TYNDALE UNIVERSITY

3377 Bayview Avenue
Toronto, ON
M2M 3S4

TEL:
416.226.6620
www.tyndale.ca

Pre-print citation: Kochetov, Alexei, and Paul Arsenault. "Kalasha Affricates: An Acoustic Analysis of Place Contrasts." *Journal of South Asian Languages and Linguistics*, 6, no. 2, (2020): 1-24. Preprint. https://doi.org/10.1515/jsall-2019-2013

This is a pre-copyrighted, version of the article accepted for publication in the Journal of South Asian Languages and Linguistics.

Version of Record (VOR) Citation: Kochetov, Alexei, and Paul Arsenault. "Kalasha Affricates: An Acoustic Analysis of Place Contrasts." *Journal of South Asian Languages and Linguistics*, 6, no. 2, (2020): 245-280. (https://doi.org/10.1515/jsall-2019-2013)

Alexei Kochetov and Paul Arsenault

Kalasha affricates: An acoustic analysis of place contrasts

Abstract: Kalasha (Northwestern Indo-Aryan, spoken in Pakistan) exhibits a complex set of ten affricate phonemes, which is exceedingly rare among the world's languages and not representative of the broader South Asian context. This paper presents results of an acoustic analysis of place contrasts (dental, retroflex, and alveolopalatal) in affricates of four laryngeal specifications (voiceless unaspirated, voiceless aspirated, non-breathy voiced, and breathy voiced). These consonants were produced by four male speakers of Kalasha in a variety of phonetic contexts, resulting in a sample of close to 700 affricate tokens. A series of acoustic analyses of the data revealed that place contrasts in Kalasha affricates are distinguished robustly by both burst/frication spectra and formant transitions, but not by duration, which correlates more with laryngeal features. Place distinctions are somewhat diminished for voiced affricates but are largely unaffected by aspiration and syllable position. Most of these results are consistent with what is known about comparable (yet laryngeally simpler) place contrasts in other languages outside of South Asia. However, some of them are unique and may reflect the typological uniqueness and complexity of Kalasha's affricate system.

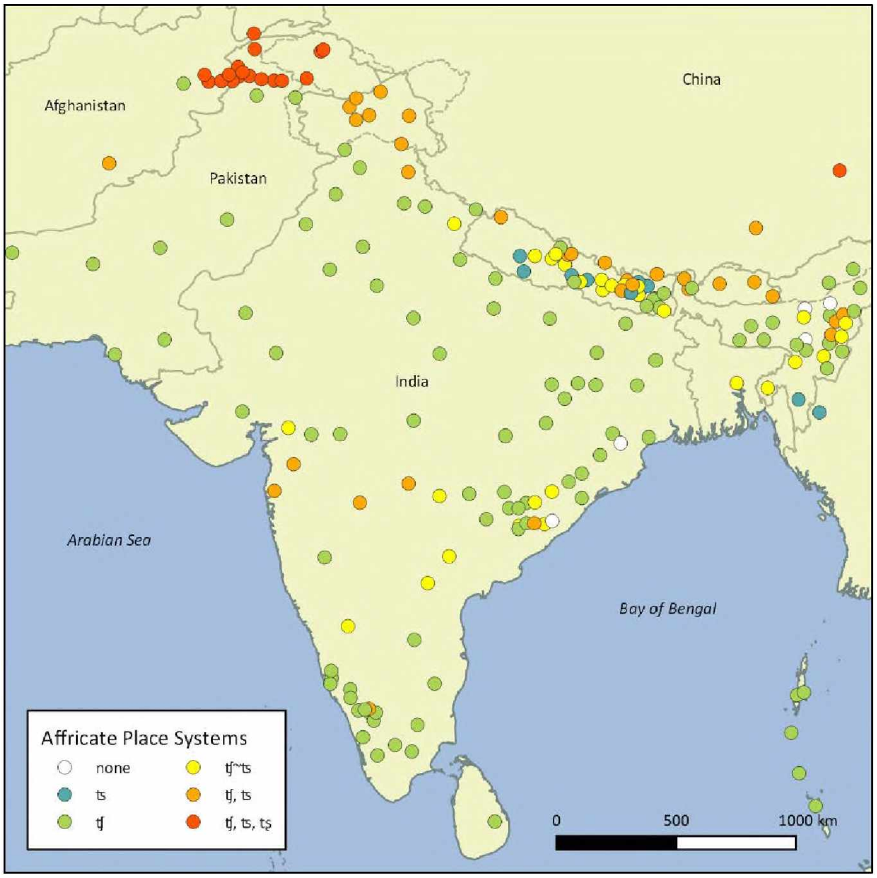
Keywords: Kalasha, Indo-Aryan, affricates, acoustic analysis, spectra, typology

1 Introduction

Affricates are not uncommon in consonant inventories of world languages. However, most languages have affricates at a single place of articulation (e.g. postalveolars /ʧ, ʤ/; Maddieson 1984). In Maddieson & Precoda's (1990) sample of 451 languages, only 18% of them have affricates at two places, and just 3% have affricates at three places. The latter group includes Burushaski (isolate), Jaqaru (Aymaran), Mandarin Chinese (Sino-Tibetan), and Mazatec (Oto-Manguean), where affricates contrast at the dental/alveolar, retroflex, and alveolopalatal places of articulation. Kalasha and other Indo-Iranian (Indo-Aryan and Nuristani) languages of the Hindu-Kush region are not part of this sample, but they exhibit equally complex place contrasts in affricates, which are not characteristic of other Indo-Iranian languages. For instance, Kalasha features a three-way place contrast (dental, retroflex, and alveolopalatal) with four laryngeal qualities: voiceless unaspirated, voiceless aspirated, voiced, and breathy voiced. Such complex feature combinations are highly unusual in affricates, being reported in only two cases in Maddieson & Precoda's sample: Naxi (Sino-Tibetan) and Hmong (Hmong-Mien). In this paper we examine properties of the typologically rare set of affricates in Kalasha, focusing on the acoustic realization of place across various laryngeal contrasts and syllable positions. Our results demonstrate that the three-way place contrast in Kalasha affricates is robustly distinguished by noise spectra during burst/frication and by formant transitions during adjacent vowels, while showing some variation across different laryngeal classes. These results extend the phonetic typology of coronal place contrasts, highlighting some general and language-specific aspects of the phonetic realization of affricates. In addition, the results of the study contribute to the general phonetic documentation of Kalasha, the language of a culturally and linguistically threatened community of Northern Pakistan (Rahman 2006; Khan & Heegård Petersen 2016).

1.1 Kalasha affricates in the South Asian context

Most South Asian languages have a series of so-called 'palatal stops', which are realized as laminal postalveolar affricates, either palatoalveolar (/ʧ/) or alveolopalatal (/ʨ/). These typically exhibit laryngeal contrasts for voicing (i.e. /ʧ/ vs. /ʤ/) and (in some cases) aspiration and breathy voice (i.e. /ʧ/ vs. /ʧʰ/ vs. /ʤ/ vs. /ʤʱ/). In most cases, the postalveolar affricates are the only affricates in the language. Some languages of south-central India exhibit a contrast or variation between denti-alveolar and laminal postalveolar affricates (/ʦ/ vs. /ʧ/ or [ʦ]~[ʧ]; e.g. Marathi, Konkani, and others). Similar patterns of contrast and variation are found in languages of the Himalayan region, most notably (but not exclusively) among languages of the Tibeto-Burman family. The most complex affricate systems of South Asia are found in languages of the Hindu-Kush region in northern Pakistan and Afghanistan, an area characterized by a "proliferation of affricates" (Ramanujan & Masica 1969: 565). Languages in this region typically exhibit a typologically rare three-way contrast between dental/alveolar, alveolopalatal, and retroflex affricates (/ts/ vs. /tɕ/ vs. /ʈʂ/).[1] Each of these generalizations can be seen in Map 1, which shows the geographic distribution of affricate place systems in languages of South Asia.



Map 1: Affricate place systems in languages of South Asia.[2]

Kalasha (ISO 639-3: kls), also known as Kalashamon, is a Northwestern Indo-Aryan language with approximately 5,000 speakers in the Chitral District of Khyber Pakhtunkwa Province in northern Pakistan (Eberhard *et al.* 2019). Like other languages of the Hindu Kush region, it maintains a contrast between dental (denti-alveolar), alveolopalatal, and retroflex affricates. These place contrasts are further supplemented with contrasts for voicing, aspiration, and breathy release, as shown in Table 1 (based on Trail & Cooper 1999; Heegård & Mørch 2004). The result is four affricate phonemes per place, except for the dental and retroflex series, which lack /ʣʱ/ and /ɖʐʱ/. Laryngeal contrasts are neutralized in syllable codas. Thus, all affricates occur in syllable onsets (word-initially and medially), but only voiceless unaspirated affricates occur in syllable codas (word-medially and finally), except after nasals, where they may be voiced (Trail & Cooper 1999; Heegård Petersen 2015). Words illustrating the various Kalasha affricates are listed in (1). Note that, although it is not phonemic, [ɖʐʱ] is reflected in the language orthography (Trail & Cooper 1999), as it occurs in cases of progressive voicing assimilation (see (1c)).

Table 1: Kalasha consonant phonemes; segments in parentheses are marginal phonemes; segments in square brackets are sub-phonemic.

	Bilabial	Dental/ Alveolar	Retroflex	Alveolo-palatal	Velar	Glottal

[1] A similar three-way place contrast among affricates is also found in some Sino-Tibetan languages of China.

[2] This map was created with QGIS 3.4. Language data was extracted from a survey of literature describing 260 language varieties in South Asia and surrounding areas. See Arsenault (2017) for details.

	Bilabial		Dental/ Alveolar		Retroflex		Alveolo-palatal		Velar		Glottal
Plosive	p	b	t	d	ʈ	ɖ			k	g	
	p^{h}	b^{ɦ}	t^{h}	d^{ɦ}	ʈ^{h}	ɖ^{ɦ}			k^{h}	g^{ɦ}	
Affricate			ʦ	ʣ	ʈʂ	ɖʐ	ʨ	ʥ			
			ʦ^{h}		ʈʂ^{h}	[ɖʐ^{ɦ}]	ʨ^{h}	ʥ^{ɦ}			
Fricative	(f)		s	z	ʂ	ʐ	ɕ	ʑ	(x)		h
Nasal		m		n		(ɳ)					
Rhotic				r							
Lateral				ɫ lj							
Approximant		w						j			

(1) Place and laryngeal contrasts in Kalasha affricates (data from Trail & Cooper 1999)

a. Dental

/ʦ/	ʦat	'size'	ʈriʦ	'(kind of) bird'
/ʦ^{h}/	ʦ^{h}ar	'funeral food'		
/ʣ/	ʣaraj	'rennet'		

b. Alveolopalatal

/ʨ/	ʨaw	'four'	diʨ	'earlier'
/ʨ^{h}/	ʨ^{h}ar	'noise'		
/ʥ/	ʥa	'wife'		
/ʥ^{ɦ}/	ʥ^{ɦ}aw	'fence'		

c. Retroflex

/ʈʂ/	ʈʂok	'unstable'	diʈʂ	'sexual abstinence'
/ʈʂ^{h}/	ʈʂ^{h}ok	'pulp'		
/ɖʐ/	ɖʐaʈʂ	'spirit beings'		
[ɖʐ^{ɦ}]	katag ɖʐ^{ɦ}ir (/katag ʈʂ^{h}ir/)	'new milk'		

Diachronically, alveolopalatal affricates in Kalasha have three main sources: (i) retention of Old Indo-Aryan (OIA) palatal stops; (ii) palatalization of OIA dental stops when they were followed by /j/; and (iii) fortition of /j/ in word-initial position (Turner 1962–1966, Trail & Cooper 1999). Retroflex affricates have evolved historically from the OIA consonant cluster /kʂ/ (Morgenstierne 1973; Masica 1991) or from alveolopalatal affricates under the influence of regressive consonant harmony (Arsenault & Kochetov 2011, Arsenault 2012, 2015). Dentals are the least frequent affricates in the Kalasha lexicon (especially voiced /ʣ); their origins are mostly obscure, although some cases can be reliably attributed to the OIA /t/ + /s/ sequence (Morgenstierne 1973). In sum, Kalasha exhibits a rich set of place and laryngeal contrasts in affricates. Some of these are inherited from Old Indo-Aryan, while others are innovations.

1.2 Acoustics of affricate places and the current study

Previous phonetic descriptions of Kalasha affricates have been largely impressionistic (Trail & Cooper 1985; Heegård & Mørch 2004; De Carlo 2010; Heegård Petersen 2015). The same can be said about descriptions of affricates in neighboring languages, such as Dameli (Perder 2013), Indus Kohistani (Zoller 2005), Khowar (Liljegren & Khan 2017), Palula (Liljegren & Haider 2009), and Wakhi (Yoshie 2005) – all of which exhibit similar 3-way place contrasts in affricates (but with fewer laryngeal distinctions). To the best of our knowledge, there has been no acoustic investigation of affricates in any language of the Hindu-Kush region. The goal of this study is to provide an acoustic characterization of place contrasts in Kalasha affricates and discuss our findings in relation to previous acoustic work on similar contrasts in languages outside the region.

Our analysis of Kalasha builds on insights obtained from studies of affricates in languages such as Anong (Thurgood 2009), Komi-Permyak (Kochetov & Lobanova 2007), Mandarin (Svantesson 1986; Lee 1999; Mays 2008), Polish

(Żygis, Pape, & Jesus 2012), and Serbian (Miller-Ockhuizen & Zec 2003), among others. Each of these languages distinguishes retroflex affricates from alveolopalatal affricates (or apical postalveolars from laminal postalveolars). Apart from Komi-Permyak, each of them also distinguishes these posterior affricates from some form of anterior coronal affricate, either dental or alveolar. Table 2 summarizes relevant results of these studies with respect to place differences among voiceless affricates. The studies varied in terms of the acoustic properties that were investigated. Altogether, however, it is evident that complex affricate contrasts are distinguished by a combination of noise spectra (affricate burst and/or frication), vowel transitions to or from affricates, and occasionally by affricate duration. In general, retroflex and alveolopalatal spectra are characterized by noise concentrated at mid-to-low frequencies (measured as noise centre of gravity, COG, or its main peaks), compared to dentals or alveolars, which exhibit noise concentrated at higher frequencies. The noise spectra of posterior affricates are often described as 'peaked' and less variable (higher kurtosis and lower SD) relative to anterior affricates. They also exhibit a more gradual decrease of energy toward higher frequencies (lower skewness). Within the posterior class, retroflexes tend to have lower and more defined spectral peaks than alveolopalatals, while alveolopalatals tend to have longer releases and higher F2 transitions from adjacent vowels. Curiously, retroflex affricates did not show lower F3 transitions in these languages, as expected of retroflex consonants (Ladefoged & Maddieson 1996; Hamann 2003). This suggests that they may not be produced with significant tongue tip retraction. It is worth noting that retroflexion is limited to affricates, or maximally to sibilants (affricates and fricatives), in these languages; whereas, in Kalasha, the retroflex affricates are part of a larger set of retroflex phonemes that includes (unaffricated) plosives, vowels, and possibly nasals.

Table 2: Selected results of previous studies of place of articulation in affricates: Thurgood (2009) on Anong (Tibetan; onset /tsʰ, ʈʂʰ, tɕʰ/), Kochetov & Lobanova (2007) on Komi-Permyak (Finno-Ugric; onset and coda /ʈʂ, tɕ/), Miller-Ockhuizen & Zec (2003) on Serbian (Slavic; onset /ʈʂ, tɕ/), Svantesson (1986; S) on Mandarin (Chinese; onset /ts, tsʰ, ʈʂ, ʈʂʰ, tɕ, tɕʰ/), Lee (1999; L) and Mays (2008; M) on Mandarin (onset /ts, ʈʂ, tɕ/), and Żygis et al. (2012b) on Polish (Slavic; onset /ts, tɕ, ʈʂ/); see Section 2.3.2 for descriptions of variables.

Component/Variable		**Differences**	**Language**
burst spectra	COG	tɕ > ʈʂ	Komi-Permyak
		tɕ > ts > ʈʂ	Polish
	SD	ts > tɕ > ʈʂ	Polish
	kurtosis	ʈʂ > tɕ > ts	Polish
	skewness	ts > tɕ > ʈʂ	Polish
frication spectra	COG	tsʰ > tɕʰ > ʈʂʰ	Anong
		tɕ > ʈʂ	Serbian
		ts(h) > tɕ(h) > ʈʂ(h)	Mandarin (S)
		ts > tɕ > ʈʂ	Mandarin (L)
		ts > tɕ, ʈʂ	Mandarin (M)
		ts > tɕ > ʈʂ	Polish
	SD	ts > tɕ > ʈʂ	Polish
	kurtosis	ʈʂ > ts, tɕ	Mandarin (M)
	skewness	tɕ, ʈʂ > ts	Mandarin (M)
		ts > tɕ > ʈʂ	Polish
release duration		tɕ > ʈʂ	Komi-Permyak
		tɕ > ʈʂ	Serbian
		tɕ > ʈʂ	Mandarin (M)
		ts, tɕ > ʈʂ	Polish
formant transitions	F1	tsʰ > tɕʰ, ʈʂʰ	Anong
		ʈʂ > tɕ	Komi-Permyak
		ts, ʈʂ > tɕ	Polish
	F2	no differences	Anong
		tɕ > ʈʂ	Komi-Permyak
		tɕ > ʈʂ	Serbian
		tɕ > ts, ʈʂ	Mandarin (M)

Component/Variable	Differences	Language
	ʨ > ʦ, ʈʂ	Polish
F3	no differences	Anong
	no difference	Komi-Permyak
	no difference	Polish

Among the studies reviewed, only two (Mays 2008; Żygis *et al.* 2012b) examined the full range of acoustic variables in Table 2, and only one of them (Żygis *et al.* 2012b) examined both burst and frication intervals of affricates. The use of two intervals was found to be important, as each one provides somewhat different information about place contrasts. In our study, we follow this approach. Similarly, we also employ spectral moments (Forrest *et al.* 1988), a set of measures that quantitatively characterize spectral shapes (see Section 2.3.2).

Most of the previous studies have focused on a subset of affricates, typically voiceless unaspirated ones (/ʦ, ʨ, ʈʂ/). We include affricates of all laryngeal specifications – voiceless aspirated and unaspirated, as well as modal and breathy voiced affricates (henceforth, voiced unaspirated and aspirated, respectively). We also include syllable position as a potential factor affecting the realization of place contrasts. Previous studies have shown that spectral and durational properties of noise can be realized somewhat differently for voiceless and voiced consonants (at least in fricatives; Jongman, Wayland, Wong 2000; Jesus & Shadle 2002; Żygis, Fuchs, & Koenig 2012), as well as for onset and coda positions (Kochetov & Lobanova 2007). While examining the full set of Kalasha affricates, we focus on measurements distinguishing place. Thus, we do not consider measurements specific to laryngeal features, such as F0 and H1-H2 (see e.g. Clements & Khatiwada 2007 and Mikuteit & Reetz 2007 on affricates in Nepali and Bengali).

In sum, the primary goal of the current study is to identify the spectral properties distinguishing place contrasts in Kalasha affricates, and to compare these results with those obtained for similar contrasts in other languages. A secondary goal is to determine if and how place contrasts in Kalasha affricates are affected by laryngeal features (voicing and aspiration) and syllable position. The study also contributes to the phonetic documentation of this relatively understudied and threatened South Asian language.

2 Method

2.1 Speakers

For the purpose of this study, four male speakers of Kalasha were recorded, henceforth referred to as KM1-KM4. All were males in their thirties (with the mean age of 32) from the Bumburet (Mumoret) valley in Chitral, Pakistan. They left their home country in their early twenties, and at the time of the recording were residing in Greece. All four speakers are multilingual, with Greek, English, Khowar, and Urdu listed as their other languages. Khowar, in particular, was acquired by the speakers in their early childhood, as it is the lingua franca of the Chitral valley (Bashir, 2003; Liljegren & Khan 2017). Although all the speakers reported using Kalasha regularly and maintaining close contact with the Kalasha community in Pakistan, potential influences of other languages on their Kalasha speech cannot be discounted. These could, in principle, be manifested in less distinct realizations of place and/or laryngeal contrasts in affricates, as the contact languages exhibit smaller phonemic sets of these sounds: /ʦ, ʣ/ in Greek (Arvaniti 2007), /ʧ, ʤ/ in English, /ʧ, ʧʰ, ʤ, ʤʱ/ in Urdu (Schmidt 2003), and /ʦ, ʦʰ, ʣ, ʈʂ, ʈʂʰ, ɖʐ, ʨ, ʨʰ, ʥ/ in Khowar (Liljegren & Khan 2017).

2.2 Materials and procedure

We compiled a word list to investigate various phonetic and phonological phenomena of Kalasha. The list was based on Trail & Cooper's (1999) Kalasha dictionary and verified with speaker KM1. For the present study, we selected recordings of 169 lexical items containing 177 affricates, as summarized in Table 3. Counts of items (affricate occurrences in words) varied per affricate phoneme and syllable position due to inherent differences in phoneme frequency and phonotactic distribution within the Kalasha lexicon (e.g. dental affricates are relatively infrequent and laryngeal contrasts are neutralized in syllable codas; see Section 1). The allophone [ɖʐʱ] was also included and treated as a distinct sound for our purposes, because it is distinguished orthographically in Trail and Cooper's (1999) dictionary (see (1c)). Onset position included word-initial and word-medial affricates; coda position consisted of word-final affricates. All words were produced in isolation, typically twice. In total, 687 tokens were collected. Numbers of tokens varied across speakers: 391 tokens for KM1, 64 for KM2, 48 for KM3, and 184 for KM4. Data sets for each speaker contained all place and laryngeal contrasts, except for /tsʰ/ and [ɖʐʱ] in the case of KM2, and /tɕʰ/ in the case of KM3.

Table 3: Counts of occurrences of affricates in words (items) and tokens used in the study.

Place	**Laryngeal features**	**C**	**Position**				**Total**	
			onset		**coda**			
			items	**tokens**	**items**	**tokens**	**items**	**tokens**
dental	voiceless unaspirated	/ts/	5	22	5	22	10	44
	voiceless aspirated	/tsʰ/	2	10	--	--	2	10
	voiced unaspirated	/dz/	6	24	--	--	6	24
retroflex	voiceless unaspirated	/ʈʂ/	20	82	10	44	30	126
	voiceless aspirated	/ʈʂʰ/	21	74	--	--	21	74
	voiced unaspirated	/ɖʐ/	4	17	--	--	4	17
	voiced aspirated	[ɖʐʱ]	1	6	--	--	1	6
alveolopalatal	voiceless unaspirated	/tɕ/	58	242	16	50	74	292
	voiceless aspirated	/tɕʰ/	11	20	--	--	11	20
	voiced unaspirated	/dʑ/	15	62	--	--	15	62
	voiced aspirated	/dʑʱ/	3	12	--	--	3	12
		All	146	571	31	116	177	687

The recordings were made in a quiet room in Thessaloniki, Greece for KM1 and KM4, and in Athens, Greece, for KM2 and KM3, using a *Zoom H4n* digital recorder and an *AudioTechnica AT831b* lavalier microphone, with a 44,100 Hz sampling rate.

2.3 Analysis

2.3.1 Annotation

Annotation and acoustic analysis were performed using Praat (Boersma & Weenink 2018). All tokens with affricates were annotated as shown in Figure 1, indicating intervals of the affricate closure (when detectable), affricate release (containing the burst, frication, and aspiration/breathy voice, if present), and the following or preceding vowel. Occasionally, affricates showed more than one burst (namely in alveolopalatals produced by KM1). In such cases, the release was taken to begin from the last burst. Acoustic measurements were made during the affricate release and the following/preceding vowels. These are described in more detail in the following subsections.

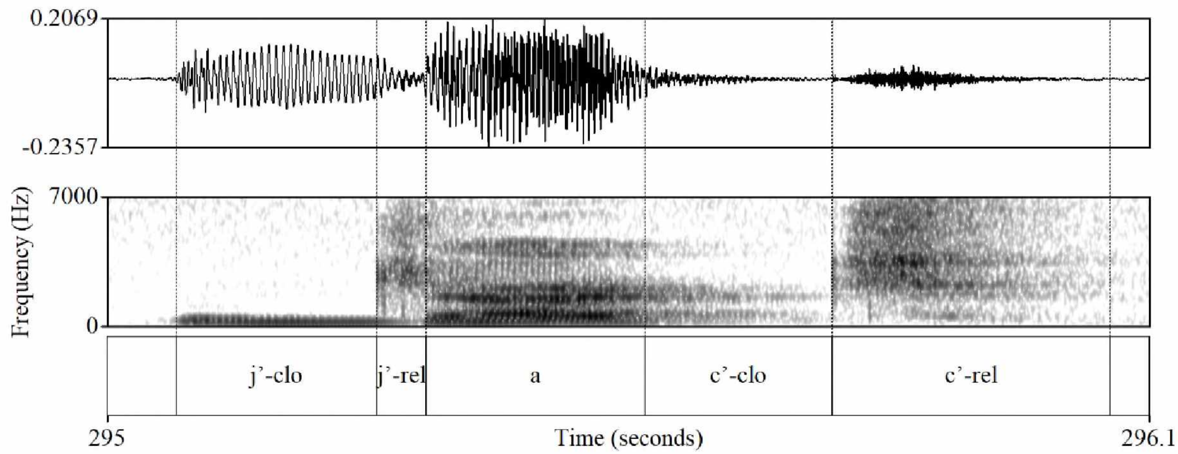


Figure 1: An example of data annotation for the word [dʑatʂ] 'spirit beings' (speaker KM1, repetition 2), with the labels *j'-clo* and *c'-clo* indicating affricate closures and *j'-rel* and *c'-rel* indicating affricate releases.

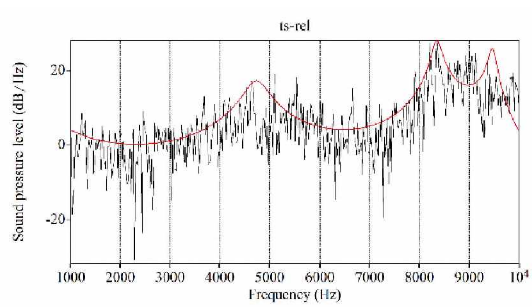
2.3.2 Burst/frication spectra and release duration

Four spectral moments – COG (Hz), SD (Hz), kurtosis, skewness (as defined below) – were extracted at five evenly distributed intervals during the affricate release. Interval 1 was used to analyze spectral properties of the affricate burst (for both onset and coda affricates). Interval 3 was used for the analysis of frication in unaspirated onset affricates, while interval 2 was used for coda affricates and aspirated onset affricates. This choice was based on the typical location of the highest noise intensity (around the midpoint or around 2/3 of the release). Spectral moments are commonly used to characterize noise spectra of obstruents (Forrest *et al.* 1988), and affricate places in particular (Mays 2008; Żygis *et al.* 2012b). They can be defined as follows:

- *Spectral centre of gravity* (COG, also called centroid or the first spectral moment): shows the mean frequency of the spectrum weighted by intensity.
- *Standard deviation* (SD) or variance: shows how much the frequencies in a spectrum can deviate from the centre of gravity (in Hz), i.e. the range of energy concentration.
- *Kurtosis*: shows how much the shape of the spectrum around COG is different from the Gaussian shape, i.e. more or less peaked; positive kurtosis indicates higher 'peakedness'; negative kurtosis indicates a flatter distribution.
- *Skewness*: shows how much the shape of the spectrum below the centre of gravity is different from the shape above COG, i.e. the spectral tilt or slant of the energy distribution; positive skewness indicates more energy at lower frequencies; negative skewness indicates energy at higher frequencies.

The use of spectral moments is illustrated in Figure 2 using tokens from one of our speakers.

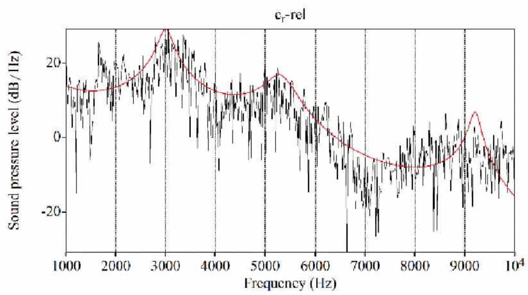
a.



/ts/

The highest intensity regions are at higher frequency (→ high COG, 7863 Hz), spread over a relatively wide range of frequencies (→ high SD, 1507 Hz); the spectrum around the peak is less peaked, flatter (low kurtosis, 3.64); the spectrum is tilted to increase from low to high frequencies (→ low skewness, -2.00).

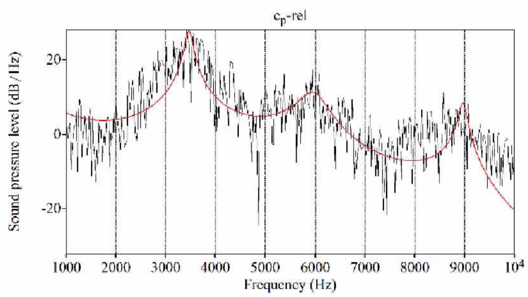
b.



/tʂ/

The highest intensity regions are at low frequencies (→ low COG, 2977 Hz), spread over a relatively narrow range (→ low SD, 1122 Hz); the spectrum around the peak is relatively peaked, showing a greater amplitude change (high kurtosis, 7.75); the spectrum is tilted to decrease from low to high frequencies (→ high skewness, 2.06).

c.



/tɕ/

The highest intensity regions are at low frequencies (→ low COG, but somewhat higher than for /tʂ/, 3829 Hz), spread over a relatively narrow range (→ low SD, 1334 Hz); the spectrum around the peak is relatively peaked (high kurtosis, 5.02); the spectrum is tilted to decrease from low to high frequencies (→ high skewness, 2.01).

Figure 2: Sample spectra of the frication noise in [tsat] 'size', [tʂaʂa] 'cheese', and [tɕapei] 'scar' (single tokens) produced by KM1, with an explanation of how these patterns are captured by spectral moments.

Duration (in seconds) was measured for the entire affricate release portion, including the burst, frication, and aspiration/breathy voice, if present.

2.3.3 Formant transitions

Vowel formants F1-F3 (Hz) were extracted at five evenly distributed intervals. For onset consonants, interval 1 was selected to represent C-V transitions; for coda consonants interval 5 was selected to represent V-C transitions. Formant values that exceeded 2.5 standard deviation from the median (6% of the data) were considered tracking errors and excluded from the analysis.

2.3.4 Statistical analyses

Given some inherent gaps in the distribution of affricates (i.e. no voiced or aspirated affricates in coda and no /dʑʱ/), the data were divided into several subsets for the purposes of statistical analysis.

Two subsets were used to analyze frication spectra and release duration. One subset contained affricates of all laryngeal specifications occurring in onset position ('place and laryngeal features in onset'). Another set contained voiceless affricates in onset and coda positions ('place and position in voiceless affricates'). The first subset was analyzed using two mixed effects models. Fixed factors were Place (dental, retroflex, alveolopalatal) and Voice (voiceless, voiced) in the first model, and Place and Aspiration (unaspirated, aspirated) in the second model[3] Random effects were the same for both models: Speaker (with random intercepts, and random slopes for Place) and Word (random inter-

[3] Note that separate analyses of voicing and aspiration were necessary given the absence of /dʑʱ/ in the inventory and some gaps for breathy voiced affricates in the data for KM2 and KM3. While the first analysis was performed on the data from all speakers, the second one was performed on data from KM1 and KM4.

cepts only).[4] For the second set ('place and position in voiceless affricates'), the model contained fixed factors of Place (dental, alveolopalatal, retroflex) and Position (onset, coda), while random effects were Speaker and Word (as above). The models were run separately for each acoustic variable: COG, SD, kurtosis, skewness, and duration. For spectral measurements, this was done for burst (interval 1) and frication (intervals 2 or 3).

Vowel transitions were analyzed in the context of all vowel qualities (/a, i, u, o/) except /e/, which did not occur next to dentals in our data. The model contained fixed factors of Place (dental, alveolopalatal, retroflex) and Position (onset, coda), and random effects of Speaker and Vowel Quality. Vowel Quality was used as a random effect because it captured the extensive vowel-specific variation better than Word.

All analyses were performed using the *lme4* package (Bates *et al.* 2015) for *R* (R Core Team). P-values were obtained using the chi-square test implemented in the *Anova()* function of the *lmerTest* package (Kuznetsova *et al.* 2017). Overall, the statistical analysis was expected to determine which acoustic parameters significantly distinguished affricates of different places (for the group as a whole), and whether those parameters varied based on laryngeal features and syllable position.

3 Results

Results are presented separately for affricate burst (3.1), affricate frication and release duration (3.2), and vowel formant transitions (3.3). For reasons of space, we present only summaries of statistical results. (Complete output tables of statistical analyses can be provided upon request.)

3.1 Burst spectra

3.1.1 Place and laryngeal features in onset position

Results of the LME models for four spectral moments are summarized for the Place effect in Table 4 and for Voice effect in Tables 5. As shown in Table 4, all four spectral moments were significantly affected by Place. In other words, affricate spectra differed systematically in terms of noise distribution and shape, depending on place of articulation. Pairwise comparisons revealed that most of the differences were between retroflexes, on one hand, and dentals or alveolopalatals, on the other (i.e. /ʈʂ, ʈʂʰ, ɖʐ/ and [ɖʐʱ] vs. /ts, tsʰ, dz, tɕ, tɕʰ, dʑ, dʑʱ/). Specifically, COG and SD were significantly lower for retroflexes, while kurtosis and skewness were higher, compared to other places. This indicates that, unlike dentals and alveolopalatals, retroflex bursts were characterized by a lower frequency and narrower distribution of noise, and by more pronounced peaks with a sharper decrease of energy toward higher frequencies. In addition, dentals showed a higher SD (a wider distribution of high intensity noise) than alveolopalatals. Significant interactions of Place and Voicing for COG and skewness indicated that some of the place differences were suspended in voiced affricates compared to their voiceless counterparts. Figure 3 illustrates differences in spectral moments by Place and Voicing. Means and standard deviation by consonant are provided in the Appendix (Table A1).

Table 4: Summary of statistical results for onset burst and release duration: Place effect (significance levels: '***' < 0.001 '**' < 0.01 '*' < 0.05, 'sg' significant, 'ns' 'not significant'); cells with non-significant results are shaded.[5]

Place	Comparisons	Interactions	Comment

[4] More complex models, with slopes for Speaker and Word, were also attempted but did not converge.

[5] Tables 4–10 are organized in a way similar to outputs of statistical models and post-hoc tests. They indicate whether a fixed factor of interest (e.g. the column 'Place' in Table 4) was significant and whether significant differences were manifested at some or all levels (place contrasts in the column 'Comparisons'). The tables also show whether the factor of interest significantly interacted with other fixed factors (the column 'Interactions'). Significant interactions are further explained in the column 'Comment'. For example, Table 4 indicates a highly significant ($p < 0.001$) effect of Place on COG. It further shows results of a post-hoc analysis, indicating that the Place effect was manifested in 2 out of 3 place contrast comparisons (at different levels of significance: $p < 0.01$ and $p < 0.001$). The table also indicates that Place significantly interacted with Voice (at $p < 0.001$), reflecting the fact that significant Place differences were limited to voiceless affricates and did not involve voiced ones.

		dental vs. alveolopalatal	dental vs. retroflex	alveolopalatal vs. retroflex		
COG	***	ns	dent>ret**	pal>ret***	Voice***	sg for vls only
SD	***	dent>pal*	dent>ret**	pal>ret***	ns	
kurtosis	**	ns	ret>dent**	ret>pal*	ns	
skewness	***	ns	ret>dent**	ret>pal*	Voice**	sg for vls & vd; also pal > dent for vls only

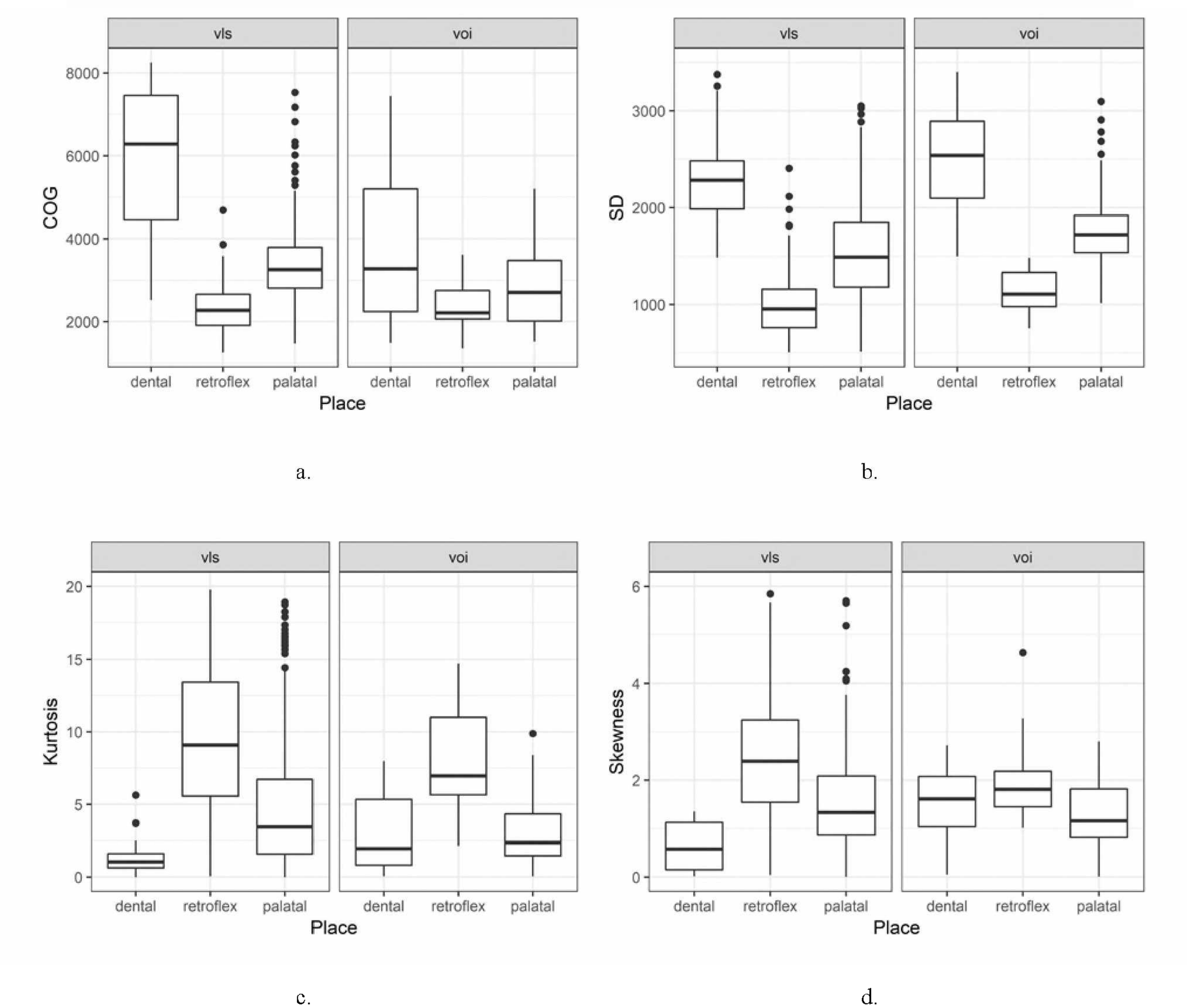


Figure 3: Boxplots for (a) COG (Hz), (b) SD (Hz), (c) kurtosis, and (d) skewness by Place and Voice (vls and voi) in onset affricates during the burst interval.[6]

Most spectral moments were also affected by Voicing (Table 5). Voiceless affricates showed higher COG and kurtosis, and lower SD than their voiced counterparts. The COG difference was limited to dentals and alveolopalatals. In addition, dentals showed higher skewness for voiced affricates than for voiceless ones.

An analysis of Aspiration (performed for speakers KM1 and KM4; see Footnote 3), not shown in the tables, revealed that this factor affected only COG: bursts of aspirated (and breathy voiced) affricates had higher values than

[6] In this and the following figures, boxplots are used to display the distribution of data. In each case, the middle "box" captures the middle 50% of the data (inter-quartile range) for a particular category; the horizontal line within the box indicates the median value; vertical lines outside the box show the upper and lower quartiles (the minimum and maximum 25% of the data); black circles further above or below indicate outliers.

their unaspirated counterparts. However, these differences were relatively small: 3275 vs. 3188 Hz. Dentals also showed lower SD values for aspirated affricates compared to unaspirated ones.

Table 5: Summary of statistical results for onset burst and release duration: Voicing effect

	Voicing effect	Comparisons voiceless vs. voiced	Interactions	Comment
COG	***	vls>vd	Place***	sg for pal & dent only
SD	***	vd>vls	ns	
kurtosis	*	vls>vd	ns	
skewness	ns	--	Place**	vd > vls for dent only

In sum, our analysis of burst spectra showed that the main differences were between retroflexes, on the one hand, and dentals and alveolopalatals, on the other. These differences were clearly captured by measurements of all four spectral moments. Furthermore, the retroflex/non-retroflex differences were manifested most clearly in voiceless affricates, as voiced spectra for all places of articulation had relatively lower frequency noise and a wider distribution of energy around the peak.

3.1.2 Place and position for unaspirated voiceless affricates

The analysis of voiceless affricates across syllable positions was intended to determine whether place differences in burst spectra were consistent in onset and coda. It revealed significant effects for three out of four spectral moments (see Table 6). These effects were due to significantly lower COG and SD, and significantly higher skewness, for retroflexes compared to the other places. Differences in kurtosis were also significant, but only for onset position where retroflexes showed higher kurtosis values than dentals and alveolopalatals. Positional differences (see Table 7) were observed for COG and kurtosis, with onsets showing lower values for the former (onset 3208 vs. coda 3890 Hz) and higher values for the latter variable (9.29 vs. 6.35). (See means and SDs in Table A2.)

Table 6: Summary of statistical results for burst in voiceless unaspirated affricates: Place effect

	Place effect	Comparisons			Interactions	Comment
		dental vs. alveolopalatal	dental vs. retroflex	alveolopalatal vs. retroflex		
COG	***	ns	dent>ret***	pal>ret***	ns	
SD	***	ns	dent>ret***	pal>ret***	ns	
kurtosis	ns	--	--	--	Position**	ret > dent, pal in onset only
skewness	***	ns	ret>dent***	ret>pal*	ns	

Table 7: Summary of statistical results for burst in voiceless unaspirated affricates: Position effect

	Position effect	Comparisons onset vs. coda	Interactions	Comment
COG	***	coda>onset	ns	
SD	ns	--	ns	
kurtosis	**	onset>coda	Place**	onset > coda for ret only
skewness	ns	--	ns	

In sum, the results for unaspirated voiceless affricates confirmed that the most significant differences in spectral burst were found in the retroflex vs. non-retroflex distinction, as reported for the entire set in the previous section. A new finding here is that spectral differences, apart from kurtosis, held for both onset and coda affricates, despite some positional variation in affricate spectra.

3.2 Frication spectra and duration

Turning to frication, the purpose of these analyses was to determine how place differences are distinguished in the *frication* portion of affricates, and whether the information provided by the frication is different from that provided by the burst. Again, we were interested in whether laryngeal features and syllable position affect the characterization of place contrasts. We also considered possible effects of place and laryngeal setting on the duration of affricate releases.

3.2.1 Place and laryngeal features in onset position

The results of the LME models for four spectral moments taken during the frication interval are summarized for the Place effect in Table 8, and for the Voice effect in Table 9. As with the burst (3.1.1), all four spectral moments were significantly affected by Place. However, here most pairwise differences were between dentals, on the one hand, and alveolopalatals and retroflexes, on the other (as opposed to retroflex vs. non-retroflex). Specifically, COG and SD were significantly higher for dentals, while kurtosis and skewness were lower, compared to other places. In addition, retroflexes showed lower COG than alveolopalatals. Significant interactions for Place and Voicing indicated that some of the place differences were reduced in voiced affricates (COG and skewness) or present in voiced affricates only (SD). Differences in spectral moments by Place and Voicing are illustrated in Figure 4. Means and standard deviations by consonant are provided in the Appendix (Table A3), which also contains plots with individual results for COG (Figure A1a), showing that speakers are consistent in their realization of the three place categories.

Table 8: Summary of statistical results for frication in onset affricates: Place effect

	Place effect	**Comparisons**			**Interactions**	**Comment**
		dental vs. alveolopalatal	**dental vs. retroflex**	**alveolopalatal vs. retroflex**		
COG	***	dent>pal***	dent>ret***	pal>ret**	Voice***	lesser differences for vd
SD	***	dent>pal*	dent>ret**	ns	Voice***	sg for voi only
kurtosis	*	pal>dent*	ret>dent*	ns	ns	
skewness	***	pal>dent*	ret>dent*	ns	Voice*	lesser magnitude for voi
duration	ns	--	--	--	ns	

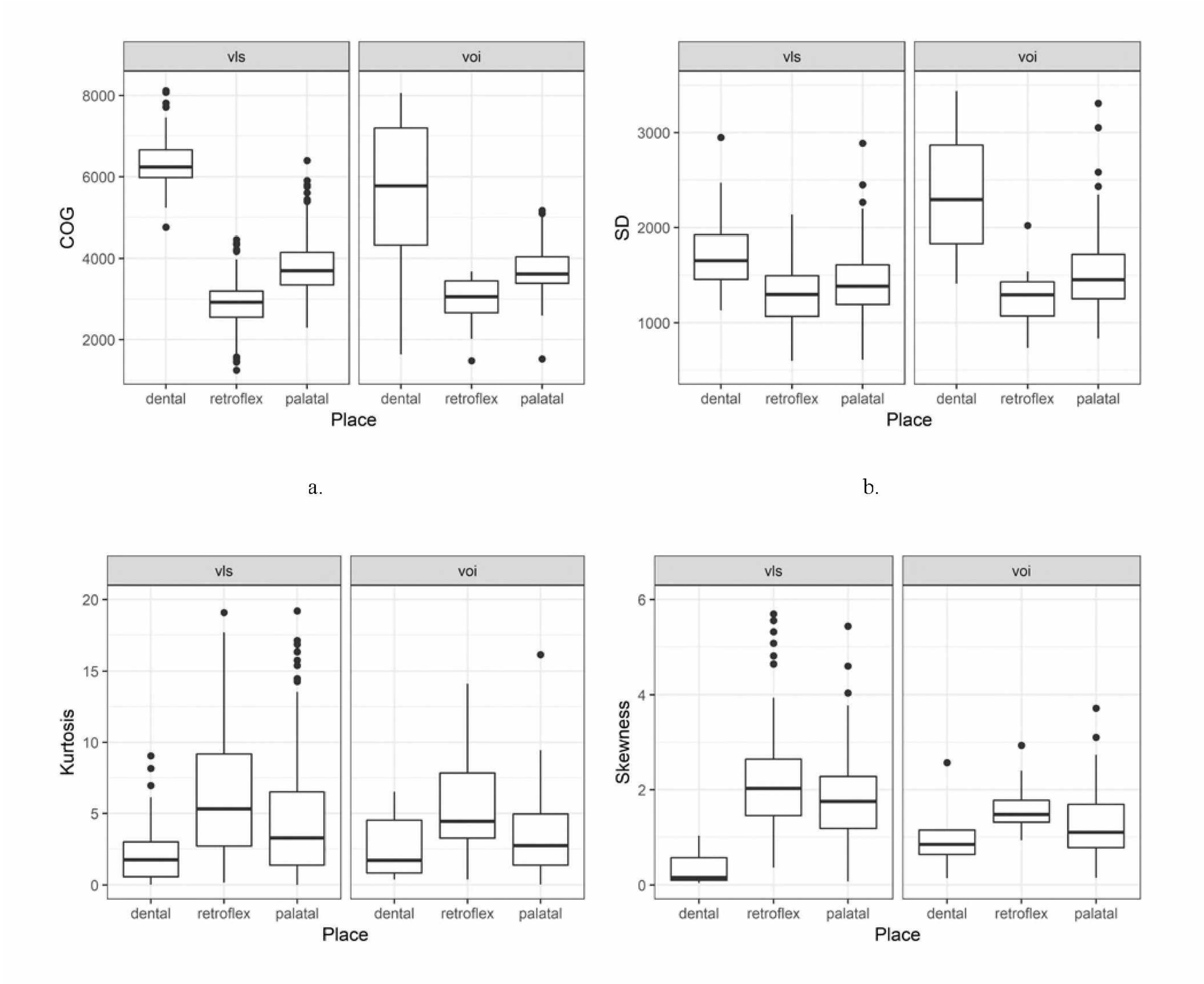


Figure 4: Boxplots for (a) COG (Hz), (b) SD (Hz), (c) kurtosis, and (d) skewness by Place and Voice (vls and voi) in onset affricates during the frication interval.

All spectral moments except kurtosis were also affected by Voicing (Table 9), with voiceless affricates showing higher COG and skewness, and lower SD, relative to their voiced counterparts. However, these differences were only significant for some places of articulation. A separate analysis of frication by aspiration revealed no significant differences (not shown here).

Duration of affricate release did not differ by place of articulation (Table 8) but did differ according to voicing (Table 9). Voiceless affricates had a considerably longer release than voiced ones. Significant differences were also observed for Aspiration, with aspirate releases being considerably longer than unaspirated ones ($p < 0.0001$). Duration differences by voicing and aspiration can be observed in Figure 5.

Table 9: Summary of statistical results for frication in onset affricates: Voicing effect

	Voicing effect	**Comparisons voiceless vs. voiced**	**Interactions**	**Comment**
COG	***	vls>vd	Place***	sg for dent only
SD	***	vd>vls	Place***	sg for dent only
kurtosis	ns	--	ns	

	Voicing effect	Comparisons voiceless vs. voiced	Interactions	Comment
skewness	*	vls>vd	Place*	for pal only
duration	***	vls>vd	ns	

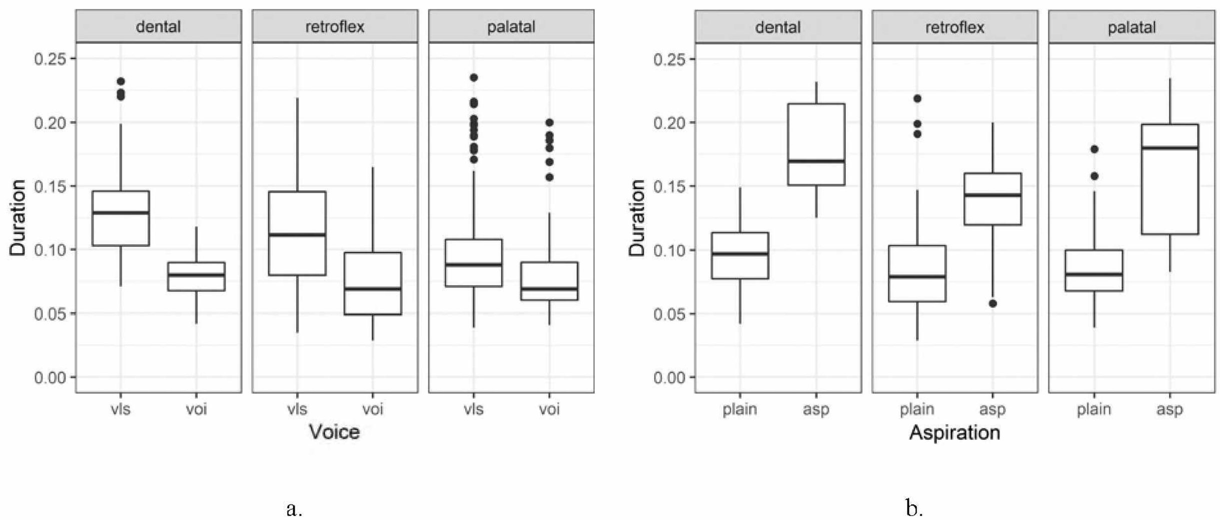


Figure 5: Boxplots for release duration (seconds) by (a) Voicing (all speakers) and (b) Aspiration (2 speakers) in onset affricates.

3.2.2 Place and position for unaspirated voiceless affricates

The analysis of voiceless affricates across syllable positions revealed the same differences for Place as reported in Section 3.2.1, except that there were no differences in kurtosis. That is, dentals showed higher COG and SD, and lower skewness compared to the other places. Positional differences in spectral moments were absent, except for some places (onset > coda for COG in dentals and SD in alveolopalatals). Coda affricate releases were significantly longer than onset releases for all places of articulation ($p < 0.0001$; onset 0.090 vs. coda 0.299). This difference can be attributed to positional lengthening, given that all coda affricates were utterance-final in the data. (See Table A4 for means and SDs.)

In sum, the results for frication showed that spectral differences primarily involved dentals and non-dentals (retroflex and alveolopalatal). This differs from the burst results (Section 3.1), where the primary distinction was between retroflexes and non-retroflexes. As in the case of burst, voicing tended to reduce spectral place differences during the frication interval, with voiced affricates having more distributed intensity peaks at lower frequencies. In contrast, aspiration had no effect on affricate spectra. Although duration did not serve to differentiate place, it did distinguish both voicing and aspiration, resulting in a 3-way duration contrast between unaspirated voiced (short), unaspirated voiceless (intermediate), and aspirated voiceless/breathy voiced affricates (long).

3.3 Formant transitions: Place and Position

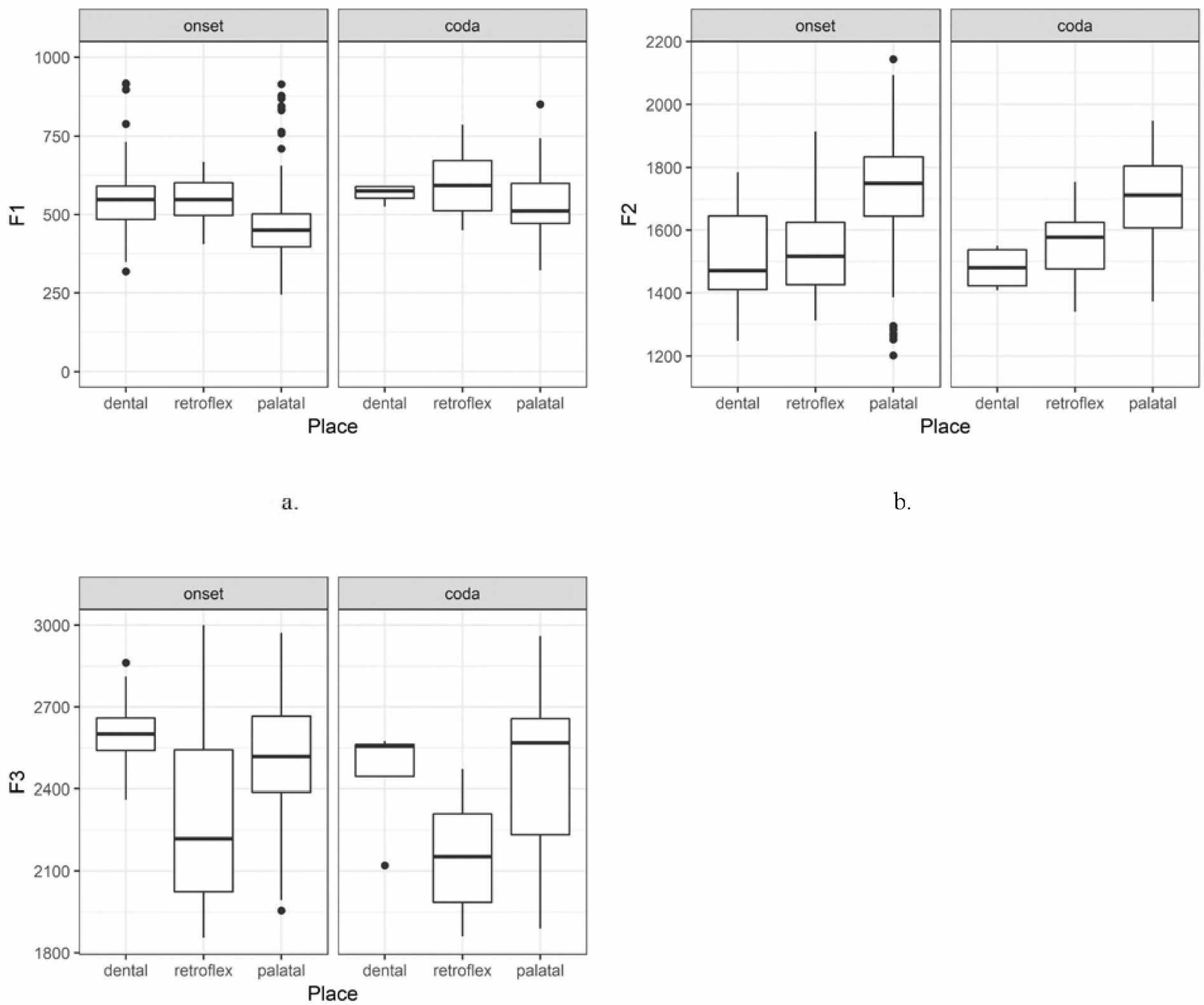
Finally, formant transitions were analyzed to determine if they contribute to place distinctions in affricates, and if they differ depending on syllable position. As shown in Table 10, all three formants were affected by Place. However, pairwise differences were observed only for some place pairs. Alveolopalatals had lower F1 values than dentals and retroflexes, and this difference was greatest in onset position. Alveolopalatals were also characterized by higher F2 values than the other places, while retroflexes exhibited lower F3 values than dentals and alveolopalatals. There were some differences based on syllable position (not shown in the table): onset affricates had significantly lower F1 values (for retroflexes and alveolopalatals only) and higher F3 values overall.

Differences in formants across places and syllable positions for one of the vowels, /a/, are illustrated in Figure 6. Note that F2 and F3 differences for place were relatively large: on average (pooled over positions and vowels) F2 was

153-176 Hz higher for alveolopalatals, and F3 was 201-281 Hz lower for retroflexes, compared to other places. In contrast, F1 differences between alveolopalatals and other places were relatively small, averaging 59-68 Hz. Means and standard deviations for formants are provided in the Appendix (Table A5). The Appendix also provides individual results for F3 (Figure A1b), which show that all speakers exhibit lower F3 next to retroflexes, relative to the other places of articulation.

Table 10: Summary of statistical results for formant transitions: Place effect

	Place effect	Comparisons			Interactions	Comment
		dental vs. alveolopalatal	dental vs. retroflex	alveolopalatal vs. retroflex		
F1	***	ns	ns	ret>pal***	Position*	greater difference in onset
F2	***	pal>dent***	ns	pal>ret***	ns	
F3	***	ns	dent>ret***	pal>ret***	ns	



c.

Figure 6: Boxplots for formants F1-F3 in Hz by Place and Position, transitions from vowel /a/ to/from affricates.

In summary, results for formant transitions revealed place differences involving all three formants. However, the most significant differences were between alveolopalatals and non-alveolopalatals with respect to F2, and between retroflexes and non-retroflexes with respect to F3. Some positional differences in formants were also observed.

4 Discussion

The primary goal of this study was to investigate acoustic properties of place of articulation within Kalasha's complex and typologically rare set of affricates. The main results for place of articulation are summarized in Table 11. Recall that, among the reviewed studies, only Żygis *et al.* (2012b) examined spectral properties of both burst and frication intervals, noting some differences in the information they provide. The current results confirm the usefulness of this approach because the two sets of measurements provided complementary information about Kalasha affricates. Specifically, burst spectra primarily distinguished retroflexes from non-retroflexes (dental and alveolopalatal), while frication spectra primarily distinguished dentals from posterior coronal places (retroflex and alveolopalatal). In both cases, retroflexes were characterized by strong concentrations of noise at lower frequencies (lower COG and SD), clearly defined intensity peaks (higher kurtosis), and a gradual decrease of energy towards higher frequencies (higher skewness). In both cases, dentals showed the opposite pattern: more variably distributed noise at higher frequencies (higher COG and SD), weaker defined intensity peaks (lower kurtosis), and a gradual increase of energy towards higher frequencies (lower skewness). Alveolopalatals showed different patterns depending on the interval that was measured. They were more like dentals in their burst and more like retroflexes in frication. This suggests that the location of constriction in alveolopalatal affricates changes from the closure to the frication, being more anterior (likely alveolar) for the former and more posterior (likely alveolopalatal) for the latter.

Overall, the spectral results for Kalasha are largely consistent with previous studies of similar affricate contrasts. Lower COG (or main peak) for retroflexes compared to dentals and alveolopalatals was also reported for voiceless (unaspirated or aspirated) affricates in Anong (Thurgood 2009; based on frication), Mandarin (Svantesson 1986; Lee 1999; Mays 2008; based on frication), and Polish (Żygis *et al.* 2012b; based on both burst and frication). The same difference was reported for the retroflex-alveolopalatal contrast in Komi-Permyak (Kochetov & Lobanova 2007, based on burst) and Serbian (Miller-Ockhuizen & Zec 2003, based on frication). (Note that the latter two studies did not analyze dental affricates.) The results for other spectral moments are also largely consistent with previous work, most notably with Mays's (2008) findings for Mandarin and the findings of Żygis *et al.* (2012b) for Polish. The posterior affricates of Kalasha, as measured in the frication interval, have lower SD (as in Polish, but not in Mandarin), higher kurtosis (as in both Mandarin and Polish), and higher skewness (as in Mandarin, but not in Polish), relative to anterior affricates. Similar differences were also observed for the Kalasha retroflex-dental contrast during the burst interval, comparable to results for Polish and Mandarin. The different patterning of Kalasha alveolopalatals in burst and frication measurements has a parallel in Polish. There, however, alveolopalatal /ʨ/ had the highest COG of the three places, which suggests an even greater adjustment of place between closure and frication in Polish. In previous studies, all observations about place differences were based on unaspirated voiceless affricates (or voiceless aspirated ones in Anong). The current study is the first to show that place differences are largely consistent across laryngeal categories, although they tend to be reduced (or absent for some variables) in the voiced series.

There is at least one notable difference between Kalasha's affricates and those of the other languages reviewed. Our study found no correlation between place of articulation and duration of affricate release (burst plus frication and aspiration, if present). This stands in contrast to other studies, where retroflexes were found to have a shorter release duration than other affricates (Miller-Ockhuizen & Zec 2003; Kochetov & Lobanova 2007; Mays 2008; Żygis *et al.* 2012b). It is possible that duration differences for place are suppressed in Kalasha due to the important role that duration plays in signaling laryngeal contrasts (see below). All the languages reviewed here have fewer laryngeal contrasts than Kalasha; they have either two laryngeal categories (Komi-Permyak, Polish, and Serbian) or three (Anong and Mandarin), whereas Kalasha has four.

Table 11: Summary of results across different analyses of place of articulation.

Variable		**Place differences**
burst spectra	COG	ʦ, ʦʰ, ʨ, ʨʰ > ʈʂ, ʈʂʰ
	SD	ʦ, ʦʰ, ʣ > ʨ, ʨʰ, ʥ, ʥʱ > ʈʂ, ʈʂʰ, ɖʐ, ɖʐʱ
	kurtosis	ʈʂ, ʈʂʰ, ɖʐ, ɖʐʱ > ʦ, ʦʰ, ʣ, ʨ, ʨʰ, ʥ, ʥʱ (but for vls. in onset only)
	skewness	ʈʂ, ʈʂʰ, ɖʐ, ɖʐʱ > ʦ, ʦʰ, ʣ, ʨ, ʨʰ, ʥ, ʥʱ
frication spectra	COG	ʦ, ʦʰ, ʣ > ʨ, ʨʰ, ʥ, ʥʱ > ʈʂ, ʈʂʰ, ɖʐ, ɖʐʱ
	SD	ʣ > ʥ, ʥʱ, ɖʐ, ɖʐʱ
	kurtosis	ʈʂ, ʈʂʰ, ɖʐ, ɖʐʱ > ʦ, ʦʰ, ʣ (but no diff. in position analysis)

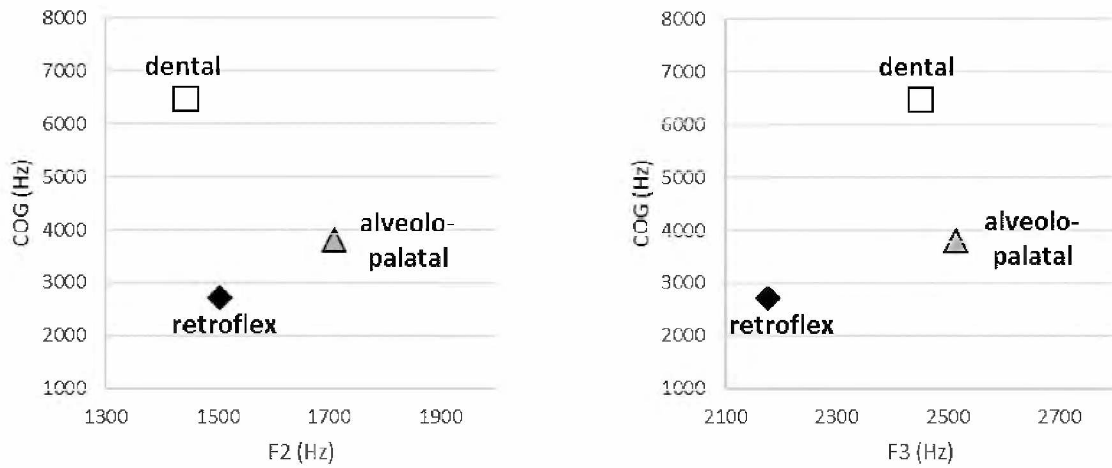
Variable		Place differences
	skewness	ʈʂ, ʈʂʰ, ʨ, ʨʰ > ʦ, ʦʰ
release duration		no differences
formant transitions	F1	ʈʂ, ʈʂʰ, ɖʐ, ɖʐʱ > ʨ, ʨʰ, ʥ, ʥʱ
	F2	ʨ, ʨʰ, ʥ, ʥʱ > ʦ, ʦʰ, ʣ, ʈʂ, ʈʂʰ, ɖʐ, ɖʐʱ
	F3	ʦ, ʦʰ, ʣ, ʨ, ʨʰ, ʥ, ʥʱ > ʈʂ, ʈʂʰ, ɖʐ, ɖʐʱ

Our results indicate that formant transitions to or from affricates also provide important information about place of articulation, supplementing the robust cues found in burst and frication spectra. Firstly, alveolopalatals were distinguished from other places by a higher F2, and from retroflexes by a lower F1. The low F1 and high F2 of alveolopalatals reflect the raising and fronting of the tongue body to produce this articulation (Ladefoged & Maddieson 1996). Secondly, retroflex affricates were distinguished from all non-retroflexes by a lower F3. Although F3 was lower overall for retroflexes, it also varied somewhat by position: it was lower in VC transitions than in CV transitions. The low F3 for retroflexes indicates that the tongue tip is raised and retracted behind the alveolar ridge. The difference in F3 between VC and CV transitions indicates that the tongue tip moves forward (to some degree) between the onset and release of retroflex affricates (Ladefoged & Maddieson 1996; Hamann 2003).

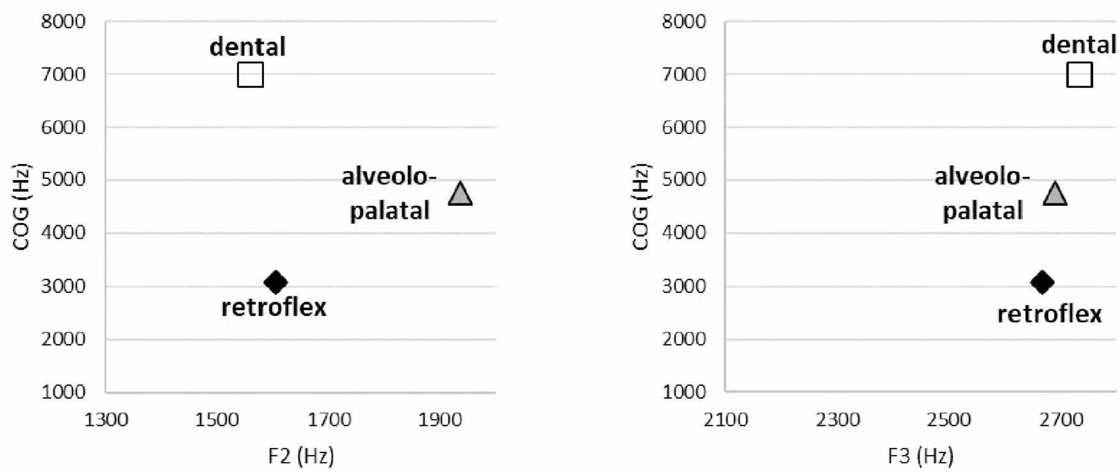
The Kalasha results for F2, and to some extent F1, are consistent with most previous studies. F2 was found to be significantly higher next to alveolopalatals as opposed to retroflexes or dentals (if examined) in Komi-Permyak, Mandarin, Polish, and Serbian (Kochetov & Lobanova 2007; Mays 2008; Żygis *et al.* 2012b; Miller-Ockhuizen & Zec 2003). In addition, alveolopalatals were found to have lower F1 transitions compared to retroflexes in Komi-Permyak and Polish. However, none of these differences were observed in Anong (Thurgood 2009), possibly reflecting lesser magnitude or temporal extent of tongue body raising/fronting for alveolopalatals in that language. Differences in F2 observed for Kalasha are also of interest given the use of this parameter (as manifestation of secondary palatalization or velarization) to enhance contrasts in crowded phonemic inventories (e.g. Kochetov 2017 on Russian sibilant fricatives; Punnoose, Khattab, & al-Tamini 2013 on Malayalam liquids).

The considerable lowering of F3 before and after Kalasha retroflexes is expected of this place of articulation (Hamann 2003). Nevertheless, it is a novel finding for affricates. F3 lowering has been conspicuously absent in previous studies of retroflex affricates in other languages. Specifically, studies of Komi-Permyak (Kochetov & Lobanova 2007), Mandarin (Mays 2008), and Polish (Żygis *et al.* 2012b) found no significant differences in F3 between retroflex and non-retroflex affricates. In these languages, retroflexion is either limited to affricates or, maximally, to affricates and fricatives. Moreover, retroflex affricates in Mandarin and Polish are alternatively classified as apical postalveolar (Lee & Zee 2003; Jassem 2003). Kalasha is unique in that its retroflex affricates are part of a robust system of retroflex phonemes that includes stops, affricates, fricatives, vowels, and possibly nasals. This may have a bearing on how retroflex affricates are articulated in the language. For instance, previous descriptions have suggested that Kalasha affricates are produced with notable tongue tip retraction, possibly to a greater degree than its retroflex stops (Heegård & Mørch 2004). This would explain why Kalasha affricates are clearly distinguished by lowering of F3 in both VC and CV transitions, while retroflex affricates in some other languages are not.

To illustrate some important similarities and differences between Kalasha and one of the languages reviewed, Figure 7 plots average COG and F2/F3 values for affricates in Kalasha and Polish. Data for Polish are from Żygis *et al.* (2012b: Appendix), where voiceless affricates were analyzed in onset position before /a/. To facilitate the comparison, we selected Kalasha voiceless unaspirated affricates in the same phonetic context. The Polish sample included female and male speakers; hence formant and COG values are higher on average than those in the Kalasha sample. The plots on the left side of Figure 7 indicate that the three-way place contrast is distinguished by COG during the frication interval in both languages (dental > alveolopalatal > retroflex), with F2 further differentiating alveolopalatals from dentals and retroflexes. The patterns are remarkably similar, although Polish shows a slightly greater difference in F2 (likely reflecting a greater degree of tongue body raising/fronting). In contrast with this, the plots on the right side of Figure 7 are quite different. Kalasha clearly distinguishes retroflex affricates from others in terms of F3, while Polish hardly shows any difference in F3 between the various affricates.



a. Kalasha



b. Polish

Figure 7: Acoustic space for (unaspirated) voiceless fricative contrasts, arranged by frication COG and F2 (left) or COG and F3 (right) for (a) Kalasha and (b) Polish (from Żygis et al. 2012b).

A secondary goal of the study was to determine if and how place contrasts are affected by laryngeal features (voicing and aspiration) and syllable position. The main results for laryngeal features and syllable position are summarized in Table 12. The results showed that affricate voicing was captured well by burst spectra. Overall, voiced affricates tended to have lower COG and kurtosis, and higher SD, relative to their voiceless counterparts. These trends reflect a lower frequency noise distribution in voiced affricates, with greater variation and less pronounced peaks. This had the effect of reducing distinctions for place between voiced affricates. This finding provides further evidence for the view that place distinctions between voiced affricates are not as phonetically robust as their voiceless counterparts and, hence, are less common cross-linguistically (Żygis *et al.* 2012a). Voicing differences were less evident in the frication period where they were limited to either dentals or alveolopalatals. Aspiration, by comparison, was only distinguished by burst COG, possibly reflecting a slightly different tongue placement for aspirates. Both voicing and aspiration were clearly distinguished by affricate release duration. Unaspirated voiced affricates had the shortest release durations, aspirated and breathy affricates had the longest, and voiceless unaspirated affricates were intermediate. Such differences are well expected and consistent with previous work on four-way laryngeal contrasts in general (e.g. Benguerel & Bhatia 1980 on Hindi, Clements & Khatiwada 2007 on Nepali; Mikuteit & Reetz 2007 on affricates in Nepali and Bengali). It should be noted that our results for aspiration and (in particular) breathiness should be considered tentative, given relatively small numbers of tokens and uneven distribution of relevant contrasts across the speakers (see Table 3). The use of these laryngeal features requires further attention, given some previously noted instability in the language (Heegård & Mørch 2004) and differences between Kalasha and other neighboring languages, including Khowar (Liljegren & Khan 2017).

Some positional differences were also observed in our results (cf. Kochetov & Lobanova 2007 on Komi-Permyak). Apart from duration differences that were expected given the reading task (i.e. utterance-final lengthening), these were rather small in magnitude and limited to a few variables. Overall, syllable position did not significantly affect the realization of place contrasts.

Table 12: Summary of results across different analyses of laryngeal features and position.

Variable		**Laryngeal differences (onset)**	**Position differences (voiceless)**
burst spectra	COG	ʦ, ʦʰ, ʨ, ʨʰ > ʣ, ʥ, ʥʱ ʦʰ , ʨʰ, ʈʂʰ, ɖʐʱ, ʥʱ > ʦ , ʨ, ʈʂ, ʣ, ɖʐ, ʥ	coda > onset
	SD	ʣ, ɖʐ, ɖʐʱ, ʥ, ʥʱ > ʦ, ʦʰ, ʨ, ʨʰ, ʈʂ, ʈʂʰ ʦ > ʦʰ	no differences
	kurtosis	ʦ, ʦʰ, ʨ, ʨʰ, ʈʂ, ʈʂʰ > ʣ, ɖʐ, ɖʐʱ, ʥ, ʥʱ	onset > coda (for ʈʂ only)
	skewness	ʦ, ʦʰ > ʣ	no differences
frication spectra	COG	ʦ, ʦʰ > ʣ	no differences
	SD	ʣ > ʦ, ʦʰ	no differences
	kurtosis	no differences	no differences
	skewness	ʨ, ʨʰ > ʥ, ʥʱ	no differences
release duration		ʦ, ʦʰ, ʨ, ʨʰ, ʈʂ, ʈʂʰ > ʣ, ɖʐ, ɖʐʱ, ʥ, ʥʱ ʦʰ, ʨʰ, ʈʂʰ, ɖʐʱ, ʥʱ > ʦ, ʨ, ʈʂ, ʣ, ɖʐ, ʥ	coda > onset
formant transitions	F1	n/a	coda > onset (ʨ, ʈʂ only)
	F2	n/a	no differences
	F3	n/a	onset > coda

Finally, it should be noted that this study was based on data obtained from Kalasha speakers who have lived outside the home community for an extensive period of time. The results indicate that native contrasts in affricates, as produced by our speakers, remain robust and consistent with previous descriptions (cf. Heegård & Mørch 2004), and do not seem to show obvious effects of other contact languages. It is nevertheless important for future research to validate these findings based on data from larger groups of speakers residing in the ambient community. It is also important to systematically examine differences in the realization of affricates (and other sounds) between Kalasha and Khowar, and possible influences of the latter, sociolinguistically dominant language.

5 Conclusion

In conclusion, the three-way place contrast in Kalasha affricates is distinguished reliably by a combination of burst spectra, frication spectra, and formant transitions, but not by duration of burst, which correlates more with laryngeal features than with place. The distinction between dental and posterior places (alveolopalatal and retroflex) is signaled most clearly by frication spectra; while the distinction between retroflex and non-retroflex (dental and alveolopalatal) places is signaled most clearly by burst spectra and F3 transitions. Alveolopalatals are most clearly distinguished by F2 transitions. Place distinctions are somewhat diminished for voiced affricates but, overall, aspiration and syllable position have minimal effect on the realization of place contrasts.

Most of these results are consistent with what is known about comparable contrasts in other languages outside of South Asia. However, some of them are unique and may reflect the typological uniqueness and complexity of Kalasha's affricate system. For instance, while burst/frication duration correlates with place in other languages, it correlates with laryngeal features in Kalasha, possibly reflecting the fact that Kalasha maintains more laryngeal distinctions than any of the other languages previously investigated. Similarly, Kalasha's retroflex affricates are clearly distinguished by low F3 transitions, a result that is expected for retroflex segments but conspicuously absent for retroflex affricates in previous studies. This indicates that the retroflex affricates of Kalasha are produced with a greater degree of retroflexion than those of the other languages in question, all of which are spoken outside of South Asia. Again, this may reflect the typological complexity of Kalasha's phonemic system, in which retroflexion carries a heavier functional load. Thus, the current study extends the phonetic typology of coronal place contrasts, highlighting both general and language-specific aspects of the phonetic realization of affricates.

Acknowledgements

We are grateful to our Kalasha speakers, and would particularly like to thank Sikandar Kalas, Taj Khan Kalash, and Yasir Bazik. Thanks also to two anonymous reviewers for thoughtful comments and suggestions that helped us improve the paper, to Jan Heegård Petersen for putting us in touch with the speakers and for sharing his expertise on the language, and to Ron Trail, and Greg and Elsa Cooper for sharing Kalasha materials that were useful in designing this study. The research was partly supported by a Social Sciences & Humanities Research Council of Canada grant (#435-2015-2013) to the first author.

References

Arsenault, Paul. 2012. Retroflex consonant harmony in South Asia. Toronto: University of Toronto dissertation. http://hdl.handle.net/1807/33911.

Arsenault, Paul. 2015. Retroflex consonant harmony: An areal feature in South Asia. Journal of South Asian Languages and Linguistics 2(1). 1–28. http://dx.doi.org/10.1515/jsall-2015-0001.

Arsenault, Paul. 2017. Retroflexion in South Asia: Typological, genetic, and areal patterns. Journal of South Asian Languages and Linguistics 4(1). 1–53. https://doi.org/10.1515/jsall-2017-0001.

Arsenault, Paul & Alexei Kochetov. 2011. Retroflex harmony in Kalasha: agreement or spreading? In Suzi Lima, Kevin Mullin & Brian Smith (eds.), Proceedings of the North East Linguistic Society 39, 55–66. Amherst: GLSA.

Arvaniti, Amalia. 2007. Greek phonetics: The state of the art. Journal of Greek Linguistics 8. 97–208.

Bashir, Elena. 2003. Dardic. In George Cardona & Dhanesh Jain (eds.), The Indo-Aryan languages, 818–894. New York & London: Routledge.

Bates, Douglas, Martin Maechler, Ben Bolker & Steve Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67(1). 1–48. doi:10.18637/jss.v067.i01.

Benguerel, A. P. & T. K. Bhatia. 1980. Hindi stop consonants: An acoustic and fiberscopic study. Phonetica 37(3). 134–148.

Boersma, Paul & David Weenink. 2018. Praat: Doing phonetics by computer [Computer program]. Version 6.0.39. http://www.praat.org (accessed 3 April 2018).

Clements, G. N., & R. Khatiwada. 2007. Phonetic realization of contrastively aspirated affricates in Nepali. In Jürgen Trouvain & William J. Barry (eds.), Proceedings of the 16th International Congress of Phonetic Sciences, 629–632.

Di Carlo, Pierpaolo. 2010. I Kalasha del Hindu Kush: Ricerche linguistiche e antropologiche [The Kalasha of the Hindu Kush: Linguistic and anthropological research]. Vol. 12. Firenze University Press.

Eberhard, David M., Gary F. Simons, & Charles D. Fennig (eds.). 2019. Ethnologue: Languages of the world. Twenty-second edition. Dallas, Texas: SIL International. Online version: http://www.ethnologue.com.

Forrest, Karen, Gary Weismer, Paul Milenkovic & Ronald N. Dougall. 1988. Statistical analysis of word-initial voiceless obstruents: Preliminary data. Journal of the Acoustical Society of America 84(1). 115–123.

Hamann, Silke. 2003. The phonetics and phonology of retroflexes. Utrecht: LOT Press.

Heegård Petersen, Jan. 2015. Kalasha texts – With introductory grammar. Acta Linguistica Hafniensia 47, sup1. 1–275. doi:10.1080/03740463.2015.1069049.

Heegård, Jan & Ida E. Mørch. 2004. Retroflex vowels and other peculiarities in the Kalasha sound system. In Anju Saxena (ed.), Himalayan languages, past and present, 57–76. Berlin & New York: Mouton de Gruyter.

Jassem, Wiktor. 2003. Polish. Journal of the International Phonetic Association 33(1). 103–107.

Jesus, Luis M. T. & Christine H. Shadle. 2002. A parametric study of the spectral characteristics of European Portuguese fricatives. Journal of Phonetics 30(3). 437–464.

Jongman, Allard, Ratree Wayland & Serena Wong. 2000. Acoustic characteristics of English fricatives. Journal of the Acoustical Society of America 108. 1252–1263.

Khan, Taj, & Jan Heegård Petersen. 2016. Dynamics of cultural survival of Kalasha. In Ulrik Høj Johnsen, Armin W. Geertz, Svend Castenfeldt & Peter B. Andersen (eds.), In the footsteps of Halfdan Siiger: Danish research in Central Asia,115-136. Århus: Moesgaard Museum.

Kochetov, Alexei. 2017. Acoustics of Russian voiceless sibilant fricatives. Journal of International Phonetic Association 47(3). 321–348.

Kochetov, Alexei & Alevtina Lobanova. 2007. Komi-Permyak coronal obstruents: Acoustic contrasts and positional variation. Journal of International Phonetic Association 37. 51–82.

Kuznetsova, Alexandra, Per B. Brockhoff & Rune H. B. Christensen. 2017. lmerTest package: Tests in linear mixed effects models. Journal of Statistical Software 82. 1–26.
Ladefoged, Peter, & Ian Maddieson. 1996. Sounds of the world's languages. Oxford: Blackwell Publishers.
Lee, Wai-Sum. 1999. An articulatory and acoustical analysis of the syllable-initial sibilants and approximant in Beijing Mandarin. In Proceedings of the 14th International Congress of Phonetic Sciences, 413–416.
Lee, Wai-Sum & Eric Zee. 2003. Standard Chinese (Beijing). Journal of the International Phonetic Association 33(1). 109–112.
Liljegren, Henrik, & Afsar Ali Khan. 2017. Khowar. Journal of the International Phonetic Association 47(2). 219–229.
Liljegren, Henrik, & Naseem Haider. 2009. Palula. Journal of the International Phonetic Association 39(3). 381–386.
Mays, Chanelle. 2008. An acoustic study of affricates in the Songyuan dialect of Mandarin Chinese. Individual paper, Ohio State University.
Maddieson, Ian. 1984. Patterns of sounds. Cambridge: Cambridge University Press.
Maddieson, Ian & Kristin Precoda. 1990. Updating UPSID. UCLA Working Papers in Phonetics 74. 104–120.
Masica, Colin P. 1991. The Indo-Aryan languages. Cambridge: Cambridge University Press.
Mikuteit, Simone & Henning Reetz. 2007. Caught in the ACT: The timing of aspiration and voicing in East Bengali. Language & Speech 50(2). 249–279.
Miller-Ockhuizen, Amanda & Draga Zec. 2003. Acoustics of contrastive palatal affricates predict phonological patterning. In Proceedings of the 15th International Congress of Phonetic Sciences, 3101–3104.
Morgenstierne, Georg. 1973. Indo-Iranian frontier languages, vol. 4, the Kalasha language. Oslo: Universitetsforlaget.
Perder, Emil. 2013. A grammatical description of Dameli. Stockholm: Stockholm University dissertation.
Punnoose, Reenu, Ghada Khattab, & Jalal al-Tamini. 2013. The contested fifth liquid in Malayalam: a window into the lateral-rhotic relationship in Dravidian languages. Phonetica 70, 274–297.
R Core Team. 2014. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. URL http://www.R-project.org/. [Computer program]
Rahman, Tariq. 2006. Language policy, multilingualism and language vitality in Pakistan. In Anju Saxena & Lars Borin (eds.), Lesser-known languages of South Asia: status and policies, case studies and applications of information technology, 73–106. Berlin: Mouton de Gruyter.
Ramanujan, A. K. & Colin Masica. 1969. Toward a phonological typology of the Indian linguistic area. In T. A. Sebeok (ed.), Current trends in linguistics, volume 5: Linguistics in South Asia, 543–577. Paris: Mouton.
Schmidt, Ruth Laila. 2003. Urdu. In George Cardona & Dhanesh Jain (eds.), The Indo-Aryan languages, 250–285. New York & London: Routledge.
Svantesson, Jan-Olof. 1986. Acoustic analysis of Chinese fricatives and affricates. Working Papers in Linguistics 25(1). 195–211.
Thurgood, Ela. 2009. Coronal contrasts in Anong. Journal of the International Phonetic Association 39(1). 53–66.
Trail, Ronald & Gregory R. Cooper. 1985. Kalasha phonemic summary. ms.
Trail, Ronald & Gregory Cooper. 1999. Kalasha dictionary – with English and Urdu. Islamabad: National Institute of Pakistan Studies, Quaid-i-Azam University and Summer Institute of Linguistics.
Turner, R. L. 1962–1966. A comparative dictionary of Indo-Aryan languages. London: Oxford University Press. http://dsal.uchicago.edu/dictionaries/soas/.
Yoshie, Satoko. 2005. The sound system of Gojal Wakhi. Area and Culture Studies 71. 43–80.
Zoller, Claus Peter. 2005. A grammar and dictionary of Indus Kohistani, volume 1: Dictionary. Berlin & New York: Mouton de Gruyter.
Żygis, Marzena, Susanne Fuchs & Laura L. Koenig. 2012a. Phonetic explanations for the infrequency of voiced sibilant affricates across languages. Laboratory Phonology 3(2). 299–336.
Żygis, Marzena, Daniel Pape & Luis M. Jesus. 2012b. (Non-) retroflex Slavic affricates and their motivation: Evidence from Czech and Polish. Journal of the International Phonetic Association 42(3). 281–329.

Appendix

Table A1: Means and standard deviations (sd) for *burst* spectral moments of Kalasha affricates (onset position).

C	COG (Hz)		SD (Hz)		kurtosis		skewness	
	mean	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**
/ʦ/	5728	1986	2405	442	0.43	1.56	-0.31	1.05
/ʦʰ/	6630	973	2016	513	0.98	1.59	-0.81	0.65
/ʣ/	3839	1908	2681	678	1.29	2.98	0.82	1.31
/ʈʂ/	2134	573	915	339	21.74	25.01	2.87	2.00
/ʈʂʰ/	2444	540	1076	289	12.55	10.79	2.36	1.16
/ɖʐ/	2260	404	1124	212	9.35	4.45	1.91	0.64

C	COG (Hz)		SD (Hz)		kurtosis		skewness	
	mean	sd	mean	sd	mean	sd	mean	sd
[ɖʐʱ]	2570	969	1150	199	9.43	9.21	2.14	1.29
/tɕ/	3300	928	1512	521	6.05	8.58	1.42	1.22
/tɕʰ/	4073	510	1691	376	2.76	3.64	1.54	0.75
/dʑ/	2747	842	1787	429	2.62	2.47	1.24	0.73
/dʑʱ/	3387	1010	1668	317	1.92	1.58	0.94	0.62

Table A2: Means and standard deviations (sd) for *burst* spectral moments of Kalasha voiceless unaspirated affricates by position.

C	Position	COG (Hz)		SD (Hz)		kurtosis		skewness	
		mean	sd	mean	sd	mean	sd	mean	sd
/ts/	onset	5728	1986	2405	442	0.43	1.56	-0.31	1.05
/ʈʂ/	onset	2134	573	915	339	21.74	25.01	2.87	2.00
/tɕ/	onset	3300	928	1512	521	6.05	8.58	1.42	1.22
/ts/	coda	5978	2020	2077	714	5.63	21.80	-0.38	2.06
/ʈʂ/	coda	2598	582	1142	343	9.88	10.58	2.13	1.27
/tɕ/	coda	4108	1016	1534	445	3.55	7.07	1.04	1.05

Table A3: Means and standard deviations (sd) for *frication* spectral moments of Kalasha affricates (onset position).

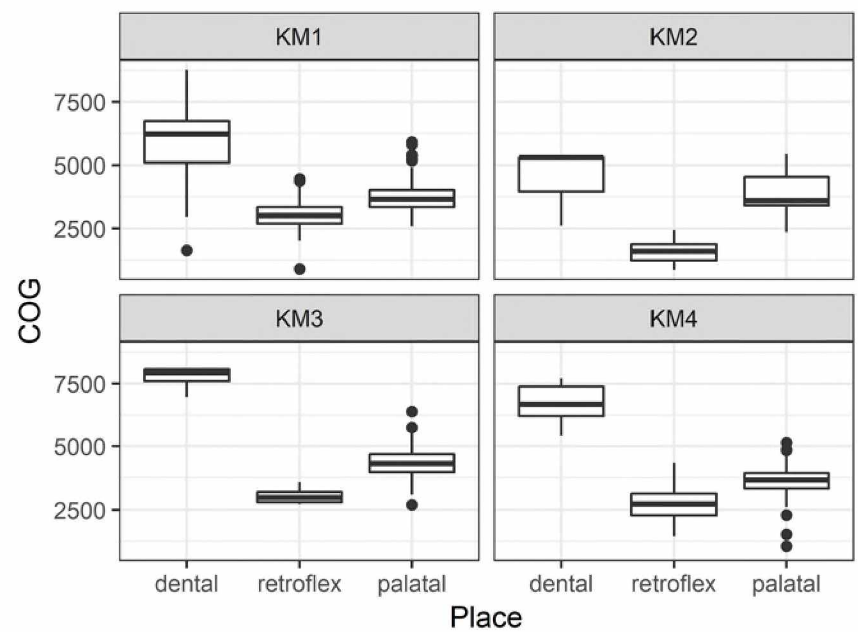
C	COG (Hz)		SD (Hz)		kurtosis		skewness		duration (sec)	
	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
/ts/	6475	1059	1711	446	1.95	2.69	-0.56	0.98	0.108	0.024
/tsʰ/	6670	848	1705	334	1.65	1.94	-0.77	0.83	0.179	0.038
/dz/	5613	1848	2330	617	1.12	2.50	-0.32	1.22	0.080	0.018
/ʈʂ/	2708	702	1259	331	10.24	12.55	2.33	1.32	0.090	0.034
/ʈʂʰ/	3018	634	1344	274	6.40	6.68	1.92	1.03	0.140	0.031
/ɖʐ/	2885	627	1289	300	5.62	3.43	1.62	0.54	0.059	0.020
[ɖʐʱ]	2841	1003	1129	253	13.20	21.15	2.45	2.05	0.124	0.026
/tɕ/	3786	706	1417	351	3.93	4.69	1.65	0.92	0.089	0.024
/tɕʰ/	3882	535	1369	213	5.44	3.16	2.13	0.74	0.184	0.041
/dʑ/	3726	578	1530	401	2.80	3.55	1.13	0.75	0.071	0.020
/dʑʱ/	3726	719	1663	749	3.22	4.95	1.06	0.95	0.135	0.048

Table A4: Means and standard deviations (sd) for *frication* spectral moments of Kalasha voiceless unaspirated affricates by position.

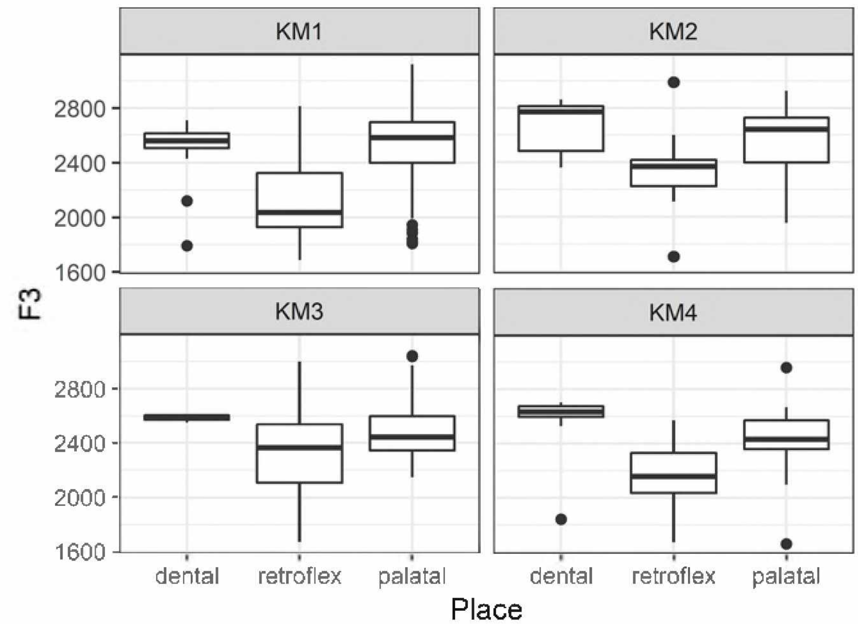
C	Position	COG (Hz)		SD (Hz)		kurtosis		skewness		duration (sec)	
		mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
/ts/	onset	6475	1059	1711	446	1.95	2.69	-0.56	0.98	0.108	0.024
/ʈʂ/	onset	2708	702	1259	331	10.24	12.55	2.33	1.32	0.090	0.034
/tɕ/	onset	3786	706	1417	351	3.93	4.69	1.65	0.92	0.089	0.024
/ts/	coda	5440	1433	1894	657	3.43	15.20	0.23	1.39	0.348	0.105
/ʈʂ/	coda	2907	599	1259	329	6.25	5.91	1.83	0.92	0.282	0.082
/tɕ/	coda	3886	786	1290	295	5.38	6.63	1.75	1.02	0.273	0.058

Table A5: Means and standard deviations (sd) for vowel transitions to and from Kalasha affricates by position.

C	Position	F1 (Hz)		F2 (Hz)		F3 (Hz)	
		mean	**sd**	**mean**	**sd**	**mean**	**sd**
/ʦ/	onset	517	104	1544	220	2618	109
/ʦʰ/	onset	677	238	1507	259	2560	44
/ʣ/	onset	461	90	1553	167	2525	233
/ʈʂ/	onset	492	129	1496	254	2231	343
/ʈʂʰ/	onset	430	171	1558	378	2307	336
/ɖʐ/	onset	490	66	1672	121	2480	363
[ɖʐʱ]	onset	308	86	1810	117	2195	152
/ʨ/	onset	416	100	1661	208	2424	274
/ʨʰ/	onset	521	253	1694	347	2392	303
/ʥ/	onset	375	65	1893	181	2627	290
/ʥʱ/	onset	395	116	1567	389	2446	157
/ʦ/	coda	433	100	1478	340	2445	163
/ʈʂ/	coda	578	109	1563	124	2118	220
/ʨ/	coda	508	102	1700	196	2406	339



a.



b.

Figure A1: Sample results for individual speakers: (a) COG of frication spectra of voiceless affricates and (b) F3 transitions during the vowel /a/ to/from affricates.