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Acoustics of Kalasha laterals

Alexei Kochetov,[1,a)] Jan Heegård Petersen,[2] and Paul Arsenault[3]
[1]Department of Linguistics, University of Toronto, 100 Saint George Street, Toronto, Ontario M5S 3G3, Canada
[2]Department of Nordic Studies and Linguistics, University of Copenhagen, Emil Holms Kanal 2, 2300 København S, Denmark
[3]Department of Linguistics, Tyndale University, 3377 Bayview Avenue, Toronto, Ontario, M2M 3S4, Canada

ABSTRACT:
Kalasha, a Northwestern Indo-Aryan language spoken in a remote mountainous region of Pakistan, is relatively unusual among languages of the region as it has lateral approximants contrasting in secondary articulation—velarization and palatalization (/ɫ/ vs /lʲ/). Given the paucity of previous phonetic work on the language and some discrepancies between descriptive accounts, the nature of the Kalasha lateral contrast remains poorly understood. This paper presents an analysis of fieldwork recordings with laterals produced by 14 Kalasha speakers in a variety of lexical items and phonetic contexts. Acoustic analysis of formants measured during the lateral closure revealed that the contrast was most clearly distinguished by F2 (as well as by F2-F1 difference), which was considerably higher for /lʲ/ than for /ɫ/. This confirms that the two laterals are primarily distinguished by secondary articulation and not by retroflexion, which is otherwise robustly represented in the language inventory. The laterals showed no positional differences but did show considerable fronting (higher F2) next to front vowels. Some inter-speaker variation was observed in the realization of /ɫ/, which was produced with little or no velarization by older speakers. This is indicative of a change in progress, resulting in an overall enhancement of an otherwise auditorily vulnerable contrast.
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I. INTRODUCTION

A. Lateral approximants in Kalasha

Kalasha[1] also known as Kalashamon, is a Northwestern Indo-Aryan language with between 3000 and 5000 speakers in the Chitral District of Khyber Pakhtunkwa Province in northern Pakistan (Eberhard *et al.*, 2019). While the language is still widely used in the community, it is considered threatened given the political situation in the region and the increasing cultural and religious attrition (Rahman, 2006; Khan and Heegård Petersen, 2016).

Kalasha has a relatively large inventory of consonants and vowels, which is presented in Table I (Trail and Cooper, 1999; Mørch and Heegaard, 1997; Di Carlo, 2010; Heegård Petersen, 2015; Kochetov *et al.*, 2019). Of particular interest is the robust distinction between retroflex and non-retroflex sounds, spanning both consonants (retroflex and dental/alveolar stops, affricates, and fricatives) and vowels (retroflex and non-retroflex nasalized and non-nasalized vowels). Two lateral consonants (indicated in bold in Table I), however, are not part of this set of contrasts. The dental /ɫ̪/ (henceforth /ɫ/) and the alveolar /lʲ/ are articulated in the anterior region of the palate and most notably characterized by secondary articulation—velarization and palatalization. As there are no other consonants in Kalasha that show secondary velarization or palatalization, the phonetic basis for the contrast is an open question that requires investigation.

Examples of near-minimal pairs with laterals in various syllable onset and coda contexts are provided in Table II. The two laterals are almost equally frequent: /ɫ/ occurs in 401 lexemes, making up 2.5% of all consonants (in 5880 lexical items in the database that the online dictionary by Trail and Cooper, 1999, is based on), while /lʲ/ occurs in 498 lexemes, making up 3.2% of all consonants. Both laterals occur in a variety of contexts, showing no apparent restrictions; however, /ɫ/ is more frequent in the word-initial onset position, while being rather rare in coda positions (see Table S I in the supplemental material).[2] This asymmetry is at least partly due to the vocalization or deletion of coda /ɫ/ in some forms (e.g., [haw] vs [ˈhaɫas] "plough," nominative singular and genitive singular; Morgenstierne, 1973, p. 191; Mørch and Heegaard, 1997, p. 88). Both /ɫ/ and /lʲ/ are found in native words and in loanwords, although there is a tendency for /lʲ/ to occur more often in loanwords (see Tables S II and III).[2] Note that Old Indo-Aryan is assumed to have a single lateral /l/ (Turner, 1966; Masica, 1991), and thus, the Kalasha system is an innovation.

In sum, the lateral contrast is well-established in Kalasha phonology, showing no categorical restrictions (despite some statistical asymmetries) across syllable/word positions, phonetic contexts, and lexical strata. As

[a)]Electronic mail: al.kochetov@utoronto.ca

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TABLE I. A phonemic inventory of Kalasha (a) consonants and (b) vowels; marginal phonemes are shown in parenthesis (the classification is based on Kochetov *et al.*, 2020; see also Mørch and Heegaard, 1997; Trail and Cooper, 1999).

(a)	Bilabial		Dental/alveolar		Retroflex		Alveolopalatal/palatal		Velar		Glottal
Plosive	p	b	t̪	d̪	ʈ	ɖ			k	g	
	pʰ	bʱ	t̪ʰ	d̪ʱ	ʈʰ	ɖʱ			kʰ	gʱ	
Affricate			ts	dz	ʈʂ	ɖʐ	tɕ	dʑ			
			tsʰ		ʈʂʰ		tɕʰ	dʑʱ			
Nasal		m		n							
Trill/tap				r							
Fricative			s	z	ʂ	ʐ	ɕ	ʑ			h
Approximant		w						j			
Lateral approximant				ɫ lʲ							

(b)	Front				Central				Back (round)			
High	i	i˞	ĩ	ĩ˞					u	u˞	ũ	ũ˞
Mid	e	e˞	ẽ	ẽ˞					o	o˞	õ	õ˞
Low					a	a˞	ã	ã˞				

mentioned above, the presence of this contrast in the language, however, is somewhat unexpected given that most coronal consonants participate in anterior vs posterior primary articulation contrasts (dental/alveolar vs retroflex or alveolopalatal).

Another puzzle presented by Kalasha laterals involves their somewhat contradictory descriptions in the literature. The earliest accounts of Kalasha report only one lateral, *l* (Leitner, 1880; Grierson, 1919). Likewise, Morgenstierne (1973, p. 190), based on field work conducted in the 1920s, lists only one lateral in his consonant chart, a plain *l*. Nevertheless, his notes and accompanying vocabulary list include a "palatal" lateral (*l'* or *ly*) occurring in a few words (e.g., *l'ash* "late, slow," *lyakhi* "very big" and *-al'* "3sg.pres."; Morgenstierne, 1973, pp. 191ff). In their phonemic analysis, Cooper and Trail (1983–1999) posit two laterals, an apical dental *l* (corresponding to our /ɫ/) and a laminal alveolar *l̄* (corresponding to our /lʲ/)). The authors report that the "difference between the two l's is close to the difference in English between clear and dark *l*," the alveolar being clear and the dental being dark. The phonemic distinction between the two laterals was maintained in their dictionary (Trail and Cooper, 1999), where the dental lateral was written *ḷ* and the alveolar lateral was written *l*. The distinction is also reflected in the writing system that the two linguists helped develop for Kalasha, where /ɫ/ is written *l'* (with the apostrophe also used to denote retroflexion on other consonants) and /lʲ/ is written *l* (Cooper, 2005, 2011).

Mørch and Heegaard (1997, pp. 46, 51–52) confirm Trail and Cooper's description, analyzing the two phonemically distinctive laterals as dental and alveolopalatal in terms on place of articulation and transcribing them /l̪/ and /l/ accordingly. The difference in the primary place between the two laterals was supported by a fieldwork palatographic study (one male speaker, born around 1970) that clearly showed a narrow contact between the tongue and the teeth in the upper mouth for /ɫ/ [Fig. 1(a)], and a slightly retracted, alveolar (or alveolopalatal) place of articulation for /lʲ/ [Fig. 1(b)]. The narrow area contact for /ɫ/ indicates an apical articulation; the much broader contact area for /lʲ/ indicates a laminal articulation.

The authors (Mørch and Heegaard, 1997, p. 52; Heegård and Mørch, 2004, p. 61) note that the dental lateral is often (but not always) velarized, while the alveolar lateral is frequently palatalized, indicative of some within- and across-speaker variation. Auditorily, these secondary articulations are more prominent than the primary places of articulation and more easily distinguished by their colouring effect on adjacent vowels (e.g., fronting /u/ and /o/ and raising /a/ next to /lʲ/ and retracting most vowels next to /ɫ/). Of interest in this description is the apparent variability in the realization of secondary articulations. Similarly, Bashir

TABLE II. (Near-)minimal pairs in various (a) onset and (b) coda contexts (based on Trail and Cooper, 1999).

		/ɫ/	/lʲ/
(a)	#_V	/ˈɫɕik/ "slip away"	/lʲaɕ/ "softly"
	#C_V	/kɫok hik/ "stop laying eggs (of chicken)"	/klʲok/ "wooden lock on a door"
	ˈV_V	/ˈaɫa/ "3p.sg.near.acc"	/ˈhalʲa/ "high up"
	Vˈ_V	/koˈɫustu/ "fodder of grape waste"	/boˈlʲutɕu/ "newly formed unripe fruit"
(b)	V_#	/gaɫ/ "hockey-like game"	/dʑanˈgalʲ/ "jungle"
	V_.CV	/paɫˈgetɕʰik/ "to cover"	/malʲˈgiri/ "companion"
	VC._V	/brazanˈɫo/ "flying squirrel"	/hamˈlʲa ˈkarik/ "attack someone"

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FIG. 1. (Color online) The tongue contact with the roof of the mouth for /ɫ/ and /lʲ/ (previously unpublished images based on Mørch and Heegaard, 1997).

(1988) in her thesis on Kalasha syntax, hedges her description of the laterals: "Based on my hearing of these sounds,… it seems one should characterize the /l/ as palatalized and the /l̄/ as velarized" (pp. 35–36), while noting in a later account of the language that /l/ is "strongly palatalized" (Bashir, 2003, p. 851).

In subsequent work on the Birir variety of North Kalasha, Di Carlo (2010, pp. 72–73) recognizes two lateral phonemes in keeping with Trail and Cooper (1999), Mørch and Heegaard (1997), and Bashir (2003). However, Mela-Athanasopoulou (2014, pp. 6–7), without further discussion, posits three laterals: an alveolopalatal *l*, a retroflex /ɭ/, and a palatal *ly*. A retroflex lateral has not been reported in any other studies of Northern Kalasha (or Southern Kalasha; see Mørch and Heegaard, 1997, pp. 62–65, 80–88, and Heegård and Mørch, 2017). The words to which she ascribes three laterals contain either /ɫ/ or /lʲ/ in the dictionary by Trail and Cooper (1999) (e.g., [lʲambur] "dike," [ɫawak] "fox," and [lʲiç] "sliver, splinter").

To summarize, previous descriptive accounts of Kalasha laterals show no consensus on the status or precise phonetic realization of the consonants. However, most recent accounts agree that the laterals differ to some degree in their secondary articulations (velarized or dark vs palatalized or clear) and type of primary constriction (apical vs laminal or dental vs alveolar) with palatographic evidence provided for the latter distinction. Some discrepancies in previous descriptions, however, might be due to variation in the production of these sounds or possibly ongoing changes in their realization. The goal of this paper, therefore, is to examine the acoustic properties of Kalasha laterals in a variety of contexts and styles and, in so doing, contribute to the phonetic documentation of this phonetically under-documented language.

B. Lateral approximants in neighboring languages

Before we turn to the acoustics of laterals, it is important to examine variation in lateral systems in a broader region—northern Pakistan, northwestern India, and eastern Afghanistan. This area is home to languages belonging to Indo-Aryan, Iranian, and Nuristani branches of Indo-Iranian (the Indo-European family), as well as some Tibeto-Burman languages and the isolate Burushaski. Despite the wide linguistic genetic differences, languages in the region have long been observed to exhibit common phonological and phonetic traits, indicative of linguistic convergence due to close contact and bilingualism among its populations (Liljegren, 2017). One might expect that the secondary articulation contrast in Kalasha laterals is part of a larger regional pattern if not internally motivated. This, however, is not evident as most languages in the region (shown in Fig. 2) have only a single ("plain") lateral approximant (indicated with white circles).[3] Languages with a two-way lateral contrast tend to distinguish retroflex laterals from plain dental or alveolar laterals (/l/ vs /ɭ/; indicated with red

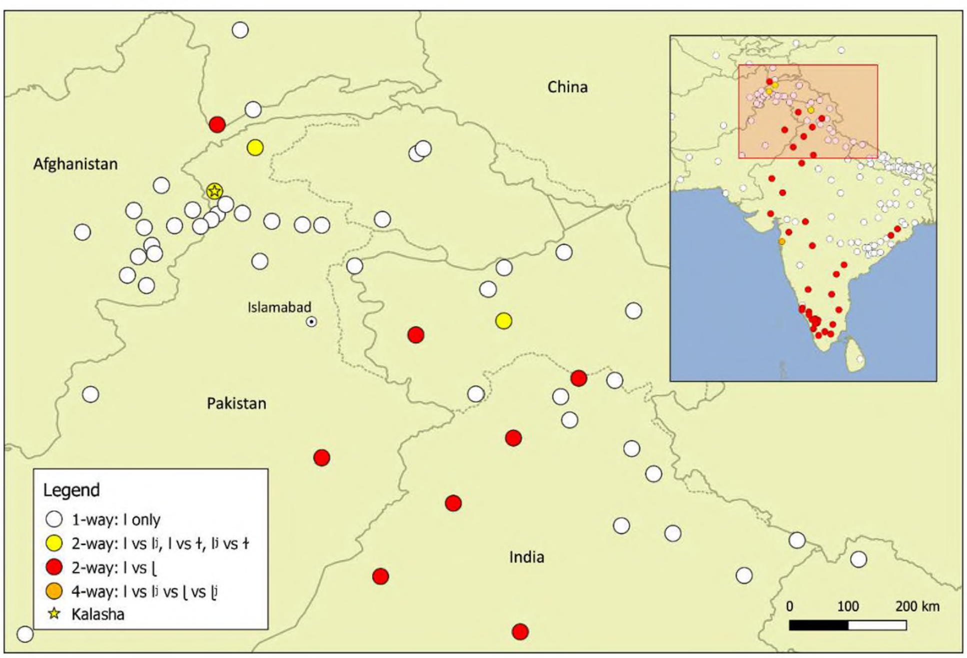

FIG. 2. (Color online) Lateral contrasts in languages of northwestern South Asia.

circles in Fig. 2), most notably Indo-Aryan languages along the India-Pakistan border, far to the southeast of Kalasha (Arsenault, 2017).

There are two languages that show secondary articulation contrasts (yellow circles in Fig. 2). One language is Kashmiri, which is geographically remote from Kalasha, where the phonemes /l/ and /lʲ/ are part of a larger plain-palatalized contrast involving almost all consonants (Wali *et al.*, 1997). The other language is Khowar, a close Northwestern Indo-Aryan relative and a sociolinguistically more dominant neighbor of Kalasha (Bashir, 2003). Khowar is described as having a contrast between an alveolar/post-alveolar /l/ (which is "often slightly palatalized") and a velarized dental /ɫ/ (Liljegren and Khan, 2017). Note that this contrast is likely to be acoustically similar to that of Kalasha as both palatalization and velarization tend to be signaled by differences in F2 frequency (see below). Since younger Kalasha speakers are often fluent in Khowar (Heegård Petersen, 2015, p. 13), any variation or change in one language may be related to (or conditioned by) the other. Unfortunately, it is not currently possible to establish phonetic influences of or parallels with neighboring languages given that no acoustic or articulatory work exists on lateral systems in languages of the region. Another goal of this paper, therefore, is to set the stage for a more systematic acoustic investigation of consonant contrasts in the region. As a first step in this direction, we will perform a preliminary comparison of Kalasha laterals to those in some of the languages of the region.

C. Acoustics of lateral contrasts and contextual variation

Having reviewed the linguistic background on Kalasha laterals, we turn to phonetic properties that distinguish lateral place contrasts in general. Palatalized (or clear) laterals are produced with various degrees of tongue body raising and fronting, accompanied by a central constriction in the denti-alveolar (or somewhat more posterior) region (Ladefoged and Maddieson, 1996, pp. 196-197; Recasens, 2012). The front position of the entire tongue results in a large back cavity, whose half-wavelength resonance is manifested acoustically as a high F2 frequency (1500–2000 Hz; Fant, 1970; Stevens, 1998). Velarized (or dark) laterals, on the other hand, are produced by retracting the tongue dorsum toward the uvular or upper pharyngeal regions, accompanied by a tongue tip constriction in the denti-alveolar region (often more front than for /lʲ/) and some lowering of the tongue body due to lateral compression. This configuration splits the cavity behind the primary constriction into oral and pharyngeal sub-cavities, producing an acoustic effect of a lower F2 frequency (800–1200 Hz; Narayanan *et al.*, 1997; Recasens, 2012). While F2 is the primary correlate of secondary articulations, F1 and F3 of laterals may also be affected by the respective tongue shapes. F1 is, for all laterals, a Helmholtz resonance created by the lateral constriction and the cavity behind it (Fant, 1970; Stevens, 1998; Tabain *et al.*, 2016). It is generally lower for laminal and clear (palatalized) laterals compared to apical and dark (velarized) laterals, with diverse explanations for the difference provided in the literature (the jaw raising or the smaller cross-sectional area; Bladon, 1979; Stevens, 1998; Recasens, 2012; Tabain *et al.*, 2016). F3 in laterals is assumed to correspond to the front cavity resonances (Fant, 1970; but see Stevens, 1998, for a different analysis), and, thus, differences in this formant are expected to be minimal in dentals/alveolars that differ primarily in secondary articulations. However, strongly dark alveolar laterals have been reported to show higher F3 (at least in the context of low vowels; Recasens, 2012), an effect that can be attributed to a secondary constriction in the upper pharynx (Al-Tamimi, 2017). Finally, F3 can be at least partly suppressed by the lateral antiresonance—some loss of energy resulting from a side-branch (a pocket of air above the tongue). This antiresonance is estimated to fall between 2000 and 3000 Hz (Fant, 1970; Bladon, 1979). Overall, this suggests that secondary palatalization/velarization differences in laterals are signaled primarily by F2 and, to a lesser extent, by F1 and F3. Given this, the formant metrics F2-F1 and F3-F2 (differences between F2 and F1, and F3 and F2) can provide additional useful information about lateral contrasts. Specifically, F2-F1 is expected to be higher, while F3-F2 is expected to be lower for palatalized (clear) laterals compared to their velarized (dark) counterparts (Sproat and Fujimura, 1993; Nance, 2014; Kirkham *et al.*, 2019; Al-Tamimi, 2017).

Unlike denti-alveolars with secondary articulations, F3 is the main correlate of retroflexes—articulations produced by raising and retracting the tongue tip behind the alveolar ridge (Narayanan and Kaun, 1999; Narayanan *et al.*, 1999). As would be expected, a larger front cavity produces lower F3 resonances (as well as lower F4 resonances) compared to denti-alveolar laterals. For example, F3 for the subapical retroflex /ɭ/ in Tamil (Dravidian) can be as low as 1800 Hz. This value is likely to be higher for apical retroflexes, which tend to be produced with no substantial tip curling (as in Indo-Aryan languages; Ladefoged and Maddieson, 1996). If retroflexion is accompanied by some tongue dorsum backing, we would expect a lower F2 as well. However, differences in F2 in retroflex systems appear to be language-particular (see below) and so, apparently, are differences in F1.

Table III summarizes results of several previous acoustic studies of lateral contrasts involving secondary articulations [Table III(a)], retroflexion [Table III(b)], or both [Table III(c)]. Note that F2 for palatalized (and alveolopalatal) laterals is relatively high, between 1700 and 1900 Hz (for males; higher for females), while F2 for velarized laterals is low, between 750 and 1100 Hz. Some variation is due to the fact that languages tend to differ in degrees of tongue body raising/fronting or tongue dorsum retraction. As a result, as Recasens (2012) observed, there is a continuum within the dark and clear categories of laterals with some languages or dialects having more or less velarized (dark) or palatalized (clear) sounds. Plain (non-palatalized and

TABLE III. Average F1, F2, F3 formant values and F2-F1 and F3-F2 differences (in Hz) during the lateral closure for languages with (a) palatalization/velarization (as well as alveolopalatals), (b) retroflexion, and (c) both types, based on various acoustic studies; f = female, m = male; — = values not reported.

	Study	Language	C	F1	F2	F3	F2-F1	F3-F2
(a)	Fant (1970)	Russian (1 m)	ɫ	350	800	2250–2900	450	1775
			lʲ	230	1600	2300	1370	700
	Bolla (1981)	Russian (1 m)	ɫ	300–400	750–800	2550	425	1775
			lʲ	200–250	1850	2600	1625	750
	Moosmüller *et al.* (2016)	Albanian (13 m)	ɫ	354	1069	—	715	
			l	310	1501	—	1191	
	Charles and Lulich (2018)	Brazilian Portuguese (1 m)	ɫ	448	1046	2520	598	1474
			lʲ	317	1754	2433	1437	679
			(ʎ	300	1783	2376	1483	593)
	Nance (2014)	Scots Gaelic (23 f)	ɫ	409	1048	3288	639	2240
			l	399	1610	3287	1211	1677
			lʲ	359	1953	3307	1594	1354
(b)	Dave (1977)	Gujarati (1 m)	l	290	1540	2660	1250	1120
			ɭ	540	1460	2310	920	850
	McDonough and Johnson (1997)	Tamil (1 f, 1 m)	l	400–500	1700	2900	1250	1200
			ɭ	400–500	1800	2200	1350	400
	Narayanan *et al.* (1999)	Tamil (1 m)	l	400	1200	2400	800	1200
			ɭ	400	1460	1800	1060	340
	Punnoose *et al.* (2013)	Malayalam (8 m)	l	360	1695	2542	1335	847
			ɭ	465	1251	2241	786	990
	Tabain and Kochetov (2018)	Kannada (10 m)	l	325	1635	2710	1310	1075
			ɭ	370	1705	2480	1335	775
		Malayalam (10 m)	l	325	1670	2710	1345	1040
			ɭ	370	1515	2480	1145	965
(c)	Tabain *et al.* (2016)	Arrernte, Pitjantjatjara, Warlpiri (19 f, 3 m)	l̪	319	1684	2837	1365	1153
			l	374	1619	2839	1245	1220
			ɭ	364	1662	2762	1298	1100
			(ʎ	339	2104	2896	1765	792)

non-velarized) laterals, like /l/ or /l̪/ in Albanian, Scots Gaelic, and Australian Aboriginal languages tend to show intermediate F2 values (around 1400–1500 Hz for males and higher for females). The two types of laterals are also distinguished by F1 (somewhat lower for palatalized laterals) but not consistently by F3. Note that for all these languages, F2-F1 is lower for velarized laterals, while F3-F2 is lower for its palatal(ized) or plain counterpart.

In languages with dental/alveolar vs retroflex contrasts [Tables III(b) and III(c)], the place distinction is clearly signaled by F3, which is about 300–500 Hz lower for /ɭ/ than for /l/ in South Asian languages (yet smaller in Australian languages), while there is no consistent distinction in F1 and F2. For example, /ɭ/ in Tamil shows a somewhat higher F2 than /l/ , while the opposite is observed in Malayalam. Given this, the formant difference metrics do not show clear patterns although there is a tendency for F3-F2 to be lower for retroflexes.

Taken together, these studies suggest that the first three formants and their differences should provide an adequate acoustic discrimination of lateral place contrasts, whether this is palatalization/velarization or retroflexion. It should be kept in mind that acoustic differences between consonants can only be taken as suggestive of their possible articulatory realizations. Further articulatory work will be required to verify acoustic results.

Regardless of the contrast type, all laterals are expected to show some variation depending on the quality of adjacent vowels and syllable position. With respect to the former, coarticulation of laterals to front vowels results in clearer (higher F2), more palatalized sounds, while coarticulation to back (or rounded) vowels results in darker (lower F2), more velarized sounds (Recasens, 1999). With respect to syllable position, laterals tend to be realized clearer (higher F2) in syllable-initial position and darker in syllable-final position. In the study by Recasens (2012), however, languages (23 European languages/dialects) differed greatly in the magnitude of differences caused by vowel contexts and syllable position, indicative of a distinction between gradient phonetic coarticulation and more categorical allophonic patterns (roughly showing F2 differences of below 200–300 Hz and above 400 Hz, respectively). It should be noted that much of the previous work on coarticulation and positional variation has been done on languages with a single lateral (e.g., English /l/, Sproat and Fujimura, 1993; Browman and Goldstein, 1995; Narayanan *et al.*, 1997) or on plain or velarized laterals disregarding their phonemic palatal(ized) counterparts (e.g., investigations of Catalan /ɫ/ in Recasens and Espinosa, 2005; Catalan, Portuguese, and Russian /ɫ/ in Recasens, 2012). However, we might expect this variation to be constrained by the need to maintain a phonemic contrast (Manuel, 1990). In light of this, it would be of interest to examine such variation in Kalasha, a language featuring a lateral place contrast.

It should also be noted that apart from a handful of recent studies (Punnoose *et al.*, 2013; Nance, 2014; Tabain *et al.*, 2016; Moosmüller *et al.*, 2016), many reports on lateral contrasts have been based on one or two speakers, even in languages that are otherwise well documented phonetically. One of the goals of the present paper is to provide a relatively larger-scale description of laterals in an under-documented language. This is done by examining these sounds as produced by 14 speakers of Kalasha, the sample representing about 0.35% of the language population, which is larger than any of the studies reviewed above (but perhaps comparable to Tabain *et al.*, 2016).

Based on previous acoustic studies, we can make specific predictions about the acoustic realizations of the lateral contrast in Kalasha. If Kalasha laterals are indeed distinguished by secondary palatalization and velarization, we would expect them to exhibit robust differences in F2 (/lʲ/ > /ɫ/) as well as in F2-F1 (/lʲ/ > /ɫ/, due to F2 differences, as well as the possible F1 difference, /ɫ/ > /lʲ/). Assuming a relatively stable F3, we should expect F3-F2 differences to be just the opposite of F2-F1 (/ɫ/ > /lʲ/). This difference may be further increased if /ɫ/ shows a higher F3 (as has been observed for strongly velarized laterals). Front and back vowel contexts are expected to affect both laterals, but coarticulation and positional differences should be relatively small given the phonemic contrast. At the same time, we may expect some additional intra- and inter-speaker variation in the magnitude of the contrast given the inconsistencies in earlier descriptions of the language and our auditory impressions. Relatedly, it is also possible that /ɫ/ is produced as retroflex, at least under certain conditions or by some of the speakers. In this case, we would expect clear differences in F3 (/lʲ/ > /ɫ/) with possible other formant differences (e.g., F3-F2, /lʲ/ > /ɫ/).

II. METHOD

A. Speakers and recordings

For the purpose of this study, we combined four sets of recordings representing speech samples with laterals produced by 14 speakers of Kalasha. The recordings were performed at different times and different locations, also differing in the demographics of the speakers and recording settings. Nevertheless, combining these datasets was thought to be an important first step toward an acoustic characterization of the poorly understood lateral contrast. Details for the datasets are summarized in Table IV and organized by speakers' gendesr, home locations, occupations, levels of education, and estimated years of birth.[4] The 1997_P set, representing six speakers (four females), was recorded in 1997 at the speakers' homes in the Bumburet and Rumbur valleys of Chitral. This was done by J.H.P. and Ida Elisabeth Mørch using a cassette recorder and a Sennheiser clip-on microphone (Wedemark, Germany).The 2004_PG set, representing two male speakers, was recorded by J.H.P. in hotel rooms in Islamabad in 2004 (for PM3) and Thessaloniki (for GM1), using the same equipment as in 1997. The 2005_P set, representing three male speakers, was recorded in 2005 at the speakers' homes in the village Kraka, Bumburet. This was done by a native Kalasha speaker and language consultant Nabaig, using an analog cassette recorder with a built-in microphone. All the analog recordings were later digitized at a 44 100 Hz sampling rate to WAV format at the University of Copenhagen by J.H.P. The last set, 2017_G, represented four male speakers, one of whom (GM1) appeared in the previous set. The recordings were made in 2017 in quiet hotel rooms in Thessaloniki (for GM1 and GM4) and Athens (for GM2 and GM3). This was done by A.K. using a Zoom H4n digital recorder (Tokyo, Japan) and an AudioTechnica AT831b clip-on microphone (Tokyo, Japan) with a 44 100 Hz sampling rate.

All but three participants in the sample were from the Bumburet valley. Two other participants were originally from the Birir valley, and one was from the Rumbur valley, but all were residing in Bumburet at the time of the recording. In all these locations, the Northern dialect of Kalasha is spoken (Heegård and Mørch, 2017). The speakers' estimated years of birth ranged from 1946 to 1988 with the three oldest speakers (1946–1952) appearing in the 2005_P set and the three youngest speakers appearing in the 2017_G set. Most participants in the first two sets did not go to school and were illiterate (with PM2 and PF4 being exceptions). The speakers in the other two sets were well educated with three of them having completed university degrees. Speakers also differed in terms of their occupations with jobs requiring interactions with the outside community largely conditioned by the level of education. The education and occupation differences largely corresponded to the speakers' uses of other languages. Older speakers and females were largely monolingual, while all younger males were fluent in Khowar and had some knowledge of Urdu and English (which are the languages of higher education). In addition to the languages of Pakistan, the 2017_G speakers reported being fluent in Greek. While living in Greece for considerable time, they mentioned using Kalasha on a regular basis and maintaining close contact with the Kalasha community in Pakistan. GM1 and GM4 had served multiple times as language consultants and were proficient users of the recently developed Kalasha writing system (Cooper, 2005). GM4's recording took place soon after his return from a trip to Chitral, where he was involved in efforts to develop school education in Kalasha.

B. Materials, equipment, and procedure

All recordings for the first three sets involved spoken language – folklore stories or elicitations of various grammatical constructions.[5] No read speech was recorded given the lack of Kalasha orthography at that time and the illiteracy of most of the participants. Given the nature of the spoken language sample, numbers of items (distinct word

TABLE IV. Recording sets and the background of Kalasha speakers examined in the study. Note: outside since = age since living outside the community.

Recording set (year, location)	Speaker code	Gender	Home	Occupation	Education	Estimated year of birth and age (yr)
1997, Pakistan (1997_P)	PM1	M	Kraka, Bumburet	Shepherd	No	1967, 30
	PM2	M	Guru, Birir	Contractor	Yes (high school)	1971, 26
	PF1	F	Kraka, Bumburet	Housewife	No	1962, 35
	PF2	F	Batthet, Rumbur	Housewife	No	1972, 25
	PF3	F	Guru, Birir, living in Kraka, Bumburet	Housewife	No	1977, 20
	PF4	F	Kraka, Bumburet	Schoolgirl	Yes (primary school)	1983, 14
2004, Pakistan/Greece (2004_PG)	PM3	M	Kraka, Bumburet	Lawyer	Yes (university)	1979, 25
	GM1	M	Kraka, Bumburet; living in Greece	Interpreter/film maker	Yes (university)	1986, 18; outside since 18
2005, Pakistan (2005_P)	PM4	M	Kraka, Bumburet	Shepherd, village elder	No	1946, 59
	PM5	M	Kraka, Bumburet	Shepherd, village elder	No	1949, 56
	PM6	M	Kraka, Bumburet	Shepherd, village elder	No	1952, 53
2017, Greece (2017_G)	GM1	M	Kraka, Bumburet; living in Greece	Interpreter/film maker	Yes (university)	1986, 31; outside since 18
	GM2	M	Kraka, Bumburet; living in Greece	Blue collar worker	Yes (high school)	1988, 29; outside since 17
	GM3	M	Brun, Bumburet; living in Greece	Blue collar worker	Yes (university)	1987, 30; outside since 20
	GM4	M	Kraka, Bumburet; living in Greece	Researcher/educator	Yes (university)	1980, 37; outside since 19

forms) and tokens (item instances) varied from speaker to speaker. The recordings from the last set involved read speech only—word lists designed to elicit various phonemic contrasts in consonants and vowels (compiled based on the dictionary by Trail and Cooper, 1999, and in consultation with GM1). The same word list containing 16 words with laterals (interspersed with other words) was presented to all 4 speakers in Kalasha orthography. The participants were asked to repeat each word twice in isolation. However, some words were repeated more than twice, and some were omitted (when the speakers were not familiar with them). An additional 93 items were recorded from GM1 in order to include a wider range of vowel contexts and syllable positions.

Numbers of lateral tokens by dataset, position, and vowel context are presented in Table V. The total of 1845 tokens represented 572 lexical items (259 for /ɫ/ and 313 for /lʲ/). The number of tokens per item varied across speakers

TABLE V. Overall numbers of lateral items by recording condition, consonant, and tokens by consonant, position, and the tautosyllabic vowel place.

		Position		Vowel place				
Recording	Consonant	Onset	Coda	Front	Central	Back	Total	Grand total
1997_P	/ɫ/	314	5	79	209	31	*319*	
	/lʲ/	211	160	174	135	62	*371*	***690***
2004_PG	/ɫ/	170	15	111	61	13	*185*	
	/lʲ/	108	102	85	77	48	*210*	***395***
2005_P	/ɫ/	188	19	88	108	11	*207*	
	/lʲ/	92	64	55	74	27	*156*	***363***
2017_G	/ɫ/	202	14	38	132	46	*216*	
	/lʲ/	101	80	44	79	58	*181*	***397***
Total	/ɫ/	*874*	*53*	*316*	*510*	*101*	*927*	
	/lʲ/	*512*	*406*	*358*	*365*	*195*	*918*	***1845***
Grand total		***1386***	***459***	***674***	***875***	***296***	***1845***	

and datasets given differences in sample sizes and tasks. A list of most frequent items ($n = 88$), those that occurred in the sample five or more times, is presented in Table S IV.[2]

When it comes to adjacent vowels, the mid vowels /e/ and (especially) /o/ are relatively rare in the analyzed sample as they are in the Kalasha lexicon overall. We therefore collapsed all five vowel qualities (/a, e, i, u, o/) into three place categories: front (/i, e/), central (or low; /a/), and back (or rounded; /u, o/).[6] Given the rare occurrence of /ɫ/ in syllable-final position (see Sec. I A), our sample included much smaller numbers of tokens (and items) with this consonant in coda (see Table V). These distributional asymmetries were taken into account in our statistical analysis (see below).

The relative heterogeneity of the corpus—with respect to the materials and tasks, samples of speakers, and recording conditions—is a considerable limitation of the current study. This is because some relevant effects or interactions with respect to the realization of laterals can be missed in the absence of proper controls. On the other hand, the corpus has some advantages as it represents the production of laterals across different styles (including more natural spontaneous speech) and demographic groups, thus presumably more realistically reflecting the variation present among the Kalasha population. If certain differences can be observed across the current corpus, they are likely to be observed in more controlled experimental conditions as well. Our primary focus, therefore, is on the realization of the two laterals in the sample in general. Any differences that could be attributed to different datasets, gender, age, education, or other factors are also of interest, but these can only be interpreted with caution.

In addition to examining within-language differences in the realization of laterals, we performed a preliminary comparison between laterals in Kalasha and three other languages of Pakistan: Khowar (/ɫ/ and /l/), Palula (/l/), and

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Punjabi (/ɭ/ and /l/). This was done based on published single-speaker sound samples from the Journal of the International Phonetic Association (JIPA) "Illustrations of IPA" by Liljegren and Khan (2017), Liljegren and Haider (2009), and Hussain *et al.* (2019). In these samples, words were read in isolation or in carrier phrases. To minimize potential coarticulatory effects, we chose tokens of laterals occurring next to non-front vowels (21 for Khowar, 14 for Palula, and 13 for Punjabi). Given the small number of tokens and speakers for these languages, the comparison with Kalasha should be considered as exploratory and requiring further verification.

C. Annotation and analysis

Annotation and acoustic analysis were performed using Praat (Boersma and Weenink, 2018). All tokens with laterals (that were free of background noise) were manually annotated based on the waveform and spectrogram with lateral categories assigned referring to the dictionary entries of Trail and Cooper (1999). The annotations included intervals between the onset and offset of laterals, which were typically manifested by a relatively low overall amplitude, weaker formant structure, and lower F1 compared to adjacent vowels. Preceding and/or following vowels were also annotated based on the onset and offset of periodicity in the waveform and corresponding glottal pulses in the spectrogram. Figure 3 presents a sample annotated token, where an intervocalic velarized lateral is manifested in lower intensity, weaker formant pattern, and lower F1.

In some cases, the authors' auditory impressions of lateral tokens did not agree with the corresponding dictionary transcriptions or were considered indeterminate. These cases mainly involved /ɫ/ before front vowels or the same consonant produced in other contexts by older male speakers from the 2005_P set. In these and other cases, however, the annotation was based on the dictionary, while possible effects of

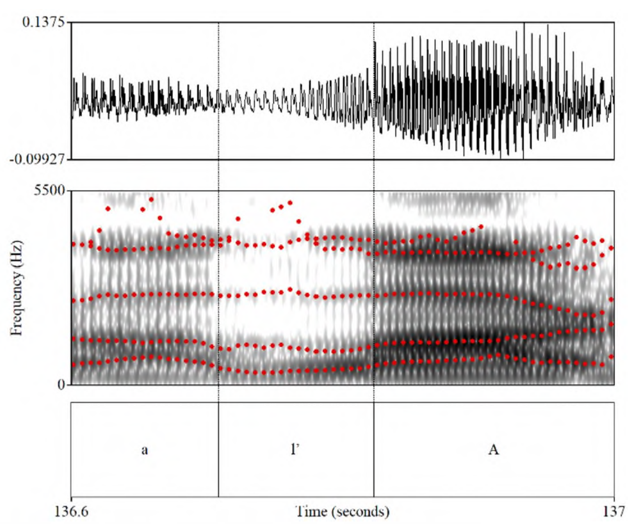

FIG. 3. (Color online) An example of an annotated token of /ɫ/ (l') in the word [kaˈɫaʂa] "Kalasha" (speaker GM1).

vowel context and dataset (or age) were considered in the statistical analysis.

Using a Praat script, the formants F1, F2, and F3 (Hz) were extracted at five evenly distributed points during the annotated consonants with the default window settings (a 25-ms Gaussian window with a 5-ms step) and the maximum formant value used in the Burg analysis set by gender (5000 Hz for males and 5500 Hz for females). The lateral midpoint (point 3) was selected for the analysis. As automatic estimation of formants can be challenging for laterals (due to their lower intensity and presence of the antiformant; see above), we performed a manual re-check of all tokens through an inspection of spectrograms and fast Fourier transform (FFT) spectra (cf. Punnoose *et al.*, 2013). A total of 23% of tokens was manually corrected. Formant values that could not be reliably determined were discarded (1.3% of all values, mainly for F3 in some fieldwork recordings from Pakistan). The same annotation and formant extraction were performed for the Khowar, Palula, and Punjabi sets.

For the analysis, we used F2 and F3 values as well as absolute differences F2-F1 and F3-F2 (see Sec. I C). To minimize physiological differences across speakers, F2 was normalized by dividing raw values of individual tokens by the F2 centroid for that speaker (following Simonet, 2010; cf. *S*-procedure by Watt and Fabricius, 2002). The centroid was calculated as a 25%-quartile average of F2 of the frontmost vowel /i/ and the palatal glide /j/, and a 75%-quartile average of the backmost vowel /u/ and the labial-velar glide /w/ (with the choice of the quartiles based on a preliminary examination of the data). The glides were included (unlike in Simonet, 2010) because vowels (and especially /u/) were often susceptible to centralization next to consonants. Average centroid values were 1825 Hz (standard deviation, SD = 35 Hz) for females and 1477 Hz (SD = 37 Hz) for males. Given this procedure, most normalized F2 (F2n) values for laterals would appear between 0.50 (extreme velarization) and 1.50 (extreme palatalization) with 1.00 being the borderline between the two secondary articulations. The normalization of F3 was performed in a similar way with the centroid being calculated based on the 25%-quartile average for back retroflex vowels (which tend to have the lowest F3) and the 75%-quartile average for the high vowel /i/ (which shows the highest F3 among Kalasha vowels; Kochetov *et al.*, 2019). Average centroid values were 2812 Hz (SD = 57 Hz) for females and 2369 Hz (SD = 95 Hz) for males. With F3n, 0.50 would indicate extreme retroflexion, while 1.50 would indicate the opposite (the extreme tongue tip-down articulation; but may also reflect place differences in general; see Sec. I C); the 1.00 would be the borderline between them. F1 was not normalized or used in the analysis other than for part of the F2-F1 metric. For reference, however, raw F1 values per speaker (as well as other measurements) are provided in the Appendix (Table VII). F2-F1 and F3-F2 differences (in Hz) were based on non-normalized F1, F2, and F3 values (cf. Sproat and Fujimura, 1993; Nance, 2014; Kirkham *et al.*, 2019). We did not convert formant values to the Bark scale for the sake of the comparison with previous studies. For the cross-language comparison, only raw F1, F2, and F3 values were used.

All four variables were analyzed separately using mixed effects models implemented with the *lme4* package (version 1.1–21; Bates *et al.*, 2017) using *R* (version 3.6.1; R Core Team, 2014). The full set of fixed effects included various phonetic and demographic factors: consonant (l_vel, l_pal), tautosyllabic V_place (front, central, back), position (onset, coda), recording set (1997_P, 2004_PG, 2005_P, 2017_G), gender (female, male), and education (yes, no). Given that most of the demographic factors did not fully cross in the model design, none of the fuller models containing both phonetic and demographic factors could converge. We therefore proceeded with separate maximally possible analyses: one with fixed factors and interactions of consonant, V_place, and position, and the other one with fixed factors consonant, gender, recording set, and education, and the interactions of the latter three with consonant. These analyses are presented in Secs. III A and III B. Random intercepts were included for speaker and item in both sets of analyses. By-speaker random slopes for consonant, V_place, and position were also attempted but yielded non-convergence. (The model formulas are provided together with summary results in the supplemental material.[2]) In each case, likelihood ratio tests were used to compare a full model to a nested model excluding the factor of interest, employing the *Anova()* function of the *lmerTest* package (Kuznetsova *et al.*, 2017). Pairwise comparisons and *post hoc* tests (with a Bonferroni correction for multiple comparisons) were performed using the *phia* package (De Rosario-Martinez, 2015). Results were visualized using the package ggplot2 (Wickham, 2009). For space reasons, all tables presenting model summaries and comparisons are given in the supplemental material.[2] Only descriptive statistics (means and SDs) were used for the cross-language comparison.

III. RESULTS

The results are presented first for the entire Kalasha corpus (Sec. A), followed by an examination of cross-speaker differences (Sec. III B) and a preliminary comparison of Kalasha data to other languages of the region (Sec. III C).

A. Lateral contrast and variation by vowel context and position

1. Normalized F2 (F2n)

Starting with F2n, a linear mixed effects model revealed significant interactions of consonant × V_place [$\chi^2(2) = 11.95$, $p = 0.0025$] and V_place × position [$\chi^2(2) = 15.40$, $p = 0.0005$] but no significant consonant × position or consonant × V_place x position interactions (see Tables S V and S VI for the summary of the model and the model comparison, respectivley).[2] We do not report significance for main effects here in the presence of significant interactions. *Post hoc* tests for the significant consonant × V_place interaction showed that F2n was significantly higher for /lʲ/ than for /ɫ/ regardless of the vowel place as well as higher for both consonants next to front vowels than for those next to central or back vowels. These differences can be observed in Fig. 4(a). We can also see that the overall magnitude of the lateral context difference was lower next to front vowels (given the greater raising of /ɫ/ than /lʲ/), which is a likely source of the interaction. *Post hoc* tests for the significant V_place × position interaction showed that the central vowel context patterned with back vowels in onset (lower F2n compared to front vowels) and with front vowels in coda (higher F2n compared to back vowels). In addition, F2n in back vowel contexts was higher in coda than in onset.

Overall, F2n values for /ɫ/ tended to be below 0.00 (and more so next to non-front vowels), which is indicative of velarization (or relative darkness); values for /lʲ/, on the other hand, were above 0.00, which is indicative of palatalization (or clarity). Notably, for both consonants, values were still relatively far from the extremes (typical of /u, w/ and /i, j/) at 0.50 and 1.50. Specifically, F2n averages were 0.80 for /ɫ/ and 1.14 for /lʲ/ (with raw F2 being 1255 Hz and 1799 Hz, respectively). This suggests that both velarization and palatalization (dark and clear quality) can be considered moderate in our data.

2. Normalized F3 (F3n)

A linear mixed effects model for F3n revealed significant effects of consonant [$\chi^2(1) = 47.03$, $p < 0.0001$], V_placeplace [$\chi^2(2) = 12.39$, $p = 0.0020$], and position [$\chi^2(1) = 5.99$, $p = 0.0144$] but no significant interactions of any of these factors (see Tables S VII and S VIII for further details).[2] As seen in Fig. 4(b), F3n was somewhat higher for /lʲ/ than for /ɫ/, yet values for both consonants tended to be above 1.00. Specifically, F3n for /ɫ/ was 1.08 (with the raw F3 being 2729 Hz) and for /lʲ/ the F3n was 1.12 (F3 is 2824 Hz). This suggests that neither of the two consonants were produced in the data as prototypical retroflexes, known to be characterized by lower F3 (see Sec. II C).

Although the V_place was significant (see above), pairwise comparisons did not reach significance, while showing marginally higher F3n next to central vowels than next to back vowels. With respect to position, F3n was higher in onset than in coda. However, the magnitude of this difference was rather small (1.10 vs 1.09) and can be considered spurious. In sum, the only notable difference for F3n is that for the lateral contrast (/lʲ/ > /ɫ/).

3. Differences F2-F1 and F3-F2

A linear mixed effects model for F2-F1 revealed significant effects of consonant [$\chi^2(1) = 1106.73$, $p < 0.0001$] and V_place [$\chi^2(2) = 95.54$, $p < 0.0001$] but no significant effect of position or any significant interactions (see Tables S IX and S X for further details).[2] With these differences, illustrated in Fig. 4(c), /lʲ/ showed considerably higher values than /ɫ/ with both consonants being affected by the vowel

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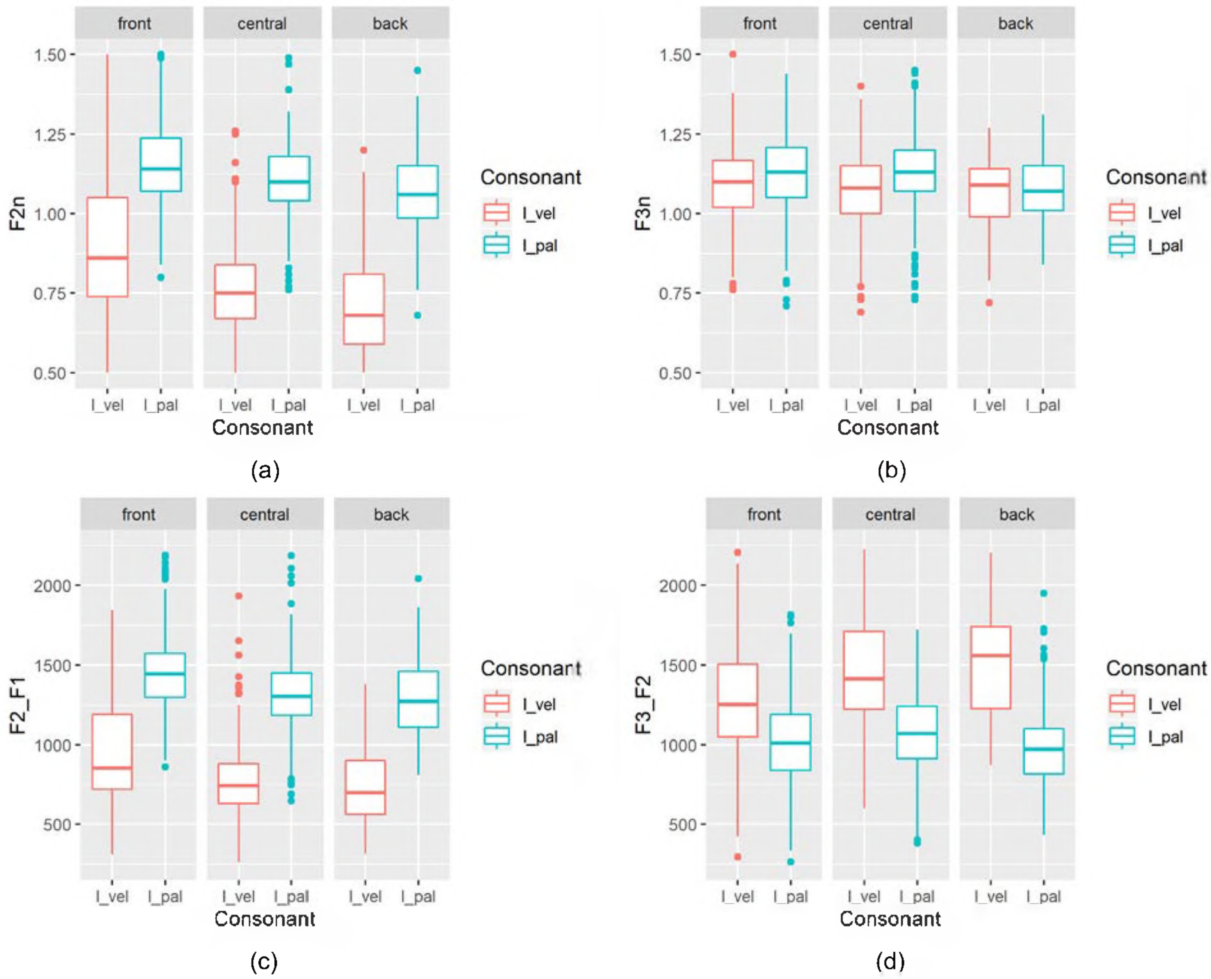

FIG. 4. (Color online) Boxplots for (a) normalized F2 (F2n), (b) normalized F3 (F3n), (c) the F2-F1 difference, and (d) the F3-F2 difference by consonant (l_vel = /ɫ/, l_pal = /lʲ/) and vowel place.

context. On average, F2-F1 was 840 Hz for /ɫ/ and 1426 Hz for /lʲ/. These values are largely due to a considerable F2 difference between the two consonants reported above (/lʲ/ > /ɫ/) as well as due to a much smaller reverse difference in F1 (/ɫ/ 418 Hz vs /lʲ/ 374 Hz).

Finally, a linear mixed effects model for F3-F2 revealed a significant interaction of consonant × V_place [$\chi^2(2) = 7.43$, $p = 0.0243$] but no significant effect of position and no significant interactions. (We do not report significant effects of consonant and V_place given the above interaction. See Tables S XI and S XII.[2]) *Post hoc* tests for the significant interaction revealed that F3-F2 difference values were higher for /ɫ/ than /lʲ/ regardless of the vowel place context (being on average 1307–1509 Hz vs 980–1060 Hz). The *post hoc* tests also revealed that F3-F2 was higher next to back vowels than when next to front vowels for /ɫ/, and higher next to central vowels than when next to front vowels for /lʲ/. These differences can be observed in Fig. 4(d). As with F2-F1, the consonant differences were largely due to the considerably lower F2 for /ɫ/ compared to /lʲ/ (as reported above). Yet, in this case the F2 difference was partly offset by the parallel but much smaller difference in F3 (see above).

B. Lateral contrast and variation across speakers

Now, we turn to the analysis of cross-speaker differences in the realization of the lateral contrast. As mentioned above, these results should be taken with caution since they are based on smaller groups of speakers and only partly crossed factors. In particular, recall that the factors gender and education largely overlap with the factor recording set so that female speakers appear in only one of the four sets (1997_P), and speakers with no education mainly appear in the sets 1997_P and 2005_P. Recording sets also represent differences in the recording conditions and—largely—speaker's birth year (with the oldest and youngest speakers occurring mainly in the sets 2005_P and 2017_G, respectively). The analysis presented below is limited to F2n and F3n as the other two variables provided similar results.

1. Normalized F2 (F2n)

A linear mixed effects model for F2n revealed significant interactions of consonant × gender [$\chi^2(1) = 4.30$, $p = 0.0381$], consonant × recording set [$\chi^2(3) = 169.77$, $p < 0.0001$], and consonant × education [$\chi^2(1) = 13.84$,

$p = 0.0002$] (see Tables S XIII and S XIV for further details).[2] As before, we do not report significance for main effects here in the presence of significant interactions. *Post hoc* tests for the first significant interaction showed that F2n was higher for /lʲ/ than for /ɫ/ for both genders. Within-consonant gender differences did not reach significance, whereas there was a tendency for females to produce lower F2n for /ɫ/ (that is, greater velarization).

Post hoc tests for the consonant × recording set interaction showed significantly higher F2n for /lʲ/ than for /ɫ/ for all four sets. Within-consonant differences were rather complex. For /ɫ/, F2n was higher for the 2005_P set than for the other three sets as well as higher for 2004_PG than for 2017_G. For /lʲ/, F2n was also higher for the 2005_P set than for the other three sets; in addition, it was higher for 2017_G than for 2004_PG and higher for 1997_P than for 2004_PG. These differences are illustrated in Fig. 5(a). Recall that the 2005_P group consisted of three male speakers who were the oldest in the sample (born 1946–1952). Given this, the higher F2n observed for this set can be attributed to somewhat different realization of the lateral contrast: lesser velarization of /ɫ/ and greater palatalization of /lʲ/ compared to younger speakers. On the other hand, we cannot discount a possible effect of different recording conditions (as this was the only dataset recorded using a built-in microphone; see Sec. II B). The observed difference between 2004_PG and 2017_G is also of interest as the sets differ in the task—speaking vs reading (among other factors), and both sets include one of the speakers, GM1. Therefore, the lower F2n is for /ɫ/ and the higher F2n is for /lʲ/ as exhibited by the 2017_G group, and might be due to the more dispersed realization of the contrast in the reading task. Note that the speakers in the 2017_G set have also resided outside the Kalasha community for considerable time. Given this, it is plausible that their realization of laterals has been influenced by contact languages—Greek or English. However, both of these languages have a single phonemic lateral (see Arvaniti, 2007, on Greek), and we would, therefore, expect to observe a merger or reduction of the contrast rather than its enhancement. The influence of the task (speaking vs reading) is, therefore, a more plausible explanation for the difference.

To confirm the task influence, we performed an analysis of GM1's data across the two sets. A linear mixed effects model with fixed factors consonant and recording set (2004_PG and 2017_G) and random intercepts for item revealed a significant interaction of the two factors [$\chi^2(1) = 108.28$, $p < 0.0001$]. As seen in Fig. 5(b), the speaker produced /ɫ/ with more velarization and /lʲ/ with more palatalization in the 2017_G (reading) set, resulting in an overall more enhanced contrast. The interaction was likely due to the greater difference (and lesser variation) between the sets for /ɫ/, which can reflect a more deliberate production of this consonant in read speech, as well as its lesser susceptibility to vowel coarticulation.

Returning to the discussion of F2n results for the entire sample, *post hoc* tests for the consonant × education interaction revealed that F2n was higher for /lʲ/ than for /ɫ/ for both levels ("yes" or "no"). Within consonant differences, F2n of /lʲ/ was higher for speakers with no formal education. While nonsignificant, F2n for /ɫ/ was also higher for the same group. Recall that the factor education was rather unevenly distributed across recording sets and genders, and thus the results may present a confound of the two factors.

Keeping in mind the limitations of the current analysis, we can tentatively conclude that the lateral contrast in F2n was conditioned by the recording set, which, in turn, overlaps with gender and education. Most recording set differences were observed between groups that differed in the task and age (birth year). Given this, it is useful to examine age differences in the realization of the lateral contrast in F2n in the speaking condition only (i.e., excluding the reading condition, 2017_G). This is done in Fig. 6. A rather steep decrease over time in F2n (increasing velarization) for /ɫ/ should be noted. In contrast, F2n values for /lʲ/ are relatively stable, while showing a minor decrease (some

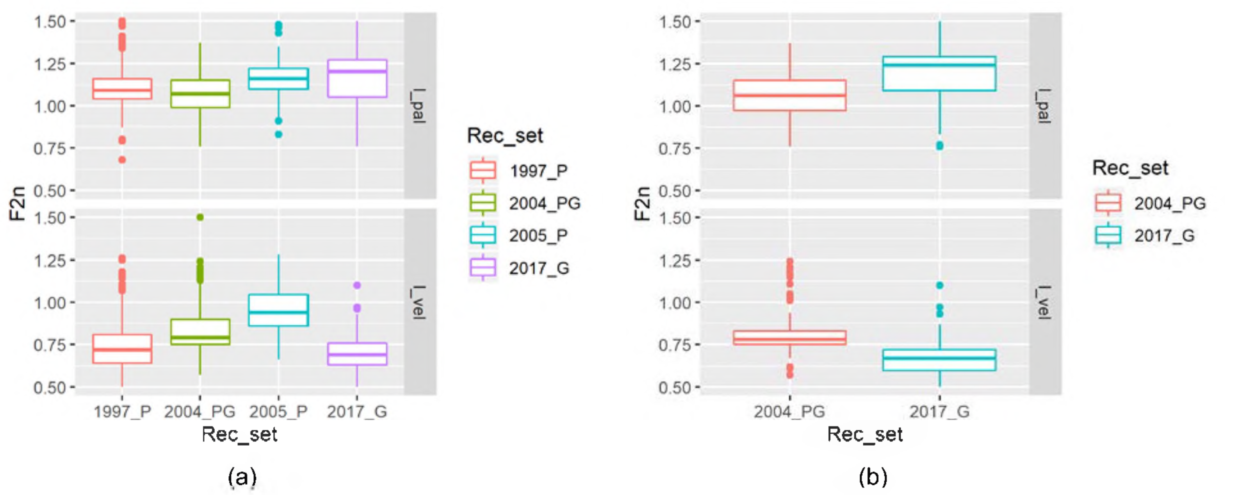

FIG. 5. (Color online) Boxplots for normalized F2 (F2n) by consonant (l_vel = /ɫ/, l_pal = /lʲ/) and recording condition (a) for the entire set and (b) for speaker GM1.

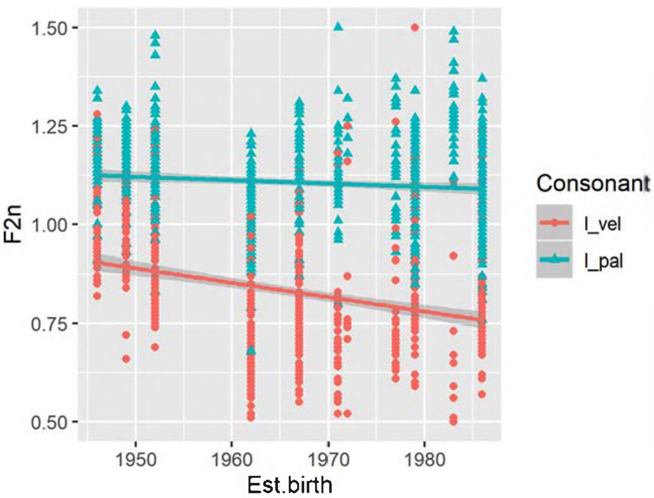

FIG. 6. (Color online) Normalized F2 (F2n) by consonant (l_vel = /ɫ/, l_pal = /lʲ/) and estimated speakers' birth years: all tokens produced in the speaking condition (11 speakers) and corresponding regression lines.

weakening of palatalization). The combined effect of this is an increased lateral contrast for younger speakers compared to older speakers, confirming our earlier observations. We will return to the interpretation of this apparent change in Sec. IV (Discussion).

2. Normalized F3 (F3n)

Turning to F3n, a linear mixed effects model revealed significant effects of consonant [$\chi^2(1) = 42.45$, $p < 0.0001$] and recording set [$\chi^2(3) = 88.61$, $p < 0.0001$] but no significant effects of gender or education and no significant interactions of any of the factors (see Tables S XV and S XVI for further details).[2] With respect to the first effect, F3n was higher for /lʲ/ than for /ɫ/. Pairwise comparisons for the recording set revealed significantly higher F3n for 1997_P and 2017_G than for the other sets. Since the first group included mainly female speakers and the second group involved the reading task, it is possible that the result conflates the recording set condition with the gender or the task. A follow-up analysis of GM1's data across the two sets did, in fact, show significantly higher F3n in the reading task (regardless of the consonant), thus confirming the task effect.

To summarize, the analyses presented in this section have confirmed that the lateral contrast was manifested primarily in F2 (as well as in F2-F1 and F3-F2 differences) and, to a smaller extent, in F3. The realization of both formants (and primarily F2) appeared to be affected by speakers' ages and tasks, and possibly other non-phonetic factors. Specifically, the contrast was realized most robustly in the reading condition (by youngest speakers in the sample) and least robustly in the speech of the oldest Kalasha speakers (in the speaking condition). The weaker realization of the contrast by the latter group was primarily due to lesser velarization of /ɫ/. Notably, this result is consistent with our auditory impressions of laterals in the samples from older speakers.

C. The Kalasha laterals in the areal context

Having established the main acoustic properties of the Kalasha laterals, the question now arises as to how these consonants compare to similar consonants in neighboring Indo-Aryan languages. Of particular interest to us is Khowar, a regional lingua franca featuring phonemic velarized and plain laterals, /ɫ/ and /l/ (Liljegren and Khan, 2017), as well as Palula, another related language but with a single phonemic lateral, plain /l/ (Liljegren and Haider, 2009). Finally, it is useful to compare the Kalasha laterals to those in a language with a retroflexion lateral contrast. For this purpose, we use a (more remotely spoken) Pakistani variety of Punjabi, which features the contrast between /ɭ/ and /l/ (Hussain *et al.*, 2019). As the data from these languages were collected using the reading task (see Sec. II B), we chose our Kalasha reading condition set (2017_G, four male speakers) for the comparison.

Means and SDs for (non-normalized) formants for each language are presented in Table VI. Note the Kalasha lateral contrast is very similar to that of Khowar in that the two laterals differ substantially in F2 and F2-F1 (lower for /ɫ/ than for /lʲ/ or /l/) as well as in F3-F2 (higher for /ɫ/ thanfor /lʲ/ or /l/). The difference between the two languages lies, perhaps, in a somewhat greater degree of velarization (lower F2) for /ɫ/ in Khowar and a slightly greater degree of palatalization (higher F2) for the other lateral in Kalasha. (Note that some degree of palatalization of the Khowar /l/ was previously reported by Liljegren and Khan, 2017.) As expected, the single lateral in Palula shows F2 values, as well as F2-F1 and F3-F2 differences, that are intermediate between the Kalasha and Khowar laterals. This further confirms that the latter two languages exhibit a secondary articulation (velarization vs palatalization) contrast.

Finally, the formant pattern exhibited by Punjabi is strikingly different from that of Kalasha (as well as Khowar and Palula). The main difference here is in F3 and F3-F2 with the retroflex having substantially lower values than the plain alveolar lateral. In addition, /ɭ/ shows a higher F1 and lower F2 and, consequently, lower F2-F1 compared to /l/. (There are also differences, not shown here, in the closure duration as /ɭ/ was produced as a very short flap.) Altogether, this preliminary comparison points to the similarity between the Kalasha

TABLE VI. Average (non-normalized) formant values for laterals produced next to non-front vowels by four speakers of Kalasha from the 2017_G set and single speakers of other Indo-Aryan languages of the region (the speaking condition).

		F1		F2		F3		F2-F1	F3-F2
Language	Contrast	Mean	SD	Mean	SD	Mean	SD	Mean	Mean
Kalasha (2017_G)	/ɫ/	341	*(169)*	1151	*(399)*	2624	*(336)*	810	1474
	/lʲ/	322	*(132)*	1687	*(243)*	2635	*(285)*	1365	948
Khowar (1 m)	/ɫ/	351	*(58)*	1043	*(178)*	2673	*(186)*	692	1630
	/l/	337	*(40)*	1600	*(154)*	2726	*(152)*	1263	1125
Palula (1 m)	/l/	378	*(28)*	1381	*(196)*	2663	*(167)*	1003	1283
Punjabi (1 m)	/ɭ/	420	*(16)*	1274	*(105)*	1831	*(54)*	854	557
	/l/	322	*(48)*	1459	*(103)*	2604	*(189)*	1137	1145

and Khowar lateral contrasts and the fact that the two languages exhibit a secondary articulation contrast rather than a retroflexion contrast. A more systematic comparison of laterals in the languages of the region is necessary to further confirm these preliminary observations.

IV. DISCUSSION

In this study, we examined the acoustic realization of the Kalasha laterals as produced by 14 speakers representing 4 different datasets. The analysis of formant patterns during the lateral closure was performed over the entire sample to determine the consonant differences as well as the effects of tautosyllabic vowel context and syllable position. An additional analysis involved a preliminary examination of differences in the realization of laterals as a function of various demographic factors. Finally, we also presented an informal comparison between Kalasha laterals and similar sounds in three other Indo-Aryan languages of the region.

The main finding of the study is that the laterals in Kalasha differ primarily in F2 (and consequently in F2-F1 and F3-F2 differences) and thus involve the dark vs clear quality or, in articulatory terms, secondary velarization and palatalization. Specifically, the Kalasha /ɫ/ shows the acoustic properties of a typical velarized dental, while /lʲ/ is acoustically very similar to palatalized/palatal laterals in other languages (see Table III). These findings confirm the classifications of the consonants in some earlier works, which were based solely on auditory impressionistic analysis (Trail and Cooper, 1999; Bashir, 1988) or in combination with static palatography (Mørch and Heegaard, 1997; Heegård and Mørch, 2004). At the same time, they do not support classifications of Kalasha laterals in some of other works, such as Morgenstierne (1973), who does not distinguish the two lateral places, and Mela-Athanasopoulou (2014), who posits a retroflex /ɭ/ (see Sec. I B).

Placing the Kalasha secondary articulation results in a cross-linguistic perspective, it is worth noting that F2 values we obtained for palatalization (with the raw F2 of 1662 Hz for males and 1995 Hz for females) are comparable to but somewhat lower than those reported for languages like Brazilian Portuguese, Russian, and Scots Gaelic (see Table III, keeping in mind the limitation of comparisons across studies). This, combined with our conclusions based on normalized F2, confirms that the Kalasha /lʲ/ is moderately palatalized (or moderately clear; see Recasens, 2012). This is also consistent with earlier observations by Cooper and Trail (1983–1999), Bashir (1988), and Mørch and Heegaard (1997) (but not consistent with Bashir, 2003, who described palatalization as strong). Regarding the velarized lateral, the values we observed (F2 of 1213 Hz for males and 1314 Hz for females) are also comparable to but not as low as those reported for languages like Albanian, Brazilian Portuguese, Russian, and Scots Gaelic (as well as Khowar; see Sec. IV C). This indicates that the degree of Kalasha velarization is also moderate (but see the discussion of inter-speaker differences below). As would be expected, the Kalasha contrast also showed clear differences in the F2-F1 metric (females, 819 Hz for /ɫ/ vs 1529 Hz for /lʲ/; males, 820 Hz for /ɫ/ vs 1299 Hz for /lʲ/). These differences were largely due to the robust F2 contrast while also being somewhat enhanced by F1 differences (which were on average 38–40 Hz). Note also that the F1 differences were smaller than those reported for other languages with palatalized laterals in Table III. The F3-F2 metric showed the reverse difference—higher for /ɫ/ than /lʲ/, which is expected given the F2 differences between the consonants, as well as previous work on similar contrasts.

One goal of the study was to determine whether the Kalasha /ɫ/ ever exhibits acoustic properties of a retroflex lateral. This is because laterals stand apart in the Kalasha consonant inventory, where most other manners of articulation exhibit a contrast in retroflexion. Furthermore, retroflex laterals are relatively common in inventories of Indo-Aryan languages, while laterals with secondary articulations (and velarization in particular) are rather exceptional (see Fig. 2). To the extent that F3 can signal retroflexion in laterals, our results did not reveal any retroflexion in Kalasha /ɫ/ or laterals in general. Although F3n values were consistently lower for /ɫ/ than /lʲ/ (by 85–104 Hz, non-normalized), they were either clearly in the range of non-retroflex articulations or near the neutral borderline between retroflex and non-retroflex articulations. Note also that non-normalized F3 values for /ɫ/ in our data, on average 2574 Hz for males and 2976 Hz for females, are much higher than would be expected for retroflex laterals, based on the literature reviewed in Table III. This was further confirmed by our comparison of the Kalasha and Punjabi laterals. We can therefore conclude that Kalasha laterals produced by our speakers do not exhibit retroflexion.

Recall that we predicted, based on Recasens (2012), that /ɫ/ would show somewhat higher F3 than /lʲ/, at least in the low vowel context. Our finding, however, is the reverse and can be attributed to the relatively moderate degree of velarization in Kalasha /ɫ/. Note also that this result in not inconsistent with differences reported for other languages. For example, somewhat lower F3 for /ɫ/ than for /lʲ/ was observed in Russian (Bolla, 1981) and Scots Gaelic (Nance, 2014; see Table III) despite the characterization of the former lateral in these languages as strongly velarized. Perhaps the observed small-scale F3 difference in such cases can be attributed to the constriction shape differences between apical and laminal articulations.

Many previous phonetic studies of laterals showed that laterals vary in their relative darkness or clarity (and thus secondary articulation) depending on the quality of adjacent vowels and syllable position (e.g., Sproat and Fujimura, 1993; Browman and Goldstein, 1995; Recasens and Espinosa, 2005). Further, the magnitude of these effects has been noted to vary widely across languages with some showing small-scale coarticulatory variation and others showing more robust allophonic differences. Differences have also been observed depending on the quality of the lateral—greater coarticulation for clear laterals and greater coarticulatory resistance for dark laterals, as observed by Recasens (2012). In his study, for instance, the difference between /i/ and /a/ contexts was on average 517 Hz for clear laterals and 148 Hz for dark laterals; positional differences were on average 210 Hz for clear laterals and 90 Hz for dark laterals. Our results for Kalasha revealed consistent coarticulatory effects in F2 (as well as in F2-F1 and F3-F2), especially fronting next to front vowels. These effects involved both laterals with the difference between front and central vowel contexts in the onset position being on average 181 Hz for /ɫ/ and 146 Hz for /lʲ/ (for males). While the coarticulatory effect for /ɫ/ is close to what is expected of dark laterals (based on Recasens, 2012), the effect for /lʲ/ is much lower. This is consistent with our prediction (see Sec. I C) that contextual variation in Kalasha would be moderate, being constrained by the need to maintain the contrast. Related to this is the finding of relatively little positional variation in laterals (reaching significance for only one of the vowel contexts and in an unexpected direction).

A less expected result is the apparent inter-speaker variation in the realization of the lateral contrast with respect to F2. Some of this variation can be attributed to the task effect—speakers who were reading the word list produced a more acoustically enhanced contrast (higher F2 for /lʲ/ and lower F2 for /ɫ/) compared to the speakers who provided continuous (and presumably less monitored) speech. This is not surprising, given the slower speaking rate and greater attention paid to distinguishing phonemic contrasts in reading. More interesting are the differences that can be tentatively ascribed to the speakers' ages. Specifically, our oldest male speakers produced /ɫ/ with considerably higher F2—lesser velarization—compared to the younger speakers (male and especially female speakers). This finding corroborated our auditory impression as some lateral tokens produced by these speakers were more difficult to categorize (see Sec. II B). Given that the realization of /lʲ/ was relatively stable across speakers (intermediately high F2), the age-related difference in /ɫ/ points to a gradual increase in the contrast from our older to younger speakers, indicative of a change in progress (see Fig. 6). Following Labov's (1994) "apparent-time hypothesis" (which assumes general stability of language after adolescence), we can tentatively suggest that sound patterns exhibited by our older speakers (born around 1946–1952) are characteristic of the state of the language before the 1970s. If this is correct, the results suggest that the earlier Kalasha lateral contrast consisted of a plain /l/ and a palatalized /lʲ/. Given the weak-to-moderate degree of palatalization, the two phonemes were not particularly well-differentiated acoustically, which explains the previous conflicting or partly inconsistent accounts of Kalasha laterals (Leitner, 1880; Grierson, 1919; Morgenstierne, 1973; see Sec. I A). A gradual increase of velarization in the original plain /l/ has likely led to a greater salience of the contrast, starting at least in the 1970s, while at the same time increasing phonetic variation in the community. This variation has been reflected in descriptions of the contrast made by various researchers in the 1980s and 1990s. Finally, the current realization of the contrast is relatively robust as reflected in our JIPA illustration of the language (Kochetov *et al.*, 2020; see Fig. 4).

In principle, the development of velarization could be driven internally—as a way of enhancing a perceptually vulnerable contrast (Liljencrants and Lindblom, 1972; Flemming, 2002). Indeed, this is a common historical path for languages with phonemic palatalized laterals (e.g., Russian; Carlton, 1991). On the other hand, it is also plausible that velarization arose through (or at least was facilitated by) the increasing contact of the Kalasha community with Khowar. As we see from our preliminary comparison in Sec. IV C, the two lateral systems are very similar in their formant patterns with Khowar showing slightly greater velarization and Kalasha showing slightly greater palatalization. Recall that, unlike our older speakers, the younger (male) speakers have had frequent contacts outside the community, were generally more educated, and, importantly, fluent in Khowar, which serves as the lingua franca of Chitral. This has likely facilitated a transfer of some linguistic features from Khowar to Kalasha. On the other hand, this generalization does not apply to our female speakers. They have had fewer opportunities for education, more limited interaction outside the Kalasha community, and, for the most part, did not speak Khowar. Perhaps it is more plausible to assume that the sound change was triggered language internally (as enhancement) and since then has been facilitated by language contact. Clearly, the question of linguistic change in the small and culturally threatened Kalasha community requires an urgent investigation. Interestingly, the contrast-enhancing sound change in Kalasha is the opposite of the neutralizing sound change in Scots Gaelic laterals reported by Nance (2014). Both cases, nevertheless, can be attributed to the presence or absence of similar secondary articulation contrasts in the dominant contact language: while Khowar has such a contrast, English does not.

V. CONCLUSION

To conclude, this study provided an extensive investigation of a lateral place contrast in Kalasha, an under-documented and threatened Northwestern Indo-Aryan language of northern Pakistan. The phonetic nature of this contrast, /ɫ/ vs /lʲ/, has been a source of some controversy in the language documentation literature. It is also somewhat unusual given the preponderance of retroflexion in the language inventory and the broader regional bias toward retroflex laterals. The results have confirmed that the Kalasha contrast indeed involves secondary articulations (in addition to some primary place differences), yet the magnitude of the contrast appears to vary across individuals, indicative of a sound change in progress. The finding of a gradual increase in the velarization of /ɫ/ over time was somewhat unexpected. Nevertheless, it explains the variability in previous phonetic descriptions of the contrast and is consistent with the increasing language contact between Kalasha and Khowar. In addition to documenting the changing sound patterns of Kalasha, this study has also provided valuable acoustic data contributing to our understanding of lateral articulations, their cross-linguistic typology, and their patterns of coarticulation.

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APPENDIX

Raw F1-F3 values per speakers, as well as other measurements, are provided in Table VII.

TABLE VII. Mean formant values by speaker and consonant.

Speaker	Consonant	F1 (Hz)	F2 (Hz)	F3 (Hz)	F2n	F3n	F2-F1 (Hz)	F3-F2 (Hz)
GM1	ɫ	354	1185	2530	0.79	1.14	831	1346
	lʲ	301	1671	2701	1.11	1.22	1377	1030
GM2	ɫ	348	1060	2532	0.73	1.10	719	1472
	lʲ	330	1648	2621	1.13	1.14	1305	974
GM3	ɫ	389	1181	2534	0.76	1.05	792	1353
	lʲ	359	1747	2643	1.13	1.09	1388	896
GM4	ɫ	366	1034	2470	0.67	1.07	668	1436
	lʲ	315	1616	2562	1.04	1.11	1315	946
PF1	ɫ	533	1306	2878	0.72	1.03	787	1577
	lʲ	488	1923	2978	1.06	1.07	1435	1068
PF2	ɫ	394	1384	3104	0.85	1.10	990	1720
	lʲ	325	2040	3002	1.25	1.07	1715	962
PF3	ɫ	431	1389	3366	0.75	1.17	959	1977
	lʲ	421	2125	3392	1.14	1.17	1704	1267
PF4	ɫ	448	1186	3058	0.65	1.04	738	1871
	lʲ	391	2333	3361	1.27	1.14	1942	1029
PM1	ɫ	414	1536	2613	1.01	1.05	1122	1077
	lʲ	399	1755	2717	1.16	1.09	1356	962
PM2	ɫ	394	1402	2545	0.99	1.01	1008	1143
	lʲ	376	1646	2614	1.16	1.04	1270	968
PM3	ɫ	475	1285	2581	0.87	1.13	810	1296
	lʲ	404	1601	2578	1.09	1.13	1197	978
PM4	ɫ	448	1315	2461	0.91	0.99	867	1146
	lʲ	376	1663	2601	1.15	1.04	1287	938
PM5	ɫ	391	1220	2780	0.80	1.13	830	1559
	lʲ	352	1748	2885	1.14	1.17	1396	1136
PM6	ɫ	467	1089	2760	0.73	1.15	639	1671
	lʲ	398	1675	2879	1.12	1.20	1277	1204
Mean	ɫ	*418*	*1255*	*2729*	*0.80*	*1.08*	*840*	*1475*
	lʲ	*374*	*1799*	*2824*	*1.14*	*1.12*	*1426*	*1026*

[1]The unique three-letter code adopted for Kalasha by the International Organization for Standardization (ISO 639-3) is kls (Eberhard *et al.*, 2019).

[2]See supplementary material at https://doi.org/10.1121/10.0001013 for additional information on the language background and statistical results.

[3]The map in Fig. 2 was created with QGIS 3.6.3. Language data were extracted from a survey of literature describing 280 language varieties in South Asia and surrounding areas. See Arsenault (2017) for details. Note that Fig. 2 focuses on lateral contrasts involving primary and secondary places of articulation and does not include laterals that differ in terms of manner or voicing. A contrast between (voiceless) lateral fricatives and (voiced) lateral approximants (/ɬ/ vs /l/) is characteristic of a number of Indo-Iranian languages along the border of northern Pakistan and Afghanistan (Masica, 1991, p. 98; Bashir, 2003) and Tibeto-Burman languages in the Himalayas of North India, Nepal, and China (Tibet).

[4]The age of the speakers is based on self-report and is approximate. This is because no official birth records were made in the region until recently.

[5]Some of the stories, including "The story of a fox," appear in Heegård Petersen (2015).

[6]All instances of the vowel /a/ before a palatal glide were classified as front because of frequent fronting (e.g., /aɫaj/ "there" as [aɫɛj] or [aɫe]). Note also that the sample excluded laterals occurring next to phonemic retroflex or nasal vowels or retroflex consonants. This was done to minimize coarticulatory effects that were difficult to control for.

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