesis, however, should be tested with perceptual experiments. To my knowledge, no such studies exist for any of the four languages.



**Figure 1:** Waveforms and spectrograms of voiced stop [d] in the word [lixode] uttered by three different speakers

### 2.1.2 Phonetic properties of other laryngeal features

Three of more recent studies on Georgian phonetics present detailed acoustical analysis of stops with respect to their laryngeal features (Grawunder, Simpson, & Khalilov, 2010; Vicenik, 2010; Wysocki, 2004). Of the seven parameters measured (closure duration, VOT, voicing into closure, relative burst intensity, F0, phonation type of the following vowel, and spectral measures of the burst) in Vicenik (2010), only VOT duration and phonation type reliably distinguish all three stop types in Georgian. VOT is longest in the voiceless aspirated series, shorter in ejectives, and shortest in voiced stops. Vowels have significantly creakier phonation after ejectives and more breathy phonation after voiceless aspirated stops. Voicing into closure distinguishes voiced stops from voiceless aspirated and ejectives, but not ejectives from voiceless aspirated. F0 in the following vowel falls for voiced and voiceless aspirated but stays flat after ejectives; yet this difference does not reach significance for all places of articulation. Mean frequency, skewness, and kurtosis of the burst were significant predictors for only a subset of places of articulation, according to Vicenik (2010).

While several results in Wysocki (2004) and Vicenik (2010) are replicated in our experiment, some are different. Our analysis confirms that stops with different laryngeal features have significantly different VOT durations. We measured the VOT of the third stop in nonce words of the CVCVCV structure, testing three places of articulation (bilabial, dental, velar) and three laryngeal features (voiced, voiceless aspirated, ejective). VOT was significantly longer in voiceless stops compared to ejectives ( $\beta = 36.1$  ms,  $t = 9.8$ ,  $df = 11$ ,  $p < 0.0001$ ) and significantly shorter in voiced stops compared to ejectives ( $\beta = -18.1$  ms,  $t = -6.1$ ,  $df = 11$ ,  $p < 0.0001$ ) at the means of other predictors (Beguš, 2017).

Wysocki (2004), Vicenik (2010), and Grawunder, Simpson, & Khalilov (2010) all claim that closure duration does not significantly differ across stops with different laryngeal features. This is a surprising result as we know that closure duration of voiced stops is cross-linguistically shorter at least compared to closure of voiceless stops (Lisker, 1957; Luce & Charles-Luce, 1985; Port, 1981). The results of our experiment, however, show a significant effect of laryngeal features on closure duration. Closure duration is significantly shorter in voiced stops than in

ejectives ( $\beta = -5.0$  ms,  $t = -3.3$ ,  $df = 20$ ,  $p < 0.01$ ) and significantly longer in ejectives than in voiceless aspirated stops ( $\beta = 3.7$  ms,  $t = 3.0$ ,  $df = 17$ ,  $p < 0.01$ ) at means of other predictors (Beguš, 2017).

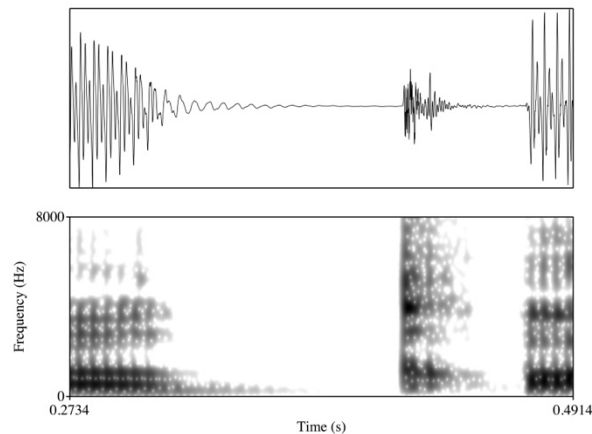
This difference in closure durations between ejective and voiceless aspirated stops is, to my knowledge, reported for the first time not just for Georgian but for ejective stops in general. Warner (1996) measures closure duration in ejective versus voiceless stops in Ingush. Closure duration was indeed shorter in plain unaspirated voiceless stops, but the difference did not reach statistical significance. These measurements are based on recordings of only one speaker.

Gordon and Applebaum (2006) measured closure duration of stops in Kabardian. They find a significant effect of laryngeal features on closure duration, but the difference is significant only for the difference between voiced and ejectives, not between ejectives and voiceless aspirated stops. Maddieson, Rajabov, and Sonnenschein (1996) measured closure duration and VOT of voiceless and ejective stops in Tsez and found no significant differences between the two groups for either of the measured parameters. McDonough and Ladefoged (1993) found no differences in closure duration between ejective and voiceless aspirated or unaspirated stops in Navajo, but unaspirated stops have significantly longer closure durations than aspirated stops. Similar results are obtained for Athabaskan Witsuwit'en in Hargus (2007): closure is longest in unaspirated voiceless stops, but there is no significant difference in closure duration between voiceless aspirated and ejective stops.

The differences in closure durations across different stop types, despite being significant, are relatively small in Georgian. We can safely maintain that such small differences do not provide a prominent perceptual cue: in fact, they fall below the Just-Noticeable Difference ratio for vocalic speech stimuli (about 0.055 in Nooteboom & Doodeman, 1980). The ratio of closure duration difference between ejective and aspirated stops compared to the full closure duration is 0.045 in our case (i.e., below 0.055).

Wysocki (2004) offers a detailed qualitative analysis of ejective stops in Georgian. Realization of ejective stops is highly variable across speakers. Ejective stops feature an audible oral release that is often higher in amplitude than the first period of the following vowel. Oral release is followed by a period of silence that is interrupted by one or more glottal releases that precede the vowel onset (Wysocki, 2004). Figure 15.2 illustrates acoustic characteristics of an ejective stop in Georgian.

Shosted and Chikovani (2006) also provide a qualitative airflow analysis of different stop types in Georgian. Oral air flow of three initial dental stops are measured. Ejective stops feature a relatively small rise in airflow that rapidly drops back to the zero level before the onset of the vowel. This fall results from glottis being closed after the oral release: once the air flow between oral closure and glottal closure is released, glottal closure prevents further airflow until it is released and the vowel onsets. Volume of the ejective oral release is considerably lower than airflow volume of voiced stops or voiceless aspirated stops. The latter have the highest volume of air flow, although the distribution is not quantified in Shosted and Chikovani (2006).



**Figure 2:** Waveform and spectrogram of a velar ejective stop in the nonce word [ɔkʰɔpʰu] uttered by a female speaker

### 2.1.3 Ejective stops and vowel duration

Vowel durations have long been known to differ before voiced and voiceless obstruents: vowels are longer before voiced than before voiceless obstruents and this generalization has been confirmed for over a dozen languages (cf. Chen, 1970, among others). The causes of these durational differences are, however, poorly understood, and several competing explanations have been proposed (Beguš, 2017). Opposing explanations arise primarily because most studies just measure vowel duration before voiced and voiceless obstruents and disregard vowel duration before obstruents with other laryngeal features. Only a subset of the studies measure vowel duration as a function of aspiration of the following stop. While most studies argue that aspiration lengthens the preceding vowel, some results are inconclusive (Durvasula & Luo, 2014; Lampp & Reklis, 2004; Maddieson & Gandour, 1976; Ohala & Ohala, 1992). Measurements of vowel duration before ejective stops are lacking altogether. Georgian is especially informative in this respect as it features voiceless aspirated, ejective, and voiced stops, which makes it possible to measure vowel duration differences before stops with all three laryngeal features.

Beguš (2017) presents results from the experiment described above with nonce words of the structure CVCV<sub>x</sub>C<sub>y</sub>V: vowel duration of V<sub>x</sub> was measured along with the closure duration and VOT of C<sub>y</sub>. V<sub>x</sub> included three vowels ([ɑ], [ɛ], and [ɔ]) and C<sub>y</sub> involved all three laryngeal features and three places of articulation (3 × 3 levels).

A model with four predictors (Laryngeal Features, Vowel, Place, and Closure duration) reveals that vowels are significantly longer before voiced stops compared to ejectives ( $\beta = 8.7$  ms,  $t = 7.1$ ,  $df = 10$ ,  $p < 0.0001$ ) and significantly shorter before voiceless aspirated stops compared to ejectives ( $\beta = -4.7$  ms,  $t = -7.2$ ,  $df = 11$ ,  $p < 0.0001$ ) (Beguš, 2017). This generalization is called the “ejection effect” and is, to my knowledge, reported for the first time, based on Georgian material. Closure duration is significantly, but only slightly negatively correlated with preceding vowel duration (for ejective stops,  $\beta = -1.8$ ,  $t = -2.4$ ,  $df = 21$ ,  $p < 0.05$ ; Beguš, 2017). There is a significant interaction between Laryngeal Features and Closure: closure

duration is significantly more negatively correlated with preceding vowel duration in voiced stops compared to ejectives.

Our experimental design also allowed us to model duration of VOT and its effect on preceding vowel duration. As shown in section 15.2.1.2, VOT significantly differs across stops with different laryngeal features. It is thus conceivable to assume that VOT duration is the primary factor that determines preceding vowel duration. The results in Beguš (2017), however, show that laryngeal features remain significant predictors even if we add VOT to the model. Vowels are longest before voiced, shorter before ejective, and shortest before voiceless aspirated stops. In addition, closure and VOT both inversely affect preceding vowel duration (Beguš, 2017).

As argued in Beguš (2017), the “ejection effect” has broader implications: it shows that laryngeal features are significant predictors of preceding vowel duration, even when effects of closure and VOT are controlled for. Several competing proposals exist for the causes of vowel duration differences before different stop types (Beguš, 2017; Chen, 1970). The results show that voice feature or closure duration alone cannot be the cause of vowel duration differences. Moreover, because laryngeal features remain significant predictors even when VOT and closure duration are controlled for, and because the durational differences are small (smaller than the Just-Noticeable difference threshold), perception is likely not the primary factor for durational differences. The “ejection effect” primarily supports two hypotheses. The first is the Laryngeal Accommodation hypothesis (Chomsky & Halle, 1968), according to which laryngeal features require complex laryngeal gestures which in turn require different times to achieve. The second is the Timing hypothesis (Kozhevnikov & Chistovich, 1967), which states that timing across syllables tends to be constant: longer closure or VOT duration is compensated with shorter vowel duration. Several factors may influence vowel duration and the new data from Georgian crucially contributes to the discussion on causes of durational differences in vowels (Beguš, 2017).

#### 2.1.4 Aspiration

Georgian voiceless aspirated stops are another aspect of Georgian phonetics that is relevant for the discussion of the role of perception versus production in phonetics. Aspirated stops in Georgian are characterized by long VOTs with high oral airflow (Shosted & Chikovani, 2006). Least-square mean VOT duration of voiceless aspirated stops in our experiment (involving 2,630 tokens of aspirated stops in position CVCVCxV across the three places of articulation) is 75.4 ms (70.4 ms for labials, 72.8 ms for dentals, and 83.0 ms for velars).

Georgian with its prominent aspiration provides insights into a process that has received increased attention, especially recently (Garrett, 2015; Jatteau & Hejná, 2016; Ohala, 1993): aspiration dissimilation (AD)—dissimilation of two subsequent aspirated stops ( $T^h \dots T^h > T \dots T^h$  or  $T^h \dots T$ ). While AD is well-documented and relatively common process, mechanisms that underlie it are poorly understood. Two lines of thought emerge in the discussion. Ohala (1993) explains the dissimilation in terms of perceptual hypercorrection: speakers assume that aspiration of the two subsequent stops is a result of assimilation and “undo” this assimilation. Garrett (2015), on the other hand, claims that motor planning errors are responsible for gradual shortening of aspiration, which over time results in aspiration dissimilation. The articulatory

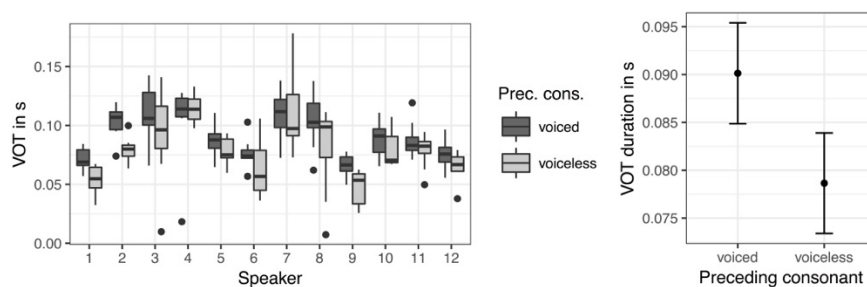


explanation predicts gradual and small phonetic differences in VOT duration, while the perception explanation predicts catastrophic and total dissimilation. Gradual and small-magnitude shortening of VOT supporting the articulatory explanation have already been reported for Aberystwyth English (Jatteau & Hejná, 2016) and Halh dialect of Mongolian (Svantesson & Karlsson, 2012). In both Halh and Aberystwyth English, however, the second stop is pre-aspirated and not post-aspirated, which means that the measured aspiration duration in these languages surfaces on the same vowel. Differences in aspiration duration have not yet been established for a language with only post-aspirated stops (Jatteau & Hejná, 2016), such as Georgian.

To test the effect of preceding aspiration on VOT of the following aspirated stop, we measured VOT duration of voiceless aspirated stops at three places of articulation, after three vowels ([ɑ], [ɛ], and [ɔ]) in Georgian. The VC<sub>x</sub> sequences were embedded into two frames: [rub\_i] and [voth\_i], i.e., a frame in which the first part ends in a voiced stop and a frame with the first part ending in a voiceless aspirated stop. VOT of C<sub>x</sub> was measured from the onset of oral release until first periodic vibration with clear formant structure of the following vowel. Altogether 213 tokens were analyzed. VOT was shorter in voiceless stops that were preceded by another voiceless aspirated stop. Figure 15.3 illustrates by-speaker differences in VOT duration as a function of preceding stop.

The data were fit to a linear mixed effects model<sup>2</sup> with preceding consonant Type, preceding Vowel, and Place of articulation with Vowel × Place interaction as fixed effects and a random intercept for Speaker. VOT is significantly shorter if another voiceless stop precedes ( $\beta = -11.5$  ms,  $t = -4.6$ ,  $df = 192$ ,  $p < 0.0001$ ).

The results bear implications for understanding of mechanisms behind aspirate dissimilation process and for the discussion on perception versus production in phonetics: the gradual effect of dissimilation of two post-aspirated stops in our experiment renders support for the articulatory explanation.



**Figure 3:** Boxplot of VOT duration across 12 speakers (top chart) and the effect of preceding consonant on VOT duration obtained from a linear mixed effects model with standard error bar.

<sup>2</sup> The linear mixed effects model was fit using the lme4 (Bates, Maechler, Bolker, & Walker 2015) and lmerTest (Kuznetsova, Brockhoff, & Christensen, 2016) packages in R statistical software (R Core Team, 2016).

### 2.1.5 Megrelian, Laz, and Svan

The other three Kartvelian languages have similar phoneme inventories as found in Georgian (see Tables 15.1 and 15.2), but have received considerably less attention. A detailed phonetic analysis of Megrelian and Laz phoneme inventory is offered among others in Imnadze (1981). Lacroix (2009) describes the Arhavi dialect of Laz, and Öztürk and Pöchtrager (2011) describe the Pazar dialect of Laz.<sup>3</sup>

While phonemic inventories are similar across Kartvelian, the phonetic realization of phonologically identical segments can differ substantially, even in closely related languages or even between different dialects of the same language. Melikishvili et al. (2011) measure several acoustical parameters of ejective stops across Caucasian languages, including Northwest Caucasian and Nakh-Dagestanian languages. The results suggest that the phonetic realization of ejective stops differs across dialects and languages. The longest VOT was measured in Svan with 49 ms and the shortest, in the Gurian dialect and standard Georgian, 26 ms and 25 ms, respectively (Melikishvili et al., 2011). Contrastive studies are helpful for the development of the typology of ejective stops (Grawunder, Simpson, & Khalilov, 2010; Kingston, 2005), but further studies with statistical analysis are needed to confirm differences in phonetic realization of ejectives across Caucasian languages and dialects.

In addition to the 12 speakers of Georgian, I also recorded a male speaker of Megrelian reading the same 675 nonce words, but in a Megrelian carrier phrase. The confound of the Megrelian experiment is that it only includes one speaker who reported to speak Georgian as a first language and who spoke Megrelian in his home village with grandparents and relatives. For the Megrelian speaker too, vowels are shorter before voiceless stops than before ejectives ( $\beta = -5.1$  ms,  $t = -2.1$ ,  $df = 623.1$ ,  $p < 0.05$ ) and longer before voiced stops than before ejectives ( $\beta = 28.4$  ms,  $t = 8.4$ ,  $df = 613.4$ ,  $p < 0.0001$ ) at the means of other predictors. This suggests that the ejection effect may be universal, at least for languages with similar realization of ejective stops to those of Georgian and Megrelian (Beguš, 2017)

### 2.2 Northwest Caucasian

A prominent feature of Northwest Caucasian languages has to do with their large consonantal and small vocalic inventories, shown in Tables 15.3 and 15.4 (see chapter 9; for counts, see Catford, 1977).

	bilab.	l.-d.	alv.	alv.- pal.	post-al.	post-al.	pal.	vel.	uvul.	phar.	glot.
stop	p, b, p'		t, d, t'					k, g, k'	q, q'		(?)
labial.	(p <sup>w</sup> )		t <sup>w</sup> , d <sup>w</sup> , t <sup>w</sup> '					k <sup>w</sup> , g <sup>w</sup> , k <sup>w</sup> '	q <sup>w</sup> , q <sup>w</sup> '		(? <sup>w</sup> )

<sup>3</sup> René Lacroix has also created and shared one of the largest databases of any Caucasian languages: Pan-dialectal documentation of Laz [<https://elar.soas.ac.uk/Collection/MPI546814>] is an online database of 230 hours of high-quality recording of four dialects of Laz with over 360 speakers recorded.



This section focuses on acoustic phonetic aspects of large phonemic inventories; NWC languages feature several typologically highly unusual segments that had been considered impossible or unattested until they were discovered precisely in these languages. Where available, I present a new acoustic analysis of typologically rare segments based on existing recordings of Ubykh from online databases LaCiTO<sup>4</sup> and the UCLA Phonetics Lab Archive. I provide statistical analyses for observations that have already been established but have not yet received quantified treatments. I also present an acoustic analysis of small vocalic inventories that are highly variable and co-articulatorily influenced by the large consonantal inventories.

Among NWC, Ubykh stands out as the system with the highest number of consonantal phonemes: 80–85 (depending on the analysis; Fenwick, 2011). Moreover, Ubykh has the highest number of consonantal phonemes of any language without clicks. It features three laryngeal features: voiced, voiceless, and ejective; four secondary articulations: palatalized, labialized, pharyngealized, and labialized and pharyngealized; six manners of articulation: stop, fricative, affricate, nasal, approximant, and trill; and ten places of articulation: bilabial, labiodental, alveolar, alveolo-palatal, two post-alveolar series (one of which is analyzed as retroflex or subapico-palatal), palatal, velar, uvular, and glottal (Colarusso, 1988; Fenwick, 2011). Descriptions vary in their analysis of Ubykh places of articulation, but they all point to a disproportionately high number of segments in the post-alveolar and uvular regions. Other NWC languages additionally feature pharyngeal place of articulation.

-low    ə  
+low    a

Table 4: A typical NWC vocalic inventory consisting of only two phonemic vowels

Note: Colarusso (1988). See section 15.2.2.3 for discussion

### 2.2.1 Typologically rare segments

Unique to Ubykh is a complete series of plain, pharyngealized, labialized, and labialized and pharyngealized uvulars that include voiceless aspirated and ejective stops as well as voiceless and voiced fricatives (Colarusso, 1988). These oppositions result in segments as typologically unusual as the labialized pharyngealized uvular ejective [q<sup>sw</sup>']. It has been hypothesized that “rounding and pharyngealization are never distinctive within a language” (Jakobson, Fant, & Halle, 1951, cited in Colarusso, 1988, p. 221). As shown by [q<sup>sw</sup>'] and other labialized pharyngealized consonants, Ubykh as well as some dialects of Abkhaz and Abaza (Chirikba,

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<sup>4</sup>The LaCiTO database is available online: [http://lacito.vjf.cnrs.fr/pangloss/corpus/list\\_rsc\\_en.php?lg=Ubykh&aff=Ubykh](http://lacito.vjf.cnrs.fr/pangloss/corpus/list_rsc_en.php?lg=Ubykh&aff=Ubykh).

2003a) can feature both secondary articulations on a single segment. To my knowledge, no language outside the NWC family features simultaneous labialization and pharyngealization.

On the other hand, some of the most common stops, such as plain voiceless or voiced velars /k/ and /g/ are marginal in Ubykh (as well as in Kabardian), appearing only in one loanword each (Colarusso, 1988). Such mismatches between cross-linguistic frequency and markedness are relevant for general constraint architecture of Optimality Theoretic frameworks (Prince & Smolensky, 2004). Currently, the most widely accepted version of Optimality Theory and Harmonic Grammar with restricted Con predicts less marked segments will be more frequent in a given environment (Beguš & Nazarov, 2017; Hayes, 2016). Languages such as Ubykh pose a problem for such predictions. Further experimental work is needed to confirm that speakers internalize such “unnatural” restrictions.

Unique to the Abzakh dialect of Adyghe are glottal stops with two secondary articulations: the dialect features a contrast between plain /ʔ/, labialized /ʔ<sup>w</sup>/, and palatalized /ʔ<sup>i</sup>/ glottal stops (Catford, 1983). Secondary articulations on glottal stops are rare: palatalized /ʔ<sup>i</sup>/ was even considered impossible (Merlingen, 1977, cited in Catford, 1983) until the segment was discovered in Abzakh. Catford (1983) presents spectrograms of plain versus palatalized glottal stop: his analysis confirms an acoustic distinction between the two phonemes that is reflected in the formant structure of the following vowel, although the effects are phonetically weak. Labialized alveolar obstruents are a prominent feature of NWC languages. Labialization in alveolar stops is realized as labial closure, and in fricatives as labial frication. For example, /t<sup>w</sup>/ is realized as a typologically rare doubly articulated bilabio- alveolar [t̪p̪].

Ubykh and Abkhaz have doubly articulated bilabio-alveolar stops (Colarusso, 1988). For the purpose of examining acoustic properties of labialized alveolars in NWC, we analyze recordings of Tevfik Esenç uttering words /dwa/ ‘awl’ and /da/ ‘now’ in isolation (from the LaCiTO online database). Figure 15.4 shows spectrograms of these words. The labialized alveolar is realized as a doubly articulated stop ([d̪b̪]). While it is possible that the weak but abrupt rise in energy at about 15 ms before the full release in the spectrogram for /dwa/ shows an alveolar release (before the labial release), further and more accurate recordings and articulatory data are needed to confirm this analysis. The formant structure provides cues for acoustic disambiguation of /d/ and /d<sup>w</sup>/: we observe lowering of all formants for the labialized stop, but especially of F3 and F4.

To test effects of doubly articulated stops on formants of the following vowel, we measured formant values in the same recording from the LaCiTO database that contains three repetitions of /dwa/ and two repetitions of /da/. Formants at 5% of vowel duration were measured in Praat (Boersma & Weenink, 2015) with a modified Vowel Analyzer Praat script (Riebold, 2013). Labialization lowers F2 ( $Z = 1.86$ ,  $p = 0.1$ ) and F3 ( $Z = 1.74$ ,  $p = 0.2$ ), but with such small sample size, no differences are significant (according to the Exact Two-Sample Fisher–Pitman Permutation Test, based on the `oneway_test` function from the `coin` package; Hothorn, Hornik, van de Wiel, & Zeileis, 2008). Further data with larger sample sizes in Abkhaz should yield more conclusive results.

Labialized alveolar stops (/d<sup>w</sup>/) that are realized as doubly articulated stops [ $\widehat{db}$ ] also appear acoustically distinct from plain labials (/b/). A recording of Ubykh words /abana/ and /adwana/ from the LaCiTO database was analyzed. The recording contains three tokens of each word. F1 is lower at 5% of vowel duration after /d<sup>w</sup>/ compared to position after a plain labial ( $Z = 2.06$ ,  $p = 0.1$ ). F3 likewise lowers after /d<sup>w</sup>/ ( $Z = 2.20$ ,  $p = 0.1$ ). F2, however, is higher after /d<sup>w</sup>/ compared to /b/ ( $Z = -2.05$ ,  $p = 0.1$ ), but none of these differences reach statistical significance. Acoustically distinct is also the vowel preceding /d<sup>w</sup>/, compared to the vowel preceding /b/, but again the differences are not statistically significant (according to the Permutation Test).

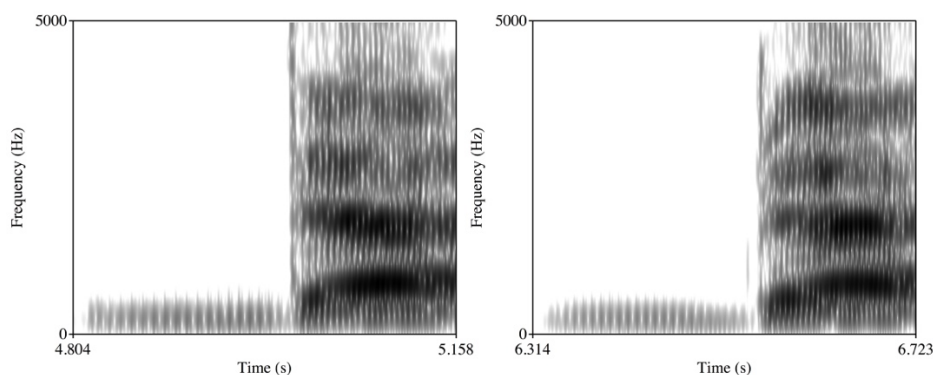
Based on the analysis above, we can conclude that Ubykh indeed has bilabio-alveolar doubly articulated stops. While doubly articulated stops involving velar and labial closure are not infrequent, those involving labial and alveolar closure are very rare. It has even been claimed that no language features a bilabio-alveolar doubly articulated stop as a contrastive phoneme (Maddieson, 1983). In light of these claims, Ladefoged and Maddieson (1996) suggest that double articulation in Caucasian might be better analyzed as secondary articulation, based on the articulatory description from Catford (1972; via Ladefoged & Maddieson, 1996), who claims that labial contact in the closure of doubly articulated stops is “light,” lips are protruded further forward, and contact is made with the inner part of the lips. It is not immediately clear, however, why these articulatory properties described in Catford (1972) would necessarily point to an analysis with secondary articulation. It is also unclear what counts as a distinctive criterion for distinguishing secondary articulation with complete closure from “true” double articulation.

Since Maddieson (1983), other cases of bilabio-alveolar doubly articulated stops have been found: Ladefoged and Maddieson (1996) present an analysis of Yelentye (spoken in Papua New Guinea) as featuring truly bilabial-alveolar doubly articulated stops. Most analyses in the literature thus rightfully maintain the double articulation status of labialized stops in NWC.

While voiceless and voiced doubly articulated bilabio-alveolar stops are featured in other languages such as Yelentye, no language outside NWC features doubly articulated bilabio-alveolar ejective stops, such as Ubykh [ $\widehat{tp}$ ’].

Further articulatory studies of labialized alveolars, especially of the ejective series, in languages such as Abkhaz, where labialized alveolars are also realized as doubly articulated stops, should reveal further information about phonetic properties of these rare segments.

The realization of labialized dentals in NWC also provides evidence for diachronic origins of doubly articulated stops, which has, to my knowledge, not been discussed so far. Ubykh and Abkhaz examples point to one potential source of doubly articulated stops: labialization as secondary articulation.



**Figure 4:** Spectrograms of /da/ ‘now’ (left) and /d<sup>w</sup>a/ ‘awl’ (right)

### 2.2.2 Fricatives

Another prominent feature of NWC phoneme inventories is the presence of a high number of fricative phonemes. As summarized in Catford (1977) and Gordon and Applebaum (2013), a canonical NWC inventory includes four sibilant fricative series: “apico- or lamino-alveolar” /s/, alveolo-palatal /ç/, “apico-postalveolar (slightly velarized)” /ʃ/ (sometimes analyzed as retroflex, e.g., in Fenwick, 2011), and the “peculiar NWC sibilant” /ʂ/. This latter is described as “laminal closed post-alveolar” (in Ladefoged & Maddieson, 1996, p. 162) and as a “hissing-hushing sound” articulated with tongue tip “rest[ing] against the alveoles of the lower teeth” with “the main articulatory channel [. . .] at the back of the alveolar ridge” (Catford, 1977, p. 290) and “not produced with the sublingual cavity that often characterizes postalveolar fricatives crosslinguistically” (Gordon & Applebaum, 2013). Adding laryngeal features to these four series of sibilants coupled with labialization as secondary articulations, systems can feature up to 14 phonemic sibilant fricatives, e.g., in Bzhedugh (Catford, 1977) or Shapsugh (Gordon & Applebaum, 2013) dialects of Adyghe. Figure 15.5 shows spectrograms of the four-way contrast with contrastive labialization in two series in Ubykh (the spectral analysis was performed in Praat, based on the recordings from the UCLA Phonetics Lab Archive). The spectrograms show the generalization established for Kabardian (Gordon & Applebaum, 2006) and for sibilants in general (Gordon, Barthmaier, & Sands, 2002): peak energy is higher for more anterior fricatives. For spectral studies of Kabardian fricatives and their influences on formant structure of the following vowel, see Gordon and Applebaum (2006); for spectrograms and X-ray tracings of Ubykh and other NWC languages, see Colarusso (1988).

Other NWC dialects can merge the four-way opposition into a three-, two-, or oneway opposition (Gordon & Applebaum, 2013). The exact phonetic realization as well as analyses of the four series of fricatives can vary substantially. For example, some NWC sibilants are analyzed as “moderately retroflex”: /ʃ/ is analyzed as /ʂ/ in Ubykh in Fenwick (2011, p. 18; see also Gordon & Applebaum, 2013). For a detailed phonetic treatment of NWC sibilants, see

Colarusso (1988), Ladefoged and Maddieson (1996), Gordon and Applebaum (2006, 2013), Fenwick (2011, p. 19), and references therein.<sup>5</sup>

Ejective fricatives are typologically even more informative. Gordon and Applebaum (2006) present a detailed acoustic study of Kabardian fricatives. Kabardian features three ejective fricatives, /fʼ/, /tʼ/, and /ʃʼ/, which are typologically uncommon and for which very few phonetic descriptions are available. Labio-dental ejective fricatives are particularly rare, attested only in Kabardian, Abaza, and some dialects of Abkhaz (Colarusso, 1988); outside Caucasian, the PHOIBLE database (Moran, McCloy, & Wright, 2014) lists only North American isolate Yuchi as having /fʼ/. Gordon and Applebaum (2006) provide valuable acoustic and articulatory information about ejective fricatives. Ejective fricatives have shorter frication duration, smaller frication intensity, and greater degree of constriction compared to their plain counterparts (based on palatography). In fact, some tokens show complete oral closure. A period with complete closure is not uncommon for ejective fricatives and is phonetically motivated (Kuipers, 1960, p. 46): closure increases intraoral pressure which facilitates an audible release of ejectives (Gordon & Applebaum, 2006). Gordon and Applebaum (2006) measure intraoral pressure and oral flow in [f] and [fʼ], uttered by one Kabardian speaker. Intraoral pressure rises substantially in production of the ejective fricative and is comparatively lower for the plain fricative. Airflow data aligns well with airflow trajectories in ejective stops (Shosted & Chikovani, 2006): for plain fricatives, it rises with frication and decreases only slightly before vowel onset. For ejective fricatives, airflow rises and decreases back to the zero level before the onset of the following vowel (Gordon & Applebaum, 2006).

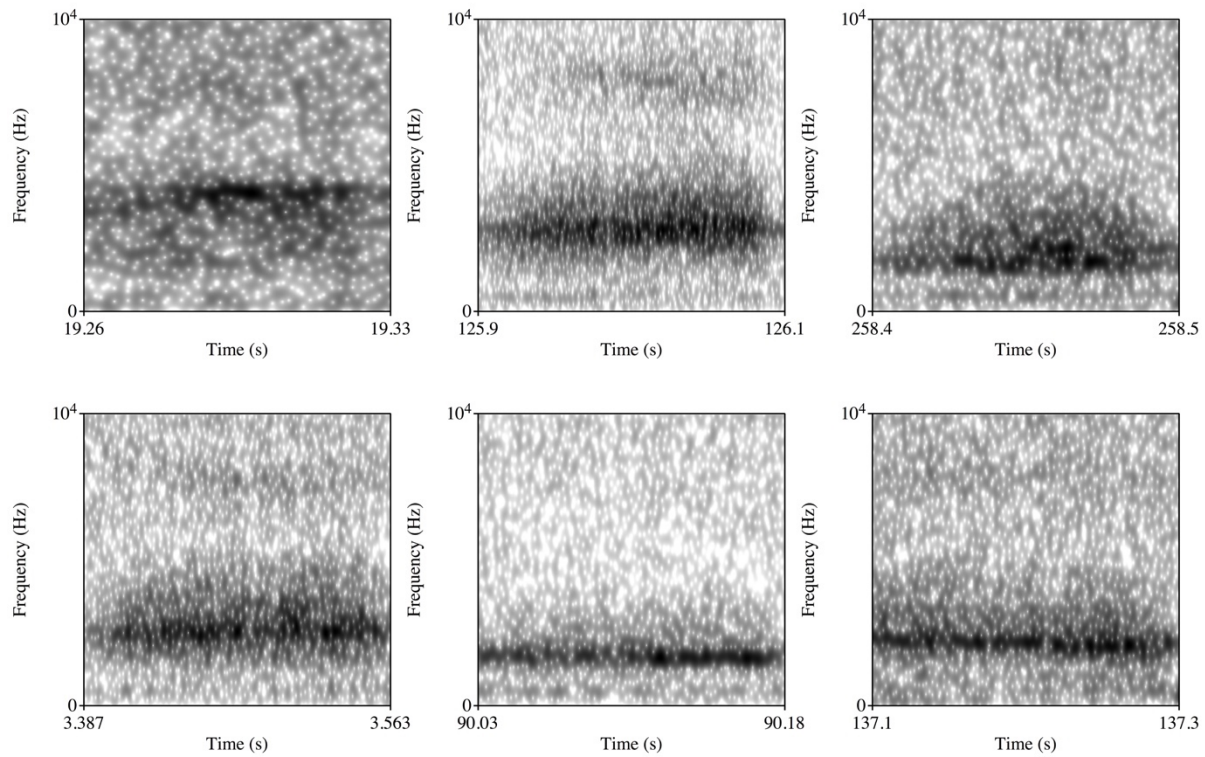
Ubykh only features one ejective fricative /tʼ/, which is marginal. Figure 15.6 gives spectrograms of two words read in isolation, /pʼtʼə/ ‘four’ (right) and /pʼə/ ‘red’ (left) from the LaCiTO database. The main characteristics of ejective versus plain fricatives reported for Kabardian are observed in Ubykh as well: frication duration is substantially shorter for the ejective fricatives. The shorter frication is followed by a period of silence which results from constricted glottis blocking the airflow. Noise in the plain fricative, on the other hand, is steady throughout the frication duration.

While most scholars accept the analyses of large consonantal systems in NWC presented thus far, some attempts have been made to reduce the unusually large consonantal systems of NWC languages by analyzing secondary articulations such as labialization and palatalization as underlying sequences of consonants + glides /j/ and /w/, which would reduce the number of phonemes across NWC languages substantially (discussion in Colarusso, 1988, p. 94). Colarusso (1988, p. 94) provides crucial evidence against this proposal. The most convincing counterevidence comes from the fact that there exist sequences of stop + /j/ in NWC that do not change to the palatalized variant of the stop but surface as two segments.

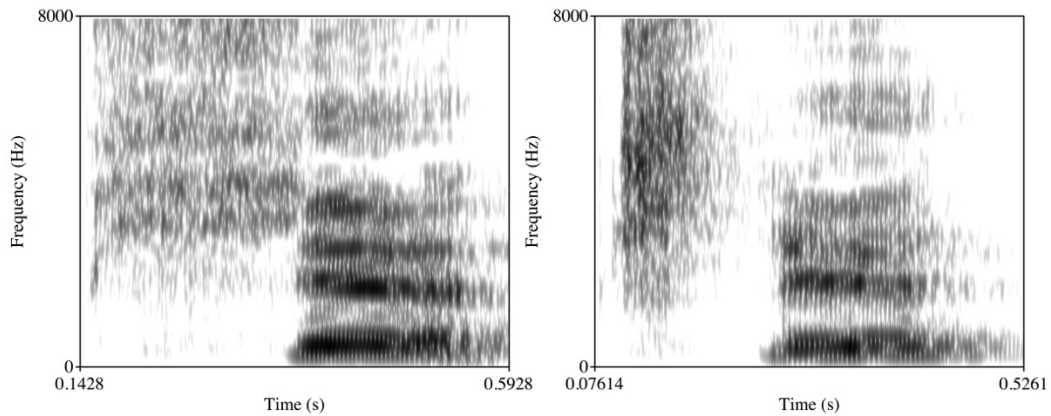
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<sup>5</sup> See chapter 9, for other descriptions and proposals concerning the place of articulation.





**Figure 5:** Spectrograms of Ubykh sibilants: /s/ (upper left), /ʂ/ (upper middle), /ʃ/ (upper right), /ɕ/ (lower left), /ɕʷ/ (lower middle) and /ʃʷ/ (lower right), based on recordings from the UCLA Phonetics Lab Archive.



**Figure 6:** Spectrograms of /pʌ/ ‘red’ (left) and /pʰʌ/ ‘four’ (right).

### 2.2.3 Vocalic inventories

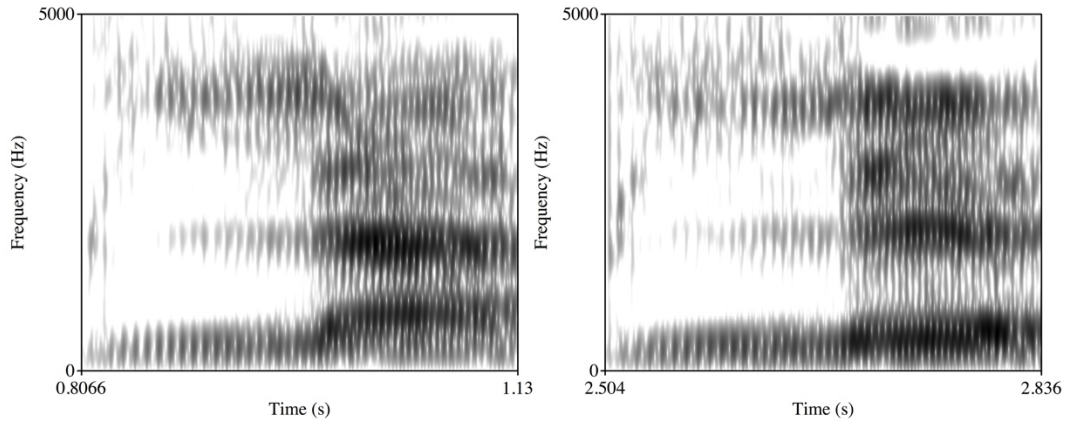
Another prominent feature of NWC languages has to do with vertical vocalic inventories limited to two or three vocalic phonemes, commonly described as /ə/, /a/, and sometimes /a:/. With a two-way phonemic contrast in the vowel system, /a/ and /ə/, we can define vowels with a single feature value, [±high], hence the term “vertical vowel system.”

Ubykh is an example of such a system: it features two vocalic phonemes, /ə/ and /a/. Some analyses include a third vowel /a:/, but this low vowel can also be analyzed as underlying /ah/, /ha/, or /aa/ (Chirikba, 2003a; Colarusso, 1988). Some researchers claim that the distribution of /ə/ and /a/ is predictable (Allen, 1956, 1965b; Kuipers, 1960) and posit only one vocalic element for Ubykh. In other words, according to the onevowel analysis, /ə/ is an automatic epenthetic vowel. It is true that /ə/ is often optional, can be deleted under certain circumstances, and, as Colarusso (1988) notes, it “has a low functional load.” He, however, shows that there exists strong evidence in favor of the phonemic status of /ə/ for all languages: Colarusso (1988, pp. 347–373) offers a detailed discussion of cases in which /ə/ contrasts with ∅.

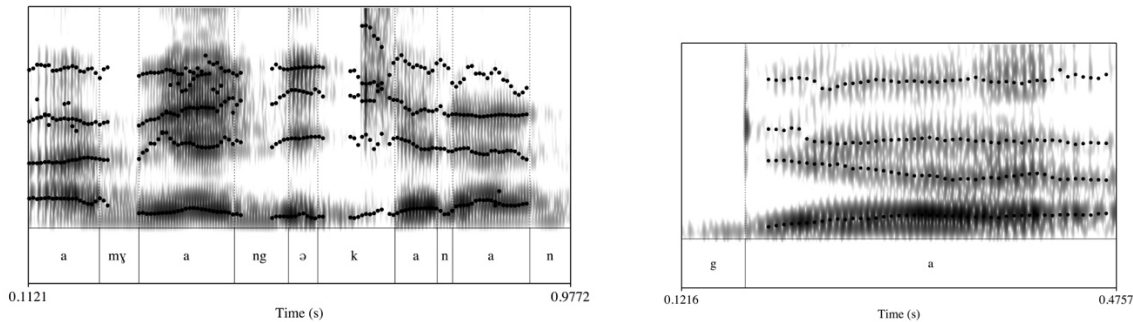
The rest of this section focuses on acoustic analyses of small vocalic inventories. That the two posited vowels have different phonetic values is confirmed by the analysis of Ubykh recordings. The LaCiTO database contains a minimal pair, /bla/ ‘eye’ and /blə/ ‘seven’, uttered in isolation. The spectrogram in Figure 15.7 clearly shows that the two vowels have different qualities. For the low vowel /a/ at midpoint of vowel duration in a relatively neutral phonetic environment, F1 = 745 Hz, F2 = 1,712 Hz; for /ə/ F1 = 424 Hz, F2 = 1,958 Hz. These formant values suggest that /a/ is phonetically relatively front and high, /ə/ is relatively high. Fenwick (2011) transcribes the two vocalic phonemes as /ɜ/ and /i/ to better reflect their phonetic values. Vowel /a:/, regardless of its phonemic status, is phonetically lower than /a/ and therefore transcribed as /ɐ/ in Fenwick (2011). Very similar analyses of vocalic inventories and their phonetic values are proposed for other NWC languages, especially in Abaza and Abkhaz; for Circassian languages the overall phonetic realization of vowels is reported to be comparatively higher (Colarusso, 1988). For spectral measurements of Kabardian vowels and their coarticulatory variation, see Choi (1991), Wood (1994), and references therein.

Small vocalic inventories are often prone to a high degree of coarticulatory influence from adjacent consonants. Colarusso (1988, p. 295) claims that “all tautosyllabic consonants tend to color vowel to a greater or lesser degree.” For example, anterior consonants produce front vowels, high consonants produce high vowels, rounded anterior consonants produce rounded vowels, cf. Ubykh /tət/ → [t<sup>h</sup>ɛt<sup>h</sup>]; /swa/ → [s<sup>h</sup>ɸœ] (Colarusso, 1988, p. 296). In Circassian, alveolars are reported to change tautosyllabic /ə/ to a high [ɪ]. High variability of phonetic values of Ubykh vowels is illustrated in Figure 15.8 that shows formant transitions in an utterance /amyjan gɟəkjanan/, from the LaCiTO database, analyzed in Praat (Boersma & Weenink, 2015). Initial /a/ has values of F1 = 753 Hz and F2 = 1,552 at midpoint, similar to the values for /a/ in isolation in Figure 15.7. All subsequent vowels are colored by palatalization: F1 lowers and F2 rises. The most radical coloring targets the schwa /ə/ between two palatalized velars /kj/ and /gɟ/ to the degree that its F1 lowers to 415 Hz and F2 rises to 2,089 Hz with almost no transitions in formant structure. Despite this heavy coloring, formants still tend to transition back to their targets in the absence of coarticulatory influence of the following consonant. In pre-pausal position, formants transition to their underlying vocalic targets, even after consonants with secondary articulations. Figure 15.8 shows formants of /a/ in /g<sup>j</sup>a/ in pre-pausal position that

clearly transition toward the target for /a/ in the second half of the vowel duration (F1 = 675 Hz, F2 = 1,626 Hz). In other words, consonants do not fully color vowels in all positions: underlying targets are still present and realized, despite some traditional descriptions implicitly suggesting that vowels are colored completely.



**Figure 7:** Spectrograms of /bla/ ‘eye’ (left) and /blə/ ‘seven’ (right)



**Figure 8:** Spectrograms of /amɣ'an g'ək'an/ (left) and /g'a/ (right)

### 2.3 Nakh-Dagestania

Nakh-Dagestania phoneme inventories are also comparatively large, primarily due to a four-way distinction in stop type in some languages (voiceless aspirated, voiced, ejective, and fortis), a high number of phoneme segments in the post-velar part of the vocal tract (pharyngeal, epiglottal, and laryngeal obstruents), and the phonemic status of secondary articulations such as labialization (Kibrik & Kodzasov, 1990). Compared to NWC, Nakh-Dagestania languages feature larger vocalic inventories, often with a length distinction. The number of Nakh-Dagestania languages and dialects and their variability in phonemic inventories is substantially greater compared to Kartvelian or NWC. Here, two illustrative languages were chosen (for a survey of phonemic inventories of most other languages, see Alekseev, 1998b; Bokarev et al.,

1967; Hewitt, 2004; Job, 2004; Kibrik & Kodzasov, 1990; Smeets, 2004; van den Berg, 2005a). Tables 15.5 and 15.7 (with data from Chechen for the Nakh and from Archi for the Dagestian group) illustrate NEC consonantal inventories, Tables 15.6 and 15.8, their vocalic inventories. Pharyngeal segments and pharyngealization are among the better-studied features of Nakh-Dagestian. Nakh-Dagestian languages provide crucial information for the typology of pharyngealization; some languages feature voiceless stops, voiced stops, and fricatives with pharyngeal and epiglottal place of articulation as well as pharyngealization or epiglottization as secondary articulation.

In what follows, I will discuss main acoustic properties of Nakh-Dagestian phoneme inventories, with a focus on pharyngealization. Because pharyngealization is also present in NWC, data from NWC languages are included in this section to supplement the analysis. Several aspects of pharyngeal place of articulation and pharyngealization as secondary articulation are still unknown, both from acoustic as well as articulatory and perceptual perspectives.

Nakh-Dagestian phoneme inventories are also comparatively large, primarily due to a four-way distinction in stop type in some languages (voiceless aspirated, voiced, ejective, and fortis), a high number of phoneme segments in the post-velar part of the vocal tract (pharyngeal, epiglottal, and laryngeal obstruents), and the phonemic status of secondary articulations such as labialization (Kibrik and Kodzasov 1990). Compared to NWC, Nakh-Dagestian languages feature larger vocalic inventories, often with a length distinction. The number of Nakh-Dagestian languages and dialects and their variability in phonemic inventories is substantially greater compared to Kartvelian or NWC. Here, two illustrative languages were chosen: for a survey of phonemic inventories of most other languages, see Bokarev et al. (1967), Kibrik and Kodzasov (1990), Job (1994), Alekseev (1998), Smeets (2004), Hewitt (2004), van den Berg (2005). Tables 5 and 7 (with data from Chechen for the Nakh and from Archi for the Dagestian group) illustrate NEC consonantal inventories, Tables 6 and 8, their vocalic inventories.

	bilab.	l.-d.	dent.	alveo.	post-al.	pal.	vel.	uvul.	phar./epi gl.	glot.
stop	p <sup>h</sup> , b, p'		t <sup>h</sup> , d, t'				k <sup>h</sup> , g, k'	q <sup>h</sup> , q', q:	ʔ	ʔ
affricate	p:		t:	ts, dz, ts', tʃ, dʒ, tʃ̣			k:			
nasal	m			n						
tap/trill				r, r̥						
fricative		v		s, z, s:	ʃ, ʒ		x	ɣ	ħ	h
approx.						j				
lat. appr.				l						

Table 5: Chechen consonant inventory

Note: From Nichols (1994, 1997a); Sylak (2011). Ingush features a very similar consonant inventory: Ingush lacks /p:/, /k:/, /dz/, and /dʒ/ but features an additional series, palatalized velars /kj, gj, kj'/' (Nichols, 2011).

	front	central	back
-round	+round		

high	i, i:	y, y:		u, u:
mid	ε, e:			o, o:
mid	je, i:ε	ɥœ, y:œ	ə	wɔ, u:ɔ
low	æ		a, a:	ɔa, ɔ:

Table 6: Chechen vowels

Note: Note: From Nichols (1994, 1997a); Nichols and Vagapov (2004); Sylak (2011); cf. Komen (2007a). Ingush vocalic inventory is similar with some differences primarily in mid vowels (as described in Nichols, 2011). For Chechen and Ingush diphthongs, see Nichols (1994, 2011).

	bilab.	dent.	post-al.	pal.	(pre-)vel.	uvul.	phar.	glot.
stop	p <sup>h</sup> , b, p'	t <sup>h</sup> , d, t', t:			k <sup>h</sup> , g, k', k:	q <sup>h</sup> , q', q:		ʔ
labial.		t <sup>w</sup> , d <sup>w</sup>			k <sup>hw</sup> , g <sup>w</sup> , k <sup>w</sup> , k: <sup>w</sup>	q <sup>w</sup> , q <sup>w</sup> '		
affricate		ts, ts', ts:'	tʃ, tʃ', tʃ:'					
labial.		ts <sup>w</sup> , ts <sup>w</sup> '	tʃ <sup>w</sup> , tʃ <sup>w</sup> '					
lateral					k <sup>l̥</sup> , k <sup>l̥</sup> '			
lat. lab.					k <sup>l̥w</sup> , k <sup>l̥w</sup> '			
nasal	m	n						
tap/trill		r						
fricative		s, z, s:	ʃ, ʒ, ʃ			χ, ʁ, χ:	ħ, ʕ	h
labial.		s <sup>w</sup> , z <sup>w</sup> , s: <sup>w</sup>	ʃ <sup>w</sup> , ʒ <sup>w</sup> , ʃ <sup>w</sup>			χ <sup>w</sup> , ʁ <sup>w</sup> , χ: <sup>w</sup>		
lateral					l̥, l̥, l̥:			
lat. lab.					l̥ <sup>w</sup> , l̥ <sup>w</sup> :			
approx.	w			j				
lat. appr.		l						

Table 7: Archi consonant inventory

Note: From Kibrik (1994); Kibrik and Kodzasov (1990); Kodzasov (1977); Ladefoged and Maddieson (1996); and Mikailov (1967).

	front	central	back
high	i, i:		u, u:
open-mid		e, e:	ə
low		a, a:	o, o:

Table 8: Archi vowels

Note: From Kibrik (1994); Kibrik and Kodzasov (1990).

### 2.3.1 Laryngeal features

As already mentioned, in addition to the “common” Caucasian three-way opposition in obstruent types with three laryngeal features (voiceless aspirated, voiced, and ejective), Chechen, Ingush, Batsbi, Andi, Avar, Lak, Lezgian, Dargwa, Tabasaran, Agul, Archi, and Tsakhur feature a “fourth type” of stops (Kibrik & Kodzasov, 1990). This series receives various different analyses; they are labeled intensive, fortis, unaspirated, or geminated consonants (Catford, 1977; Kibrik & Kodzasov, 1990; Gaprindašvili, 1966; Hewitt, 2004). The characteristic features of this series is lack of aspiration and phonetically longer closure. The exact phonetic realization differs across languages; in some languages “fortis” stops are realized as geminates intervocally (e.g., in Lak, Dargwa, and Khinalug; Catford, 1977; cf. Gaprindashvili, 1966, Kibrik, Kodzasov, & Olovjannikova, 1972), and in others as affricates (e.g., in Avar and Andi; Catford, 1977). A four-way opposition in obstruent types is also present in the Hatkoy and Shapsugh dialects of Adyghe (for a detailed phonetic study of the contrast there, see Gordon & Applebaum, 2006, 2013).

Warner (1996) presents a study of laryngeal features in Ingush and confirms most of the commonly-held phonetic generalizations concerning ejective stops. VOT in Ingush is, for example, significantly longer in voiceless stops ( $M = 45.1$  ms) and shorter in ejectives ( $M = 26.2$  ms). Ejective stops lack noise after burst; there is a significant difference in average power of post-burst noise between ejective and voiceless series, but no significant difference in average peak burst power (replicated in Grawunder, Simpson, & Khalilov, 2010). Warner also reports an audible effect of ejective stops on pitch of the following vowel. On average, the difference in pitch value at the onset of following vowel is 26.2 Hz: pitch is higher after ejectives compared to voiceless stops. The difference is significant both at the vowel onset as well as at fifth to seventh period of the vowel. On the other hand, Warner (1996) found no significant difference in peak burst power between the ejective and voiceless series. Likewise, no specific spectral characteristics of burst in ejectives were observed.

Hewitt (2004) reports a correlation between aspiration and ejection: ejectives appear “more glottalized” in those dialects that have less aspiration and vice versa. This observation is, however, not supported by any quantitative analysis. Further quantified treatments of correlations in phonetic realization of different stop types could yield important insights into a thus far unexplained variation (cf. also our observation of inter-speaker variation in stop production in Georgian in section 15.2.1.1).

### 2.3.2 Lateral obstruents

Another notable feature of Nakh-Dagestanian languages is the presence of a large number of lateral obstruents. Lateral fricatives can be voiceless ( $\text{ɬ}$ ) or “fortis” ( $\text{ɬ}^{\text{f}}$ ). Lateral affricates can be voiceless ( $\text{tɬ}$ ), ejective ( $\text{tɬ}'$ ), fortis ( $\text{tɬ}^{\text{f}}$ ), or fortis ejective ( $\text{tɬ}^{\text{f}'}$ ) (Catford, 1977; Kibrik & Kodzasov, 1990). According to Catford (1977), the system with the highest number of lateral consonants is Akhvakh, featuring seven contrastive consonants with lateral articulation (including the approximant  $/l/$ ).

Archi exhibits typologically very rare velar lateral fricatives and affricates (Kodzasov, 1977; Ladefoged & Maddieson, 1996). Archi features voiceless, voiced, geminate (or tense) pre-velar lateral fricatives (/ɬ̺/, /ɬ̺/, and /ɬ̺ː/) as well as voiceless and ejective pre-velar lateral affricate /kɬ̺̥/, /kɬ̺̥'. Moreover, the voiceless and ejective affricate and voiceless and geminate fricative can be phonemically rounded: /kɬ̺̥ˠ/, /kɬ̺̥ˠ', /ɬ̺̥ˠ/ and /ɬ̺̥ˠː/ (based on Kodzasov, 1977). Ladefoged and Maddieson (1996) provide spectrograms of these segments and a qualitative description of their acoustic properties. The pre-velar lateral fricative in Archi features strong frication and a close proximity between the second and third formants. Articulatorily, these segments are produced with tongue body constriction along the velum and the palate and with tongue tip “passively lowered to the lower teeth” (Kodzasov, 1977, in Ladefoged & Maddieson, 1996, p. 206). For further acoustic measurements of these sounds, see Grawunder, Simpso, & Khalilov (2010), who suggest that pre-velar realization of lateral fricatives and affricates is also found for some speakers of Bezhta and Avar.

### 2.3.3 Pharyngeal place of articulation

As already mentioned, one of the major topics in phonetics of Nakh-Dagestanian is pharyngealization. As Sylak (2011) points out, pharyngealization is rare in the world’s languages: only 5% of languages surveyed feature pharyngeal place of articulation or pharyngealization as secondary articulation (Maddieson, 1984). Most work on pharyngealization centers on Semitic and North American languages, and comparatively fewer instrumental studies have been done on Caucasian pharyngealization.

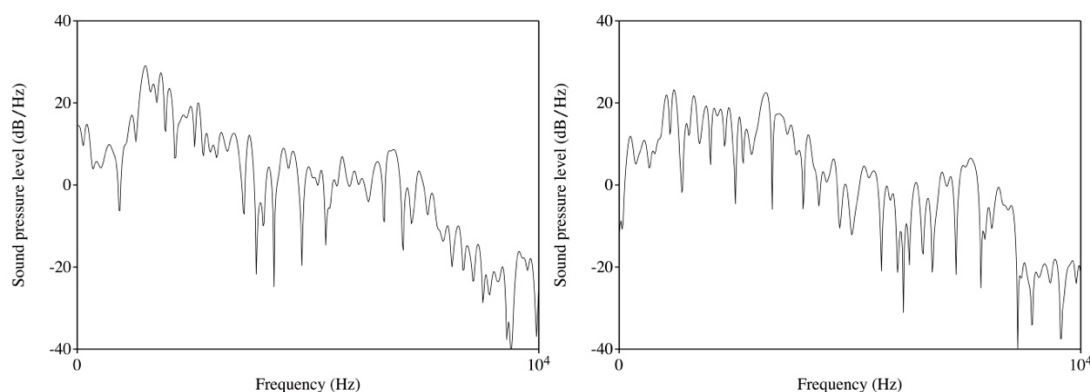
There are opposing views in the general phonetic literature on the topic of articulatory and acoustic aspects of consonants produced in the region between the uvula and the glottis: pharyngeal/epiglottal place of articulation (Catford, 1983; Esling, 1996, 1999; Laufer & Condax, 1979a, 1979b; for surveys of post-velar articulations and their phonetic and phonological properties, see Bessell, 1992; Moisik, 2013; Sylak-Glassman, 2014). For example, no consensus has been reached on the question of whether languages can contrast epiglottal and pharyngeal place of articulation, exactly which articulators are active (and in what ways) during the production of these obstruents, or what the exact acoustic properties for each place of articulation are.

Nakh-Dagestanian languages provide crucial phonetic information for the typology of segments in the radical part of the vocal tract (Catford, 1983; Esling, 1999; Kibrik & Kodzasov, 1990; Kodzasov, 1986; Ladefoged & Maddieson, 1996; Nichols, 2000). Languages of the family have a large number of phonemes with primary articulation between the glottis and uvula, the most common of which are pharyngealized voiceless /ħ/ and voiced /ʕ/ fricatives. In some languages, such as Chechen, the Nakh-Dagestanian pharyngeal series is produced at the epiglottal place of articulation (Catford, 1983). Despite the rich inventory of post-velar sounds in Nakh-Dagestanian, instrumental acoustic and articulatory studies of pharyngeal/epiglottal obstruents are still lacking. The most informative for the discussion on differences between pharyngeal and epiglottal place of articulation are the Burshag and Burkikhan dialects of Agul



(Kibrik & Kodzasov, 1990; Kodzasov, 1986; cf. Magometov, 1970; Šaumjan, 1941).<sup>6</sup> These dialects are reported to have a phonemic contrast between pharyngeal and epiglottal places of articulation (Kodzasov, 1986; Ladefoged & Maddieson, 1996). Agul features voiceless /h/ and voiced /ɦ/ pharyngeal fricatives, and voiceless /h/ and voiced /ɦ/ epiglottal fricatives. The Agul phonemic inventory also contains epiglottal stop /ʔ/ (Catford, 1983; Kibrik & Kodzasov, 1990). Altogether, Agul has five phonemes between the uvular and glottal places of articulation.

Ladefoged and Maddieson (1996) further show that the pharyngeal and epiglottal fricatives are acoustically quite different: the epiglottal series is noisier, and its formant structure resembles neighboring vowels more than that of the pharyngeal series. The latter is characterized by a high F1 above 1,000 Hz and a small distance between the first and the second formant (Ladefoged & Maddieson, 1996, pp. 167–168). Some of these observations are illustrated by spectral analysis: Figure 15.9 shows spectra of /h/ and /ɦ/ in words /hatʃ/ ‘wolf’ and /Hæŋʰ/ ‘apple’.



**Figure 9:** Spectra of /h/ (left) and /ɦ/ (right) analyzed in Praat (Boersma & Weenink, 2015) with 25 ms window length, at approximately midpoint of the fricative (where clear formant structure was visible) from recordings of Agul at the UCLA Phonetics Lab Archive.

Recently, however, Esling (1999, 2010, 1997) and others (Heap, 1997; Moisik, 2013; Sylak-Glassman, 2014) proposed that the distinction in Agul is not of place of articulation but rather of manner of articulation: Esling argues that pharyngeal fricatives are fricatives, but that what Ladefoged and Maddieson (1996) analyze as epiglottal fricatives are in fact trills. In other words, all five obstruents in Agul are produced in the same epiglottal (aryepiglottal-epiglottal) region and their primary distinction is in manner of articulation (see also Moisik, 2013). Sylak-Glassman (2014) and Moisik (2013) even question the phonemic status of the two series in Agul. The question of whether a language can phonemically distinguish pharyngeal and epiglottal place of articulation of the same manner of articulation thus remains open for further research.

<sup>6</sup>Recordings of the Burkikhan dialect of Agul with examples of obstruents in the pharyngeal/epiglottal region are available at the UCLA Phonetics Lab Archive at <http://archive.phonetics.ucla.edu/Language/AGX/agx.html>.



### 2.3.4 Pharyngealization as secondary articulation

Nakh-Dagestanian languages also have pharyngealization as a secondary articulation. Kibrik and Kodzasov (1990) distinguish two types of pharyngealization in Nakh-Dagestanian, which, according to Nichols (2000), corresponds to the distinction between pharyngeal and epiglottal places of articulation. The distinction between pharyngealization and epiglottalization as secondary articulation is, however, problematic, and several open questions remain to be answered (see Moisik, 2013, and references therein and discussion below).

Pharyngealization has been analyzed as an autosegmental/prosodic feature on the basis of pharyngeal spreading, where the pharyngealization feature spreads from one vowel/syllable in the word to neighboring vowels/syllables (Kibrik & Kodzasov, 1990; Schulze, 1997b; Sylak-Glassman, 2014), e.g., in Lak or Archi (Anderson, 1997; Kibrik, 1994, cited in Sylak-Glassman, 2014, and Moisik, 2013). Pharyngeal spreading can be sensitive to stress or blocked by other segments (Moisik, 2013; Sylak-Glassman, 2014).

In NWC languages, pharyngealization is commonly analyzed as a secondary articulation on consonants (Catford, 1983; Hewitt, 2004). In contrast, Nakh-Dagestanian pharyngealization is most commonly analyzed as a property of the vowel or of the syllable, rather than a property of the consonant (Kibrik & Kodzasov, 1990; Kodzasov, 1986; Maddieson, Rajabov, & Sonnenschein, 1996; Nichols, 2011). In some languages such as Tsez or Rutul, pharyngealization is analyzed as a property of both vowels and consonants (see Maddieson, Rajabov, & Sonnenschein, 1996; Sylak-Glassman, 2014).

Phonetic distinction between vocalic and consonantal pharyngealization is difficult to draw, because both involve similar gestures: compression or contraction of the pharynx or epiglottis that is simultaneous with vocalic or consonantal articulation (for complexity of articulations, see Moisik, 2013). This means that analyses have to rely primarily on phonological data. For example, as shown in Figure 15.10, pharyngealization in Ubykh, despite being analyzed as a consonantal feature, affects the following vowel throughout its duration by lowering the F1 and F3 values.

For both families, there are X-ray tracings and spectral analyses of pharyngealization (Gaprindashvili, 1966; Dzheyranishvili, 1959, via Ladefoged & Maddieson, 1996; Catford, 1983; Colarusso, 1988), but acoustic studies sometimes yield contradictory results. The analysis of acoustic effects of pharyngealization is complicated by several factors: pharyngealization is not homogeneous in terms of where and how it is realized (primarily on the vowel or primarily on the consonant) or in terms of place of articulation (pharyngealization vs. epiglottization). It is thus not surprising that different studies report different results.

Kingston and Nichols (1987) and Nichols (1997a) examine general acoustic effects of pharyngealization as secondary articulation in Chechen and argue that pharyngealization primarily affects formants of the vowel and VOT duration of the consonant. The authors show that VOT duration of pharyngealized consonants is longer compared to plain voiceless or ejectives (reported in Nichols, 2011, and Sylak, 2011). Nichols (1994) further reports “very noisy aspiration” or “murmured” phonation in the VOT of pharyngealized voiceless and voiced

consonants. Moreover, F1 rises and F2 and F3 lower in the presence of pharyngealization. In other words, pharyngealization “produces compaction” of the spectrum: “lowering and backing of the low vowels and centralization of the others” (Nichols, 2011).

Sylak (2011) measures formants of five male Chechen speakers and compares the measurements with predicted formant values. The predicted values are calculated based on source-filter theory and estimation of vocal tract parameters. His study confirms that pharyngealization raises F1 values and lowers F2. No significant effects of pharyngealization were found on F3. For some places of articulation, his measurements suggest that the secondary articulation is in fact epiglottization rather than pharyngealization: Nichols (2011) claims the same for Ingush. These claims can only be confirmed with further articulatory studies.

Ladefoged and Maddieson (1996) and Catford (1983) report a study of pharyngealization in Tsakhur and Udi (cf. Ibragimov, 1968, 1990). The most noticeable acoustic effect of pharyngealization reported there is a substantial lowering of F3, for anything between 150–1200 Hz (depending on the vowel and language). Additionally, F1 is reported to raise, but not as considerably. F2 lowers in /e<sup>ʕ</sup>/ and /i<sup>ʕ</sup>/ but rises in /a<sup>ʕ</sup>/, /o<sup>ʕ</sup>/, and /u<sup>ʕ</sup>/. X-ray tracing of pharyngeals in these two languages (Gaprindashvili, 1966) reveals the “curious tongue configuration. The tongue root at about the level of the tip of the epiglottis bulges backward into the pharynx, while a depression is formed in the dorsal surface of the tongue approximately opposite the uvula, with a further upward bulge further forward in the tongue,” also called the “double bunching” (Catford, 1983, p. 349; see also Bessell, 1992; Gaprindašvili, 1966; and Moisik, 2013).

In Tsez, pharyngealization is reported to affect formants of the vowel both at vowel onset as well as at its midpoint. The effects of pharyngealization differ across different vowel qualities (Maddieson, Rajabov, & Sonnenschein, 1996). Pharyngealization is reported to raise F1 in all five vowels measured, although the effect of F1 raising is greater for /i/ and /e/ compared to other vowels. F2 is lower in pharyngealized /i<sup>ʕ</sup>/, and /e<sup>ʕ</sup>/, but higher in pharyngealized /a<sup>ʕ</sup>/, /o<sup>ʕ</sup>/, and /u<sup>ʕ</sup>/ compared to their non-pharyngealized counterparts. The measurements are reported to yield “complex” results for F3. Pharyngealization is reported to lower F3 significantly in /a/ and /u/.

The magnitude of the effect of pharyngealization is greater at vowel onset compared to the mid-point position (Maddieson, Rajabov, & Sonnenschein, 1996). Gaprindashvili (1966) further suggests that the main acoustic effect of vocalic pharyngealization in Dargi is the presence of the fourth formant in the region around 1280 Hz. Moisik (2013) and Sylak-Glassman (2014) also report a number of studies that claim vowels adjacent to pharyngeal fricatives get fronted or pattern phonologically as palatalizing vowels. Fronting is reported for Avar in Sylak-Glassman (2014) (based on Charachidze, 1981), Kryz (based on Authier, 2009), and Agul (based on Magometov, 1970). For example, /o/ and /u/ are realized as [oe] and [y] in Avar if they are adjacent to a voiceless or voiced pharyngeal fricative: [gøħ] for /goħ/ ‘mountain’ (Sylak-Glassman, 2014). Moisik (2013) reports that pharyngealized vowels in Lak (based on Anderson, 1997) and Bezhta (based on Kibrik & Testelets, 2004) cause phonological palatalization. For example, in Lak /k/ and /l/ palatalize before pharyngealized fronted vowels. Effects of pharyngealization are visible beyond formant structure and VOT. Grawunder, Simpson, & Khalilov (2010) report that burst spectra differ for pharyngealized stops compared to plain stops in Tsez; the same observation is made for Tsez in Maddieson, Rajabov, &

Sonnenschein (1996). Maddieson, Rajabov, & Sonnenschein (1996) also measure formant transition of vowels before pharyngealized uvulars: the only consistent result they report is lowering of F3 of the preceding vowel (e.g., in /raq<sup>ʕ</sup>/ vs. /raq/).

The most comprehensive study of effects of pharyngealization in NWC is provided by Colarusso (1988), who offers spectrograms but no statistical data on the effects. Colarusso concludes that acoustic effects are “complex,” but he identifies the most noticeable ones: noisy energy in 400–600 Hz range (and sometimes around 1,100 Hz and 2,000–2,400 Hz) (Colarusso, 1988, p. 222).

To my knowledge, no quantified measurements of Ubykh pharyngealization have been presented in the literature, and Colarusso (1988) does not measure formants of vowels following pharyngealized segments. I analyzed a recording of two Ubykh words, /q<sup>ʕ</sup>’a:p’a/ ‘handful’ and /q’a:p’a/ ‘hand’, each uttered eight times in isolation, in apparent random order, by Tevfik Esenç (recorded by Georges Dumézil and available at LaCiTO). The following parameters of the stop following /q<sup>ʕ</sup>/ and /q’/ were measured: F0, F1, F2, F3 (all at 20%, 50%, and 80% of vowel duration).

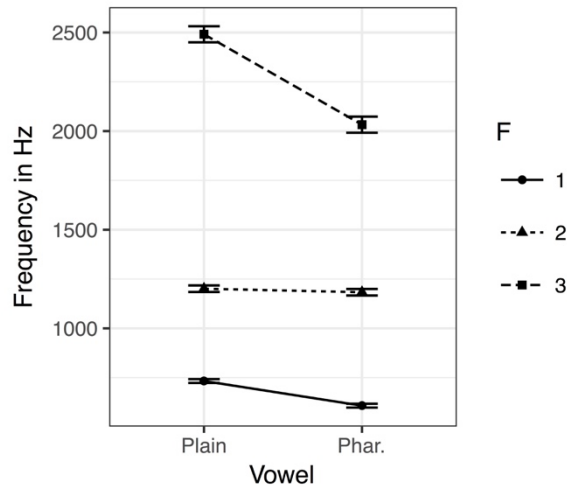
Pharyngealization significantly affects F1 and F3 values, but not F2 values. Contrary to the effects of pharyngealization observed in Chechen, Ubykh pharyngealization lowers F1 significantly at 20%, 50%, and 80% of vowel duration (at 20%,  $t = 9.1$ ,  $df = 10.2$ ,  $p < 0.0001$ ). There is no significant effect of pharyngealization on F2 at any of the three points measured (at 20%,  $t = 0.76$ ,  $df = 8.2$ ,  $p = 0.47$ ). Pharyngealization significantly lowers F3 at all three points (at 20%,  $t = 7.9$ ,  $df = 9.1$ ,  $p < 0.0001$ ). Figure 15.10 illustrates the effects of pharyngealization on the first three formants with standard errors.

Furthermore, vowel durations are significantly shorter if the vowel is pharyngealized ( $t = 4.7$ ,  $df = 13.9$ ,  $p < 0.001$ ; Welch Two Sample t-test). The data, however, show no effect of pharyngealization on F0, either at 20%, 50%, or 80% of vowel duration (at 50%,  $t = -1.67$ ,  $df = 13$ ,  $p = 0.12$  with Welch two-sample t-test).<sup>7</sup>

The effects of pharyngealization on the following vowel in Ubykh differ in some aspects from the effects summarized for Nakh-Dagestania languages above. However, the Ubykh data are limited to one speaker and a single minimal pair. F3 does indeed lower substantially after pharyngealized stops, in accordance with results from other languages. F1, however, lowers substantially too, which differs from most other studies. This discrepancy reveals that effects of pharyngealization can be quite different across languages and that detailed descriptions of acoustic effects of pharyngealization as well as their articulatory and perceptual properties are still lacking.

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<sup>7</sup> It is possible that experiments with higher power would yield different results with respect to effect of pharyngealization on F0.



**Figure 10:** Differences in vowel formants with standard errors for pharyngealized vs. plain low vowel in Ubykh (obtained with `lm()` function and effects package, Fox, 2003).

### 3 Phonotactics

Consonant clusters, especially Kartvelian clusters, are probably the best-studied aspect of Caucasian phonotactics. Articulatory and perceptual research on Georgian clusters provides crucial information for the discussion on the role of production versus perception in phonology. This section reviews the discussion on Georgian clusters and their relevance for phonological theory as well as points to aspects of Kartvelian phonotactics that have remained largely unnoticed in the current phonological literature.

#### 3.1 Georgian clusters

Traditional grammarians identify two kinds of clusters in Kartvelian: harmonic and non-harmonic (Axvlediani, 1949, among others, via Butskhrikidze, 2002). Harmonic clusters are clusters of two obstruents, a dorsal and a non-dorsal that agree in laryngeal features. Non-harmonic are all other clusters that do not belong to the harmonic group, but are permitted phonotactically in Georgian. Table 15.9 shows harmonic clusters in Georgian (from Butskhrikidze, 2002; Chitoran, 1998).

C+stop			C+fricative		
voiced	voiceless	sejective	voiced	voiceless	sejective
bg	p <sup>h</sup> k <sup>h</sup>	p'k'	bɣ	p <sup>h</sup> x	p'χ'
dg	t <sup>h</sup> k <sup>h</sup>	t'k'	dɣ	t <sup>h</sup> x	t'χ'
dzg	ts <sup>h</sup> k <sup>h</sup>	ts'k'	dzy	ts <sup>h</sup> x	ts'χ'
dʒg	tʃ <sup>h</sup> k <sup>h</sup>	tʃ'k'	dʒɣ	tʃ <sup>h</sup> x	tʃ'χ'
	sk <sup>h</sup>		zy	sx	
	ʃk <sup>h</sup>		ʒɣ	ʃx	

Table 9: Georgian harmonic clusters

Note: From Butskhrikidze (2002, p. 103).

Harmonic clusters are distinguished from non-harmonic ones phonetically and phonologically. Harmonic clusters can appear in stem-final position, never feature optional r-insertion, are copied in reduplication (e.g., /tsxel-tsxeli/ for /red-tsxeli/ ‘hot’), and according to speakers’ judgments, syllabify into the same syllable, e.g., /si.t’q’va/ ‘word’ (Butskhrikidze, 2002, pp. 103–105). This latter claim is, however, disputed. Syllabification data are based exclusively on speakers’ judgments, and Chitoran (1998) reports inconsistent judgments in her experiment.

The phonetic status of harmonic clusters has been subject to even more debate. Harmonic clusters are either analyzed as complex, doubly articulated segments or as sequences of simple segments. Some analyses divide harmonic clusters even further: coronal-dorsal clusters are analyzed as complex segments, whereas labio-dorsal clusters can be either clusters or complex segments with lexicalized distribution between the two (discussion in Chitoran, 1998). The basis for this distinction is the observation that coronal-dorsal clusters can surface in three-stop clusters, e.g., /t’k’bili/ ‘sweet’, whereas labio-dorsals cannot.

Acoustic studies of Georgian harmonic clusters yield little support for the complex-segment analysis. Chitoran (1998) analyzed harmonic clusters and corresponding sequences of two obstruents across word boundary. Her study found no significant difference in proportion of released versus unreleased stops between harmonic clusters and “harmonic” sequences of stops across word boundary: the first and second element in clusters are equally frequently released in harmonic clusters compared to sequences of stops across word boundary. Harmonic clusters almost always have two releases, contrary to what has been described impressionistically in earlier literature. Similar results are obtained in McCoy (1999), who reports that all clusters in her experiment feature two releases and that in voiced harmonic clusters a presence of an automatic transitional vowel was detected (e.g., [dəgas] for /dgas/). Moreover, measurements of duration do not support the complex-segment analysis either. Duration of harmonic clusters is not shorter compared to sequences of stops across word boundary (Chitoran, 1998; also McCoy, 1999).

Georgian clusters have also been analyzed articulatorily (Chitoran, Goldstein, & Byrd, 2002; Zhghent’i, 1956). Cross-linguistically, clusters have been found to have significantly less overlap word-initially, and significantly less overlap in front-to-back clusters compared to back-

to-front clusters. It has been argued that these patterns stem from perceptual recoverability; word-initially, clusters lack formant transitions into closure. It is reasonable to assume that the minimal overlap results from the need for more perceptual cues in a position where such cues are reduced. A similar explanation has been proposed for the smaller degree of overlap in back-to-front clusters. If back-to-front clusters overlap to a high degree, the release of the first segment in the cluster occurs when the second stop is still unreleased, which again reduces perceptual cues (as summarized in Chitoran, Goldstein, & Byrd, 2002).

Georgian clusters that feature a division into two groups (harmonic or recessive and non-harmonic or non-recessive) are perfect for testing these hypotheses. Chitoran, Goldstein, & Byrd (2002) conducted an articulatory experiment involving two speakers of Georgian, with EMA measurements of cluster articulations. Their study confirms the hypotheses outlined above: there is significantly less overlap in word-initial clusters and significantly less overlap in back-to-front (non-harmonic) clusters. Chitoran, Goldstein, & Byrd (2002) also suggest that it is precisely the high degree of overlap in front-to-back clusters that is responsible for the requirement of harmonic clusters to agree in laryngeal features. In other words, a high degree of overlap means that laryngeal features of the first stop are realized at the onset of the second stop, i.e., the members of the cluster share laryngeal features.

The hypothesis outlined above—that perceptual factors influence the degree of gestural overlap—leads to questions concerning the interplay of synchronic and diachronic effects on phonetics and phonology. While it is true that greater overlap in front-to-back clusters could be caused by perceptual mechanisms, this is not the only possible cause. Chitoran, Goldstein, & Byrd (2002) mention that the origin of harmonic clusters are likely velarized obstruents that later segmented into a sequence of two stops (as proposed in Gamkrelidze & Ivanov, 2010). However, they do not discuss the implications of this historical development. If Gamkrelidze’s reconstruction holds, then we expect harmonic clusters that go back to single segments to have greater overlap by virtue of their origin, not necessarily because of perceptual recoverability.

That perception cannot be the only cause of differences in degree of overlap is argued in subsequent articulatory work on Georgian clusters. Chitoran and Goldstein (2006) measured overlap in clusters of a stop and a sonorant. There too, back-to-front clusters such as [kl] and [rb] “are less overlapped” than front-to-back clusters (reported in Chitoran & Cohn, 2009), although perceptual recoverability plays a much smaller role when sonorants are members of clusters. In fact, as Chitoran and Cohn (2009, p. 35) point out, “liquids do not rely on their releases in order to be correctly perceived.” The authors then suggest that “perceptual recoverability is not directly encoded in the in the phonology.” Phonetic differences in the degree of overlap may have emerged for perceptual reasons, but were then phonologized over time, generalized, and encoded as part of phonological grammar. The problem of different degrees of overlap in consonant clusters across different types and positions, as well as the question of their causes and origins thus requires further investigation.

Harmonic and non-harmonic clusters of two obstruents represent just a subset of licit clusters. Kartvelian languages have consonant clusters with up to six consonants in word-initial position. Perhaps the most famous example is the Georgian word /p<sup>h</sup>rt<sup>h</sup>sk<sup>h</sup>vna/ ‘to peel’.

Large clusters are governed by different phonotactic rules across Kartvelian languages (Harris, 1991c; Öztürk & Pöchtrager, 2011, among others). Common to all restrictions is that longer clusters obligatorily include sonorants. For example, Megrelian clusters of two obstruents can only be preceded by an /r/ or an /n/ and followed by a /v/ (Harris, 1991c, based on Gudava & Gamkrelidze, 1981).

Kartvelian clusters thus pose a problem to the Sonority Sequencing Principle (SSP): if sonorants precede segments with lower sonority such as voiceless stops, SSP is violated quite severely (as in /phrthskhvna/). Some analyses of Kartvelian clusters argue that these sonorants are syllabic and that harmonic clusters are doubly-articulated single segments (Butskhrikidze, 2002). Under this analysis then, the SSP would not be violated. For example, /p'rtʃ'χ'ali/ would be analyzed as [p'rtʃ'χ'ali] or an initial sequence /bdyvna-/ would be analyzed as [bdyvna-] or possibly [bdy<sup>w</sup>na-] without SSP violations. There is, however, little external support for such a hypothesis: harmonic clusters do not behave as complex segments according to phonetic analyses, and syllabification arguments are based solely on speakers' judgments which are inconsistent (Chitoran, 1998). Phonetic analyses might reveal that sonorants undergo substantial reductions in sonority in the cluster environment, which would mean that SSP would not be violated. This is suggested by the realization of /r/, which is reported as devoiced before voiceless obstruents (Butskhrikidze, 2013; Sturm, 2016; Zhghent'i, 1956). Further acoustic and articulatory studies of phonetic realization of sonorants in clusters are much needed.

### 3.2 Svan clusters

Some aspects of cluster phonotactics differ across Kartvelian languages. Long clusters in Georgian are restricted to word-initial position. This distribution is reversed in Svan: word-initially, Svan allows only one two-member harmonic cluster (or a cluster that historically goes back to a harmonic cluster) with an optional following [w], while no such restriction exists for word-final position (Tuite, 1998a). Tuite (1998a; citing Zhghenti, 1949) illustrates long word-final clusters in Svan: /axeqwsg/ 'you stole up on something' or /xosgwz/ 'I ordered somebody'.

The restriction against word-initial clusters to the exclusion of word-final clusters is likely part of active phonology in Svan and is reflected in loanword phonology and morphophonological alternations. For example, initial clusters in loanwords undergo epenthesis (/k' aravæt' / < Rus. krovat' 'bed' ). The restriction against initial clusters is also revealed morphophonologically, in metathesis and epenthesis: /x/ of the prefix /xw-/ is deleted and /w/ is metathesized before a consonant-initial root, e.g., /xw-t'ix-e/ → [t'wixe] 'I return it' (Tuite, 1998a). If metathesis is not available, initial clusters are repaired by epenthesis, e.g., /m-t'ix-e/ → [mət'xe].

While longer clusters in Svan are not restricted to codas specifically, they are restricted to word-final position, where they necessarily appear in the coda position. In other words, Svan syllables allow many more complex codas than complex onsets. The concentration of clusters word-initially vs. word-finally in Georgian and Svan leads to questions concerning phonetic motivation in phonotactics. We also know that initial clusters are articulated with greater degree of overlap compared to final clusters, which was confirmed by articulatory studies on Georgian.

To my knowledge, no articulatory studies of Svan clusters exist; experimental studies on the topic would provide information on whether the universal distribution of the degree of overlap holds true even for languages in which complex codas are more frequent than complex onsets.

### **3.3 Outside Kartvelian**

Consonant clusters are much more restricted in Nakh-Dagestanian and Northwest Caucasian languages as compared to Kartvelian. The maximal syllable structure in many languages is CVC. Godoberi is among the languages with the most restricted syllable structure (Kodzasov, 1996; Saidova, 2004): syllables can only be closed with a sonorant or the labial [b] (Kodzasov, 1996). The tendency toward open syllables is also strong in Tsez (Alekseev & Radzhabov, 2004). While clusters are more restricted in Nakh-Dagestanian and NWC, Catford (1977) notes that most morpheme-initial clusters in Northwest Caucasian and intra-morphemic clusters in Nakh languages observe the same restriction as in Kartvelian whereby only harmonic clusters are possible, agreeing in laryngeal features, recessive, and consisting of a stop and a stop or fricative. The division of clusters into harmonic and non-harmonic thus appears to be shared by all Caucasian languages.

## **4 Processes**

Caucasian phonological systems are not characterized by a great amount of active synchronic phonological alternations. Some of the more common processes include vowel deletion in hiatus; root-final vowel deletion before a grammatical morpheme (e.g., in Nakh-Dagestanian); vowel deletion in open syllables; metathesis of /v/ and /r/ driven by the SSP (e.g., in Kartvelian); voice, place, or manner assimilation in clusters; dissimilation of two rhotics (e.g., in Georgian, Abkhaz, Abaza); labialization and delabialization of obstruents before rounded vowels; pharyngeal spreading; and vowel harmony (e.g., in Svan, Bezhta, Tsakhur).

Several processes that have the potential to affect phonological theory have gone unnoticed in Caucasian linguistics. I present them here with an appeal for further investigation, as many of these processes are poorly described.

### **4.1 Laz identical consonant deletion**

The Khopa subdialect of Laz, spoken in Sharpi, has a rule of identical consonant deletion. In a VC<sub>i</sub>VC<sub>i</sub> sequence, the first consonant is deleted in order to satisfy the OCP constraint: two identical segments are not permissible within adjacent syllables. Deletion of the consonant results in a hiatus that remains unresolved, e.g., /mkjapu-pe-k/ → [mkjaupek], /op'ts'op-up-t/ → [op'ts'oupt] or /bdziramionja/ → [bdziamionja] (Holisky, 1991, based on Kartoziya, 1968). In the Optimality Theoretic framework, this alternation is easy to account for: the OCP constraint that penalizes two identical consonants in onsets of adjacent syllables is ranked above the Max constraint. Despite theoretical predictability, such deletion, where a consonant is dropped before an identical consonant in the following syllable, is not typologically frequent. 0004866621.

### **4.2 Megrelian nasalization**



Harris (1991c) describes a rule in Megrelian whereby /p<sup>h</sup>/, /p'/, /b/, and /m/ turn into [n] before a consonant across a morpheme boundary, e.g. [k'ots-ep-i] vs. [k'ots-en-k] and [k'ots-en-s].

(1) [+lab] -> [+cor,+nas] / \_ - [+cons].

This alternation is limited to morpheme boundaries: it constitutes a case of Non-Derived Environment Blocking (NDEB; Kiparsky, 1993) where, as the name suggests, an alternation only operates in derived environments and is blocked elsewhere. Moreover, the alternation is not completely regular: it does not apply in all morphological environments (Harris, 1991c). This alternation triggers both change in manner, from obstruents to nasals, as well as change in place of articulation, from labial to coronal. At first sight, the alternation appears phonetically highly unmotivated; nasalization in a non-nasal environment (before a voiceless stop) is not phonetically easy to motivate. However, Megrelian syllable structure and cluster phonotactics might motivate the rule internally. It is reasonable to assume that the change in manner is motivated by the SSP: plateaus such as /-phkh#/ or /-phs#/ are repaired by increasing the sonority of the first element. Note, however, that /phs/ is a licit cluster in Megrelian. The change in place could be motivated by a restriction on Megrelian clusters, whereby the first element of a cluster in which second element is an obstruent has to be either /r/ or /n/. Further descriptive and experimental work is needed for more conclusive results.

### 4.3 Focus gemination

One of the more intriguing processes in Nakh-Dagestanian is focus gemination, reported for Chechen and Ingush (Nichols, 1994, 2011). The process targets the last intervocalic consonant in Chechen and first post-vocalic consonant of a word in Ingush when that word is in focus or emphasized. The consonant undergoes gemination, e.g., Ingush /lɒqɒ/ 'high' versus /lɒqqɒ/ 'high.foc' (Nichols, 2011). This process could also be analyzed as a C-reduplication of focused words, but because another synchronic process, word-final-gemination, produces identical results in Ingush (see 15.4.5), the analysis with gemination seems appropriate. In addition to gemination, focused words receive a special intonational pattern with both vowels around the geminated consonant receiving high pitch and emphasis. This intonation gives an acoustic impression of the word under focus featuring two stressed syllables (Nichols, 2011).

As Nichols points out, syntactic conditions of gemination are not always clear. For Chechen, this process seems to be "frozen in the lexicon" (Nichols, 1994, p. 20), but no such remarks are made for Ingush.

A similar process is reported in some verbal stems in Abkhaz (Hewitt, 1979a), where it is sporadic and analyzed as reduplication, e.g., /a-ħ<sup>w</sup>a-ra/ 'to say' and /a-ħ<sup>w</sup>ħ<sup>w</sup>a-ra/ 'to cry'. Gemination/reduplication in Abkhaz serves several functions: from adding intensive semantic component to onomatopoeia (Hewitt, 1979a). Further studies of this typologically rare phenomenon are needed.

## 4.4 Reduplication

Several reduplicative patterns emerge in Caucasian languages, ranging from C- or CVreduplication to total reduplication (e.g., Butskhrikidze, 2002; Schulze, 1997b). A typologically rare pattern is reported for Hinuq by Forker (2013c): reduplication morpheme is of the structure CVC(V), but the initial consonant of the reduplicated stem is replaced by /m/ or /t'/, e.g., [kole] versus [kole-mole], [hali] versus [hali-malica], [kottu] versus [k'ot-mottu], [roq'e] for [roq'e-t'oq'e]. The semantics of this reduplication is 'more emphatic or more extreme' and can target different parts of speech. This reduplication pattern is highly reminiscent of echo formations or the so-called shm-reduplication, but the semantics of Hinuq reduplication differs from the semantics of echo formations. Echo formations are "used to downplay or deride a particular phrase" (Nevins & Vaux, 2003); Hinuq reduplication is used for emphasis. This suggests that echo-formation types of reduplication which manipulate root-initial segments are possible in the function other than that of downplaying.

## 4.5 Processes targeting word-final voiceless stops

The rest of this section focuses on two processes in Nakh-Dagestanian that target consonants in word-final position: final gemination and final voicing. Both processes are typologically rare and arguably unnatural: they target the unmarked segment and turn it into a marked segment in a given environment. While final gemination might be phonetically motivated, final voicing is truly unnatural: it operates against a universal phonetic tendency that devoices word-final voiced obstruents (Beguš, 2019).

### 4.5.1 Final gemination

Nichols (2011) reports that consonants are geminated in word-final position in Ingush. Voiceless obstruents alternate with existing voiceless geminates, whereas consonants without phonemic geminate counterparts get phonetically geminated, e.g., [bat:] for /bat/ or [mag:w] for /magw/. Final gemination also targets stops and affricates (but not fricatives) in some, but not all, word-final clusters: [ford:] for /ford/. The application of the rule is morphologically conditioned: it applies in only a subset of morphological forms (Nichols, 2011).

Final gemination is typologically an unusual process. A survey of sound changes in Kümmel (2007) found only one case of final gemination, which, moreover, targets only a coronal nasal. Geminates are also articulatorily and perceptually dispreferred in wordfinal position. Long consonants are in general articulatorily more difficult to produce, but even more so in word-final position where segments have "reduced pulmonary pressure" (Iverson & Salmons, 2011, p. 1633). In addition, perceptual cues for closure duration are severely impoverished in word-final position.

While final gemination seems to operate against a universal phonetic tendency, it can also be motivated by a process that lengthens final segments. Segments are cross-linguistically phonetically longer in word-final position (Lindblom, 1968; Oller, 1973). Final gemination can

thus be analyzed as a phonetically motivated result of word-final phonetic lengthening. The morphologically limited scope of this rule, however, suggests that final gemination did not arise from a single sound change.

#### 4.5.2 Final voicing

Word-final or coda voicing (/T/ → [D] / \_#) is one of the most thoroughly discussed phonological processes. It is assumed to be a highly unnatural process which is either impossible or unattested synchronically.

The opposite process, final devoicing, has clear articulatory and perceptual motivations: phonation is difficult to maintain during closure, and this difficulty is even greater word-finally, where stops are produced “with reduced pulmonary pressure” (Blevins, 2004; Iverson & Salmons, 2011, p. 1633). Moreover, cues for presence or absence of voicing are perceptually impoverished in final position (Iverson & Salmons, 2011; Steriade, 1997). Passive phonetic devoicing in word-final position is attested even in languages without phonological final devoicing. Word-final devoicing thus fits the bill for a universal phonetic tendency (Beguš, 2019): it has a well-motivated phonetic explanation; there exists a phonetic tendency to devoice final stops even in languages without phonological devoicing; and it is very common and well-attested cross-linguistically.

Kiparsky (2006) claims that final voicing is never attested as a productive synchronic process, despite several diachronic scenarios that could lead to it (he identifies several such scenarios). In fact, he goes a step further and claims that final voicing is not only unattested but also impossible and that cognitive restrictions of synchronic grammar are responsible for this typological gap.

Because of these claims, final voicing has become a test case for the discussion of factors that influence phonological typology. The absence of final voicing is used as evidence in favor of the Analytic Bias approach that claims cognitive restrictions shape the typology; if diachronic explanation (Channel Bias; Moreton, 2008) is unable to explain the systematic gap, it has to be Universal Grammar that rules out final voicing. Blevins (2004) presents several cases of final voicing, but Kiparsky (2006) argues that none of these apparent cases qualify as synchronic final voicing—or, at least, that the described phenomena have competing alternative explanations.

The most robust example of word-final voicing is found in Lezgian, where word-final voicing targets final unaspirated stops and voices them, e.g., /rap/ → [rab] ‘needle’ (Fallon, 1998; Gajdarov, Giulmagomedov, Mejlanova, & Talibov, 2009; Haspelmath, 1993; Yu, 2004). Haspelmath (1993) and Yu (2004, p. 77) report that Lezgian distinguishes four stop series prevocally (plain voiced, voiceless ejective, voiceless aspirated, and plain voiceless), which in coda position get reduced to a three-way distinction: the plain voiceless series and voiced series merge into a single voiced series. In other words, Lezgian features a synchronic phonological alternation that targets an unmarked segment, word-final unaspirated voiceless stop, and turns it into a marked segment, voiced stops. Final voicing is limited to monosyllabic words.

The phonetic study in Yu (2004), however, shows that underlying voiced and plain voiceless series do not neutralize completely: there is a statistically significant difference between the two series in word-final position. Voiced consonants that derive from underlying plain voiceless stops have a significantly longer closure duration as well as a longer duration of voicing into closure. If we wish to maintain that Lezgian voices final stops, we must, at the same time, assume that these consonants receive (at least phonetic) lengthening as well. It is unclear from a synchronic perspective why this should happen.

The fact that the two series do not neutralize completely allows Kiparsky (2006) to propose an alternative analysis. He assumes that the Lezgian synchronic phonological system has four series of stops, but unlike Yu, he proposes that the fourth series consists of voiced geminates. Thus, instead of coda voicing, he assumes that the process in Table 15.10 is in fact onset degemination and devoicing (/D:/ → [T] / σ[ ]). Table 15.11 summarizes the two analyses.

Kiparsky's (2006) analysis, too, has its shortcomings. Like Yu, Kiparsky has to devise a two-step process: devoicing and degemination of voiced geminates in onset position, and onset devoicing is not a particularly common process in its own right. However, this derivation is by no means impossible, and Kiparsky (2008) provides evidence from other languages including Mordvin, Ewondo, and Lac Simon Algonquian (Iverson, 1983), demonstrating that initial devoicing is a possible synchronic phonological process. As a sound change, such development may be attested in Anatolian and in Selkup (Kümmel, 2007).

In sum, although Lezgian provides an apparently compelling example of final voicing, two major problems persist. First, the voicing process is limited to monosyllabic words. Second, the plain voiceless and voiced series do not neutralize completely in coda position; a phonetic difference between the two series is detectable. These problems pave the way for alternative proposals that analyze the alternating series as underlyingly voiced and assume that the synchronic phonological process in Lezgian is in fact onset devoicing rather than final voicing. Additionally, lack of speaker data from nonce word tests makes it difficult to determine how productive this process actually is. Further investigation of this typologically rare process is needed. For instance, wug tests could provide information on productivity, and dialectal research might reveal varieties that neutralize voiceless and voiced stops completely in word-final position.

Place	#	VV	
bilabial	rab	rapar	'needle'
dental	pad	patar	'side'
velar	mug	mukar	'nest'
uvular	rag	raqar	'sun'
dental	warz	wartsar	'moon'
post-alveolar	raz	rafar	'grain'

Table 10: Final voicing in Lezgian

Note: From Haspelmath (1993).

Yu (2004)		Kiparsky (2006)	
Input	Output	Input	Output
V	#		σ[ ]σ
D	D	D	D
T'	T'	T'	T'
T <sup>h</sup>	T <sup>h</sup>	T <sup>h</sup>	T <sup>h</sup>
T	D	D:	T D:

Table 11: Different input analyses of Lezgian stops in Yu (2004) and Kiparsky (2006)

## 5 Conclusion and future directions

This chapter surveyed major topics of segmental phonetics, phonotactics, and phonological alternations of Caucasian languages. Details on individual languages can be found in descriptive chapters on language families and individual languages in this volume.

The section on phonemic inventories focuses on a few main topics in each family: laryngeal features, typologically rare segments or rare phonemic oppositions, and pharyngealization. New experimental data from Georgian are presented and some phonetic generalizations, such as gradual shortening of aspiration in the context before another aspirated stop, are reported for the first time. The first section also features a new acoustic and statistical analysis of already existing recordings of Ubykh. The section on phonotactics focuses on consonant clusters and their role in the discussion on the role of perception versus production in phonology. Finally, the last section on active phonological alternations reviews data from Caucasian in light of discussion on naturalness and universals in phonology.

Each section reveals that even the major topics in Caucasian phonetics and phonology are understudied and point to those aspects that merit further research. It is surprising that languages of the Caucasus have not received more attention in phonetic and phonological literature, especially given their rich inventories of segments and a number of typologically unusual processes.

Several research projects could produce results that would be relevant for phonetic and phonological theory. Pharyngeals and pharyngealization, velar lateral fricatives, ejective fricatives, and doubly articulated bilabio-alveolar stops are some of the highly unusual segments of Caucasian languages, yet detailed and systematic phonetic descriptions of these phenomena are still lacking. Standards and technological availability of both acoustic and articulatory research tools and methods have improved dramatically since last major studies of Caucasian phonetics were undertaken; thus, the first next step in phonetic research of the Caucasus should involve instrumental acoustic and articulatory descriptions of at least those dialects that feature typologically unusual segments. Articulatory real-time MRI or ultrasound studies of pharyngeals, epiglottals, pharyngealization, and epiglottization could offer insight into the phonetics of the

radical part of the vocal tract and answer questions such as the following: Is phonemic contrast between pharyngeal and epiglottal place of articulation possible? What are acoustic correlates of pharyngeal versus epiglottal place of articulation? Exactly how many different possible articulations are there in the radical part of the vocal tract and what are their mechanisms, and what (if any) are phonetic differences between consonantal and vocalic pharyngealization? Articulatory studies of velar laterals, NWC series of sibilants, and ejective fricatives would reveal where precisely in the vocal tract the point of constriction is made for these segments and what are their acoustic correlates. The outstanding question of how we define a doubly articulated stop versus a secondary articulation and, relatedly, are doubly articulated bilabio-alveolar stops even possible should be explored on the case of NWC labialized alveolars: further, articulatory and acoustic studies of these segments, especially with respect to timing difference between two constrictions, are a desideratum.

Other topics worthy of further investigation include correlation in different acoustic parameters between stops with different laryngeal features (both intra- and inter-dialectally), phonetic typology of ejectives, phonetic effects of ejectives on neighboring sounds, and causes of aspiration dissimilation.

In phonology, several experimental studies could have a bearing on theory construction. An experimental study in the form of well-formedness judgments could reveal whether the restriction of large clusters to word-initial versus word-final position in Georgian versus Svan is part of active synchronic phonology in these two languages. Likewise, Lezgian final voicing has been analyzed phonetically and phonologically in detail, but no experimental studies exist that test synchronic productivity of this rule, and those would provide invaluable further insights into naturalness in phonology. Similarly, thorough descriptive and experimental studies of other less well-described unnatural or typologically unusual processes discussed in this chapter, such as final gemination, focus gemination, Megrelian nasalization, or Laz identical consonant deletion, would also yield further insights for theoretical questions in phonology.

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